# Hawaii Commercial Building Guidelines for Energy Efficiency

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# PREFACE

## Introduction to Energy Efficiency Guidelines

The *Hawaii Commercial Building Guidelines for Energy Efficiency* promote the design of energy-efficient buildings that are also healthy and pleasing places to spend time in. These guidelines address new construction as well as major renovation of commercial buildings.

This document is written for architects, engineers, lighting designers, contractors, building owners, and others making decisions about the design of buildings and their systems. Building professionals often have a hard time obtaining information about the relative efficiency and costs of design alternatives, especially when they are working under a tight schedule. These guidelines are intended to make that information readily accessible.

While these guidelines cover a wide range of topics, they are not intended to be comprehensive. Other energy efficiency strategies not included here may be appropriate as well.

These guidelines cover the following topics, with a separate chapter dedicated to each topic:

1. Whole Building Design
2. Natural Ventilation
3. Daylighting
4. Electric Lighting and Controls
5. Energy-Efficient Windows
6. Cool Roof Systems
7. Dehumidification
8. HVAC and Water Heating
9. Building Heating, Cooling and Power Systems

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# 1. WHOLE BUILDING DESIGN



## Overview of Whole Building Design

Hawaii's climate presents unique challenges and opportunities to designers of commercial buildings. In most of the United States it is taken for granted that heating and/or cooling systems will be installed. But in Hawaii designers often have a choice of using either air conditioning or natural ventilation in a building. There are many successful examples of both strategies.

Whether a building is naturally ventilated or air conditioned, the odds of success improve dramatically if the project team employs an integrated design — or *whole building design* — approach. This is especially true when considering a building's energy efficiency. The operating costs of energy-consuming systems such as lighting and air conditioning are highly dependent on the architectural design. For example, a well-shaded building will not only consume less energy but will likely have a smaller and less expensive cooling system. With adequate attention to cross-ventilation design, the building may need no cooling at all. In addition, a well-designed fenestration system will reduce the need for electric lighting and save large amounts of energy.

From an energy efficiency perspective, the following design issues should be addressed at the same time and as early as possible in the design process:

- Solar control strategy
- Daylighting and visual comfort strategy
- Thermal comfort strategy
- Special indoor environment requirements
- Air quality strategy

Sometimes design strategies may seem to be in conflict with one another. For example, using reflective glass for solar control limits the amount of visible light available for daylighting. Natural ventilation for thermal comfort may not always maintain the indoor temperature and humidity necessary for special equipment. But if these issues are considered early in the design process, then conflicts can be resolved and energy-efficient design options can be developed.

These general design strategies influence many specific design decisions, including:

- Siting and orientation (although there is not always much choice in Hawaii because land is scarce and views are a high priority)
- Building form (shape, number of stories)
- Fenestration design (glass type, window area, shading design, operability)
- Roof construction and surface type
- Lighting system design (luminaire type, controls)
- Mechanical system type (including ceiling fans)
- Interior space zoning
- Material selection (moisture resistance, light color, thermal mass)

The remaining sections of this chapter discuss important whole building design issues and describe design alternatives and recommendations.

## Whole Building Design and Construction Process

In the traditional design process, lack of communication among the designers sometimes leads to lost savings opportunities. In some cases, efficient HVAC equipment cannot be accommodated unless considered early in the schematic design phase (or even earlier, in the budgeting phase). Sometimes there is not enough design time budgeted at the beginning of the project to evaluate design alternatives.

While there is no single "best" design process, several steps can help ensure a successful project.

**Energy Efficiency Budget**

In the planning process, provide a budget for design coordination and evaluation of energy efficiency alternatives. Depending on the project's size, this could range from $5,000 to $50,000. In addition, the inspections and functional testing required for proper building commissioning cost roughly $0.25 per square foot of floor area.

**Integrated Design Meeting #1**

At the beginning of schematic design, hold a meeting between the architect, mechanical designer, electrical designer, lighting designer, owner/tenant, and other consultants. Consider including utility personnel to take advantage of their expertise and incentive programs.

At this meeting discuss design strategies for energy efficiency. The list of design issues in this chapter (for example, solar control strategy, daylighting and visual comfort strategy, etc.) could serve as a framework for the meeting.

The meeting should result in a list of potential strategies and design goals. Some issues will require further evaluation.

**Evaluation of Alternatives**

Following the initial meeting, evaluate design alternatives. A little extra investment at this point can save a lot later on. This step may involve simulations or engineering calculations. Thermal simulations can predict the performance of building form options or air conditioning system choices. Daylighting simulation can predict illumination levels. Rough cost estimating is important to determine the lifecycle cost of design alternatives.

**Integrated Design Meeting #2**

Hold a second integrated design meeting before finalizing the schematic design. This meeting can be used to select design alternatives and to communicate the design approach and important features to the whole team.

**Design Development Review**

Arrange for a plan and specification review before the end of design development to ensure that the design strategies are implemented properly. The project manager or construction manager should formally track the status of energy efficiency measures.

**Construction Documents Review**

Review construction documents to ensure that the plans and specs clearly state the contractors' responsibilities for installation and testing of efficiency measures.

**Submittals Review**

During the construction phase, review contractor submittals to ensure proper performance of efficiency measures. This step is critical because some substitutions may not be equal in ways that are not immediately obvious (for example, the substituted equipment may not be compatible with other controls).

**Construction Inspection**

Inspection is an obvious step and is a normal part of any construction project. However, specific inspection of energy-efficient equipment does not always occur. Conduct an inspection to confirm that controls are installed as specified and that sensors are located so they will give accurate readings.

**Functional Performance Testing**

A formal testing process is extremely valuable. When buildings are first occupied, the building systems seldom function as their designers' intended. Using the building's maintenance staff to debug problems and address occupant complaints can be very costly. Many of these problems could be eliminated by testing system performance before occupancy.

## Solar Control Strategy

To achieve a comfortable and energy-efficient building in Hawaii, controlling the amount of sunlight and heat from the sun that enters the building is key. Good solar control offers several benefits:

- Lower energy cost
- Smaller and less expensive cooling system
- Greater occupant comfort because of cooler interior surfaces
- More usable interior space because of improved comfort near windows

Effective solar control is not always easy or inexpensive. Fortunately, several strategies work well. This section provides an overview of alternatives and discusses some whole building design implications. **More details on many of these strategies may be found in the specific guidelines in this document.**

**Orientation**

Proper orientation is the most important strategy. Whenever possible, limit the amount of window and wall area on the east and west facades. Sunlight is easier to control on the north and south sides of a building.

**Fixed Shades**

The best strategy for solar control in Hawaii is to keep direct sunlight off the windows. Overhangs are typically the best choice and are especially effective on the north and south facades. The combination of overhangs and vertical fins can nearly eliminate direct solar gain for most of the year. See the Energy-Efficient Windows Guidelines for details.

**Operable Shades**

Automatic or manually controlled operable shades can replace or supplement fixed shades. When the sun is obscured by clouds or is on the other side of the building, operable shades can be adjusted to allow more light into the space and to give occupants a better view. However, operable shades are less likely to provide full long-term energy efficiency benefits compared to fixed shades because operable shades require more maintenance and their effectiveness depends on occupant behavior.

Exterior shades provide greater solar control because they block more heat from entering the building. However, interior shades may last longer, especially in areas close to the ocean or subject to harsh weather.

**Windows**

Windows are critical in the battle against the sun. A designer's first choice should be to minimize the amount of direct solar radiation that reaches the windows. If direct sunlight can be kept off the windows, then inexpensive clear or lightly tinted glass can be used. However, if it is not possible to completely shade the windows from direct sunlight, then solar-control glazing should be specified.

The most important glazing characteristic for windows in Hawaii is solar heat gain coefficient (SHGC). A low SHGC can be provided through several different technologies:

- *Heat-absorbing tints.* These tints are available in a range of colors. Some tints, typically blue or green in color, offer better visible light transmittance while providing equal or better solar control than gray or bronze tints. Consider using these blue or green tints in daylighting designs. All heat-absorbing tints get hot in direct sunlight — an important consideration for buildings where occupants sit close to windows.
- *Heat-reflecting coatings.* Several types of coatings are available. Some appear reflective; others are designed to reflect as much heat as possible while also appearing as clear as possible. The latter type of coating is called "spectrally selective" and is the best choice for simultaneously providing daylight and solar control.
- *Laminates.* These consist of plastic films sandwiched between two sheets of glass. Both heat-absorbing and heat-reflecting films are available. Heat-absorbing glass can be used to create the laminated glass sheet, providing further solar control.
- *Films.* Plastic films similar to those used to create laminated glass can be applied to the surface of the glass after the window is installed. This should be considered only as a retrofit measure because the exposed film is not as durable as glass.

In colder parts of the world, U-factor (an indicator of insulating performance) is often considered the most important feature of a window. Low U-factor is achieved using measures like multi-pane windows, infrared reflecting coatings and inert gas fill in glazing cavities. In Hawaii, where the difference between outdoor and indoor temperatures is small, U-factor is not an important issue.

**Cool Roof**

After windows, the roof is the next most significant path for solar heat to enter a building. As with windows, several effective solar control strategies are available. The first is to prevent solar heat from ever being absorbed by the roof surface. A "cool roof" surface is typically a white material that reflects solar radiation (high reflectance) and reradiates heat to the cool sky (high emissivity). Cool roof materials include white single-ply membranes, white liquid-applied coatings and white painted metal or tile.

A second solar control option is a radiant barrier, a reflective sheet with a low-emissivity surface that prevents radiant heat transfer between a hot roof and the surfaces below. For details, see the Cool Roofs Guidelines.

Finally, insulation also reduces heat gain through the roof. Foam board and fiberglass batts are two common materials. Cellulose spray-in insulation is also effective; many spray-in cellulose products are made primarily from recycled paper, an added environmental benefit.

**Walls**

As with windows, the first choice for controlling heat gain through a wall is shading. If shading is not possible, consider a light-colored exterior wall, radiant barrier, insulation and/or thermal mass to reduce heat flow. As with windows, the primary source of cooling load through walls in Hawaii is not high outdoor temperature. Rather it is solar radiation hitting the wall and heating the wall's surface. Therefore, a white uninsulated wall can be as effective as a dark wall with insulation.

**Landscaping**

Landscaping can provide excellent solar control. Place trees and shrubs in strategic locations, especially on the east or west sides where they can block morning and afternoon sun. But even if plants do not directly shade a building, they can help keep the local environment cooler. Pay special attention to shading asphalt roads and parking lots.

**Integrated Design Conflicts**

Designing for good solar control involves several tradeoffs and potential synergies. These are a few of the potential conflicts to consider when choosing an appropriate strategy.

***Solar Control vs. Daylighting***

Providing more daylight can conflict with the goal of reducing solar heat gain. However, well-designed shades can block much solar gain while also improving daylight penetration into the building. In addition, spectrally selective glazings can provide a low SHGC while also offering good visible light transmittance.

***Solar Control vs. Hurricane Safety***

Window overhangs or vertical fins might increase wind pressure on building walls during a storm. Extra structural measures may be necessary.

***Solar Control vs. Allowable Building Floor Area***

Overhangs or lanais are sometimes counted toward the allowable floor area of a building, thereby reducing the amount of interior floor area allowed.

***Solar Control vs. Maintenance***

Exterior shades should be designed to allow access for window washing. Measures to discourage roosting birds might also be considered.

**Integrated Design Benefits**

Good solar control provides benefits that affect many aspects of the building's design and operations, including:

***Air Conditioning Zoning***

Fewer air conditioning zones may be necessary if windows are effectively shaded because cooling loads will vary less between orientations.

***Air Conditioning Capacity***

An important benefit to solar control is smaller cooling loads and smaller and less expensive cooling equipment.

***Dehumidification Performance***

Typically, air conditioning equipment must be sized to meet peak solar loads through windows. If the windows are well shaded, then the equipment can be smaller and run at a more constant load. Not only does the equipment run more efficiently, but it also provides better dehumidification performance and better comfort.

### *Occupant Comfort*

Hot surfaces cause comfort problems for occupants. Therefore, solar control at the roof, walls and windows improves occupant comfort.

## Daylighting and Visual Comfort Strategy

Lighting accounts for about 40% of the energy cost for commercial buildings in Hawaii, and most of that lighting energy is consumed during daylight hours. Therefore, buildings designed to take advantage of daylight provide dramatic energy savings.

Several daylighting strategies are available, and more than one may be applied in a single project. Two broad categories of daylighting design are toplighting and sidelighting. Toplighting employs skylights or roof monitors to illuminate a space from above. Sidelighting designs use daylight from windows.

To be effective, a daylighting design must consider visual comfort. If glare is excessive, occupants may resort to using window shades, which may reduce the energy savings of the daylighting design.

To take advantage of the potential energy savings, the designers must develop a daylighting strategy early in the design process. Once decisions such as the number of stories and basic floor plan are made, many daylighting options may be eliminated.

Design team collaboration is critical to successful daylighting design. The architect, lighting designer and electrical engineer all play important roles and need to work together.

The success of a daylighting design often lies in the design details. Analysis tools such as physical models or computer simulations are very useful for selecting window size, shading configurations and space layouts. These tools can predict illumination levels and identify glare or daylight distribution problems.

### Building Form

The most basic design decisions have a big impact on daylighting potential. Single-story buildings have the greatest number of options: they can take advantage of toplighting, sidelighting or both. Multi-story buildings can achieve nearly complete daylighting through several means. A narrow floor plan, like that of many high-rise hotels, allows most indoor space to be illuminated by sidelighting. A courtyard or atrium can also allow daylight to reach interior zones of lower floors.

Space planning should account for uses that benefit from daylighting and those that don't. Most general office, medical examination, retail and educational spaces benefit from daylight access. Seldom-occupied spaces, such as storage rooms, can be given lower priority. Some types of work that are best performed with lower illumination levels will receive less benefit from daylighting. However, with careful design, even spaces with critical computer-intensive tasks can successfully employ daylighting.

**Orientation**

Orientation has an impact on daylighting effectiveness. As with solar shading design, daylight is more easily controlled on the north and south sides of a building. Whenever possible, the long sides of a building should face north and south, minimizing the east and west exposures. Good daylighting design is more difficult on the east and west sides because of glare created by direct sunlight in the morning and afternoon.

**Skylights**

Overhead skylights can be a very cost-effective means of providing pleasant and even illumination to an interior space. And in a single-story building, skylights can meet all the daytime lighting needs. Skylights are common in large spaces such as warehouses and factories, but they have also been used with great success in smaller spaces such as offices and classrooms. See the Daylighting Guidelines for details.

**Windows**

It's usually desirable to provide separate vision fenestration (windows that provide views) and daylighting fenestration (glass that provides daylighting). Vision glass should have lower light transmission to reduce glare and maintain the visual comfort of occupants close to the window. Daylighting glass, positioned higher on the wall, should transmit more visible light to provide better daylight penetration for occupants further from the window. Refer to the Daylighting Guidelines for more information.

**Lightshelves and Other Shading Devices**

Lightshelves or similar shading devices help improve the daylighting performance of windows. A good shade design serves two purposes: it blocks direct sunlight penetration and reflects diffuse light deeper into the room. See the Daylighting Guidelines for more information.

**Controls**

For a daylighting design to save energy, some form of electric lighting control is necessary. There are several control options; the best choice depends on the space type, the size of the space, and the type of lamp being controlled. See the Daylighting Guidelines.

Manual control is the simplest approach. However, occupant control is unlikely to achieve consistent and lasting savings, especially in larger buildings. Small, owner-occupied buildings are the best candidates for manual lighting control.

Automatic dimming control is the most desirable option for continuously occupied spaces such as offices. Dimming controls are least distracting and are therefore most likely to be accepted by occupants.

Automatic On/Off or multiple-step control is the best choice for spaces that are intermittently occupied, such as warehouses, workshops or similar spaces. Automatic On/Off control provides good energy savings while being relatively inexpensive.

**Costs and Benefits**

Some daylighting design options can add significant cost to the project, but daylighting's many benefits should be considered before rejecting daylighting based solely on first-cost concerns. For example, a design that allows daylight to reach all parts of the building may result in less floor area than a square floor plan that fills up the lot and has large interior spaces. But that extra cost could be worth the additional benefits. Besides saving lighting energy, a building designed for daylighting may also be able to save energy by employing natural ventilation because occupied spaces are likely to be close to openings. Even without natural ventilation, daylighting can lead to cooling energy savings because of the reduced heat gain from lights. And tenants often favor daylit spaces, increasing the value of the building.

Productivity can also be a powerful — and perhaps the most valuable — benefit to good daylighting design. The value of a mere 1% increase in occupant productivity far outweighs the investment cost for better daylighting and controls. Recent studies have shown that schoolchildren learn faster in a daylit environment.[1] Other studies seem to show improved sales in daylit retail stores; further studies are underway to verify this effect.[2] These study results indicate that energy savings are just a small part of the total benefits of good daylighting design.

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[1] Heschong Mahone Group, *Daylighting in Schools,* and *Skylighting and Retail Sales* (Pacific Gas & Electric Company, 1999). Available at www.pge.com/pec/daylight.

[2] *Productivity and Interior Environments* studies now being conducted by Heschong Mahone Group for the New Buildings Institute's *Integrated Energy Systems: Productivity & Building Science* program, a project of the State of California PIER Program. For more information, go to www.newbuildings.org/pier.

## Thermal Comfort Strategy

Thermal comfort depends on several factors, including air temperature, relative humidity, air movement and the temperature of surrounding surfaces. Therefore, several approaches to maintaining comfort are possible.

**Natural Ventilation**

From an energy efficiency and air quality perspective, natural ventilation is usually the best choice. Natural ventilation should be considered in all spaces without special indoor environment constraints (see Special Indoor Environment Requirements section). Of course, the feasibility of natural ventilation also depends on the building location.

For a successful naturally ventilated building, designers need to pay greater attention to the surroundings. Obstructions, landscaping and microclimate issues are important. Nearby sources of noise or dust can also be a constraint.

The Natural Ventilation Guidelines discuss thermal comfort and natural ventilation strategies.

**Ceiling Fans**

Ceiling fans are an effective way to provide comfort through air movement. See the Natural Ventilation Guidelines for ceiling fan design guidelines.

**Mechanical Cooling**

Mechanical cooling and dehumidification can ensure comfort for the majority of occupants. But no single condition is acceptable to all people, so even a well-designed mechanical system will not provide perfect comfort.

If choosing air conditioning for all or a portion of a building, consider the following:

- *Low supply air temperature.* By operating at a lower supply air temperature — closer to 50°F rather than 55°F leaving the cooling coil — dehumidification performance improves. And if humidity control is required, then less reheat energy will be necessary. Use a low approach coil (typically larger) to achieve the lower supply air temperature without necessarily reducing chilled water temperature.
- *Dual-path air handler.* Condition outside ventilation air (where much of the system's latent moisture-load comes from) separately from return air. Cool the outside air as low as is feasible to extract as much moisture as possible. Then provide additional cooling to the relatively dry return air if more cooling is necessary. See the Dehumidification Guidelines for details.

- *Humidity control.* Use measures such as heat pipes and run-around coils to avoid using a reheat coil. See the Dehumidification Guidelines.
- *Careful load calculation and equipment sizing.* If specifying packaged, direct expansion cooling equipment (as opposed to chilled water cooling), be especially careful not to oversize the cooling capacity. In addition, consider a unit with a refrigerant subcooling option to improve the dehumidification capacity. See the HVAC Guidelines for recommendations regarding packaged air conditioners.

**Hybrid Design**

Many successful designs employ natural ventilation and air conditioning in separate portions of the same building. For example, spaces with very high equipment loads or occupant density can be mechanically cooled, while areas such as open offices, private offices, corridors and lobbies can be naturally ventilated. A good hybrid design requires careful space planning from the start.

**Building Envelope**

Regardless of the choice of natural or mechanical ventilation, the building shell should be designed to prevent the occupants from being exposed to hot interior surfaces. Insulation reduces the interior wall and ceiling temperatures. Window shading, coated glass or both help keep windows cool. Avoid tinted glass where it will be exposed to direct sunlight. Tinted glass absorbs solar radiation and can reach very high temperatures, causing discomfort for people close to the windows.

## Special Indoor Environment Requirements

The choice between natural ventilation and air conditioning depends in part on whether natural ventilation can provide acceptable indoor conditions. One important consideration is human comfort, but another is the environment necessary for the operation of equipment or for other indoor space functions.

**Office Equipment**

Electronic equipment is designed for operation within certain temperature and humidity limits. Some electronic devices will malfunction if they get hot. Therefore it is important to make sure that any equipment located in a naturally ventilated space will tolerate temperatures of 80°F to 90°F.

Natural ventilation is not a problem for typical personal computers; they are rated to operate in temperatures as high as 95°F and relative humidity as high as 90%.

*Table 1-1. Operating temperature and relative humidity (RH) range for selected office equipment. Source: Manufacturers' product literature.*

| Product | Temperature Range °F | RH Range (non-condensing) %RH |
|---|---|---|
| **Desktop Computers** | | |
| Power Mac G4 | 50 – 95 | 5 – 95% |
| iMac | 50 – 95 | 5 – 95% |
| Power Mac G4 Cube | 50 – 95 | 5 – 95% |
| HP Desktop (Brio) | 41 – 95 | 15 – 85% |
| HP Desktop (Vectis) | 41 – 95 | 8 – 85% |
| **Laptop Computers** | | |
| IBook | 50 – 95 | 20 – 80% |
| PowerBook G4 | 50 – 95 | 20 – 80% |
| Dell Inspiron | 41 – 95 | 10 – 90% |
| **Printers** | | |
| HP Copyjet | 59 – 95 | 30 – 80% |
| HP Deskjet | 59 – 95 | 20 – 80% |
| Xerox Desktop Laser | 50 – 90 | 15 – 85% |
| IBM Laser | 60 – 90 | 20 – 80% |
| Epson Inkjet | 50 – 95 | 20 – 80% |
| **Copy Machines** | | |
| Xerox 2510 | 60 – 90 | 15 – 85% |

Some paper may curl at high humidity and affect printer or copier performance. These problems may be minimal if the paper is not subject to changing conditions. For copiers and printers located in naturally ventilated spaces, store the paper under the same conditions.

Refrigerated equipment may develop condensation on its surface if it is not well insulated. Water coolers, refrigerators and vending machines could be affected.

**Medical Facilities**

Some spaces within hospitals and other medical facilities may require pressurization controls to prevent contamination between rooms. Mechanical ventilation and cooling may be required for those areas, limiting the potential application of natural ventilation.

Medical electronics may be sensitive to temperature and humidity. Manufacturer specifications should be checked when natural ventilation is considered.

**Laboratories**

Some laboratories require exhaust systems to remove potential contaminants. The changing pressure due to natural ventilation could interfere with the safe operation of fume hoods.

**Libraries & Museums**

Some materials such as books and other paper documents require low humidity to prevent damage. Art and artifacts may also require conditions not attainable through natural ventilation.

**Retail Spaces**

Spaces with many refrigerated cases are not good candidates for natural ventilation because the humidity can create condensation problems.

## Indoor Air Quality Strategy

Good indoor air quality is best achieved through a system approach that considers:

- ventilation,
- moisture control,
- reduction of indoor pollution sources, and
- monitoring and maintenance.

**Ventilation**

For naturally ventilated buildings the most important issue is the location of nearby exterior pollution sources. Obvious sources include roads, parking lots, dusty fields, agricultural areas and some commercial or industrial activities.

Ventilation is traditionally employed as an indoor air quality solution for air-conditioned buildings. However, ventilation alone cannot guarantee a healthy building, and high ventilation rates raise energy costs.

**Moisture Control**

Good moisture control in the roof, walls and floors is important to prevent mold growth. Careful design of the air conditioning system can also improve dehumidification to inhibit mold growth.

**Indoor Pollution**

To improve indoor air quality, reducing indoor pollution sources is critical. Choose furniture and finishings with low emission rates of toxic chemicals. Ensure that air from storage spaces for chemicals and cleaning materials is directly exhausted to the outside. It is also a good idea to exhaust air from areas with photocopiers or printers.

**Monitoring & Maintenance**

Regular cleaning and maintenance of air conditioning equipment is essential. Cooling coils are nearly always host to mold growth in Hawaii, and can be sources of odor and health problems. Maintenance options include thoroughly cleaning the coils (preferably twice each year), or installing ultraviolet lamps in the air handlers to inhibit mold growth. See the HVAC Guidelines.

## Specific Building Type Issues

Different building types present different opportunities for energy efficiency. This section highlights important issues for a number of commercial and institutional building types.

### Office Buildings

***Solar Control***

Windows are the critical element in office solar control. Proper orientation and exterior shading are the preferred approach. Otherwise, glazing with low solar transmission is appropriate (but also remember light transmission for daylighting). See the Energy-Efficient Windows Guidelines for recommendations.

The roof is also important, especially for low-rise offices. See the Cool Roofs Guidelines.

***Daylighting and Visual Comfort***

Daylighting is ideal for offices, saving both lighting and cooling energy. Both sidelighting (through windows and clerestories) and toplighting (via skylights) are applicable. See the Daylighting Guidelines.

Wherever possible, try to keep the building depth narrow (under 40 feet) to allow for good daylighting and improve natural ventilation opportunities. A relatively high ceiling — 10 to 12 feet — will also improve daylight penetration and natural ventilation.

Lighting design also offers an excellent savings opportunity for offices. Consider suspended direct/indirect fixtures and appropriate (low) ambient illumination. See the Electric Lighting Guidelines.

Use occupancy sensors for lighting control.

***Thermal Comfort***

Natural ventilation works for offices in Hawaii, especially if supplemented with ceiling fans. If there’s critical equipment or materials that require special environmental conditions, consider designing the building with a small air-conditioned room in the

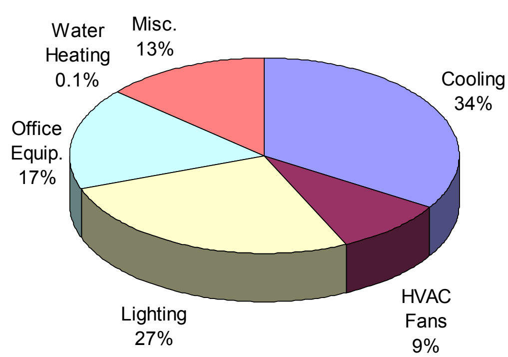



*Figure 1-1. Energy consumption for typical Hawaii office building; total 23 kWh/yr-ft$^2$.*

building core instead of conditioning the whole building. See the Natural Ventilation Guidelines.

Otherwise use a variable-air-volume air conditioning system to provide fan power savings and superior dehumidification performance compared to a constant-air-volume system. In addition, consider a dual-path system that cools ventilation air separately from return air and further improves dehumidification. See the HVAC and Dehumidification Guidelines.

***Indoor Air Quality***

Natural ventilation can often provide excellent indoor air quality. Otherwise, consider a demand-controlled ventilation system that varies the amount of outside ventilation air depending on the number of occupants. Also consider UV lamps in air handlers to inhibit mold growth. See the HVAC Guidelines.

**Retail Buildings**


***Solar Control***

For many retail buildings, especially “big box” stores, the roof is the main path for solar heat to enter the building. See the Cool Roofs Guidelines for recommendations.

***Daylighting and Visual Comfort***

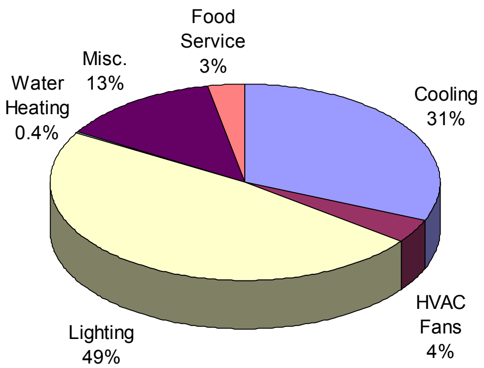
Lighting is usually the biggest energy consumer in retail buildings (except for grocery stores, where refrigeration is also significant). Therefore, special attention to lighting design is critical. Minimize the use of incandescent lamps, using them only for accent lighting. See the Electric Lighting Guidelines.

Skylights are a great choice for many retail spaces, providing lighting savings as well as excellent color rendition. See the Daylighting Guidelines for recommendations.

***Thermal Comfort***

If air conditioning is necessary, then a dual-path system may be appropriate, especially for spaces with refrigerated cases because the lower humidity will help prevent condensation.

Also consider variable-air-volume controls to minimize fan energy and improve dehumidification.



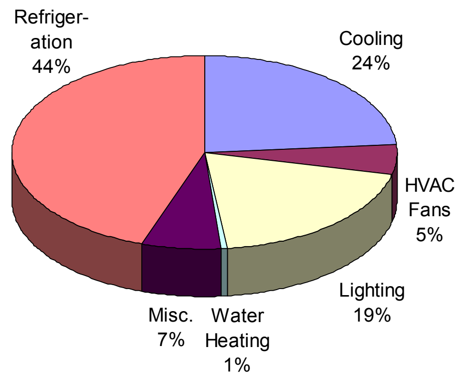




*Figure 1-2 (left). Energy consumption for typical Hawaii retail facility (excluding grocery); total 26 kWh/yr-ft$^2$.*

*Figure 1-3 (right). Energy consumption for typical Hawaii grocery building; total 53 kWh/yr-ft$^2$.*

### *Indoor Air Quality*

Consider UV lamps in air handlers to inhibit mold growth on cooling coils.

### *Other Savings Opportunities*

Recover heat rejected from refrigeration and air conditioning systems for water heating.

## School Buildings

### *Solar Control*

School buildings in Hawaii are typically naturally ventilated. Therefore, solar control is critical for comfort. Proper orientation is important, and window shading is common and highly desirable. In addition, a cool roof—such as a white roof combined with a radiant barrier—is necessary to help keep the classrooms cool and comfortable.

### *Daylighting and Visual Comfort*

Daylight has been shown to improve learning performance. Therefore, classrooms, gyms and multipurpose rooms are excellent candidates for daylighting design using windows and skylights. See the Daylighting Guidelines for details.

Lighting design is another big savings opportunity in schools. A high ceiling provides multiple benefits, allowing pendant-mounted direct/indirect lighting and improving daylight distribution and thermal comfort. See the Electric Lighting Guidelines for design and lighting control recommendations.

### *Thermal Comfort*

Natural ventilation should be the first choice for classroom comfort. Otherwise, if outdoor noise or pollution don't allow the windows to stay open, then a dual-path air conditioning system is an excellent choice because classrooms have high outside air ventilation rate requirements due to high occupant density. See the Dehumidification Guidelines for more information.

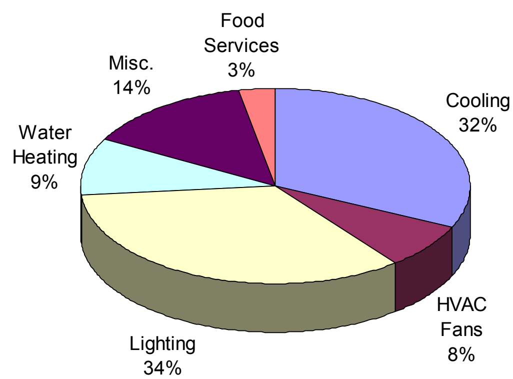



*Figure 1-4. Energy consumption for typical Hawaii school; total 9 kWh/yr-ft$^2$.*

### *Indoor Air Quality*

Natural ventilation is the best choice, assuming that outdoor air quality is reasonable. If air conditioning is installed, then humidity control is important. The system should be carefully designed so that it is not any larger than necessary. An oversized system cycles on and off more frequently and dehumidification performance degrades.

## Health Care Buildings


### *Solar Control*

Health care buildings often have less window area than other commercial building types, but high performance windows are still likely to be cost effective for solar control, especially if windows have little exterior shading.

### *Daylighting and Visual Comfort*

Many parts of health care facilities can be effective illuminated using daylight, with task lighting used for critical tasks. Lighting controls should include occupancy sensors in private office spaces and exam rooms.

### *Thermal Comfort*

Cooling is a major energy consumer in many health care facilities because many spaces use 100% outside air for ventilation (no recirculated air). In addition, some spaces such as operating rooms also require humidity control. The Dehumidification Guidelines provide recommendations for energy-saving systems such as heat pipes and run-around coils.

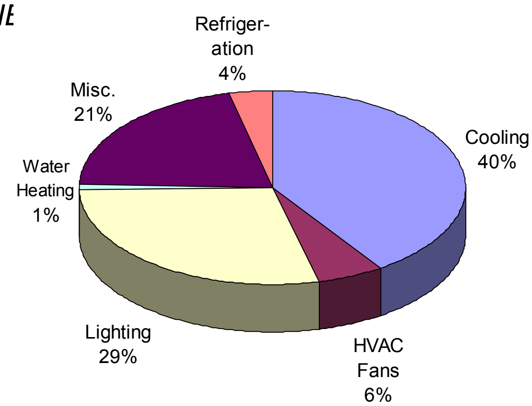



*Figure 1-5. Energy consumption for typical Hawaii health care building; total 25 kWh/yr-ft².*

### Indoor Air Quality

Humidity control is important for good indoor air quality. It's especially challenging in facilities that operate 24 hours per day, as do many health care buildings. The problem is that moisture must be removed from the ventilation air even at night when the air temperature is relatively low and cooling requirements inside the building are lower. In a conventional system the ventilation air is cooled to low temperature, perhaps 50°F to 55°F, to remove moisture and then reheated to avoid overcooling the building. The process of cooling and reheating can be energy intensive. Therefore, it is important to consider the energy-saving dehumidification techniques described in the Dehumidification Guidelines.

Another source of air quality problems can be mold growing on the damp cooling coils. UV lamps inside the air handlers can help keep coils clean. More intense levels of UV light can be used to kill microbes in the air as it flows through the air handler to help prevent the spread of diseases such as tuberculosis.

## Hotels

### Solar Control

The main challenge for solar control in hotels is providing complete window shading while also maintaining views. As much as possible, windows should be facing north or south. And balconies should be designed to keep the sun off the windows at all times (which is very difficult for east and west-facing windows). If complete shading is not possible, then consider high performance low-e windows that have low solar transmission while maintaining good views. See the Energy-Efficient Windows Guidelines for details.

### Daylighting and Visual Comfort

Hotel guest rooms typically have adequate window area for daylighting illumination. To optimize light distribution within the room, use light-colored interior surfaces. For low-rise hotels, consider small skylights in bathrooms.

Avoid the use of energy-intensive incandescent lighting. Modern compact fluorescent fixtures can provide good color rendition, lower energy consumption, and much longer life.

***Thermal Comfort***

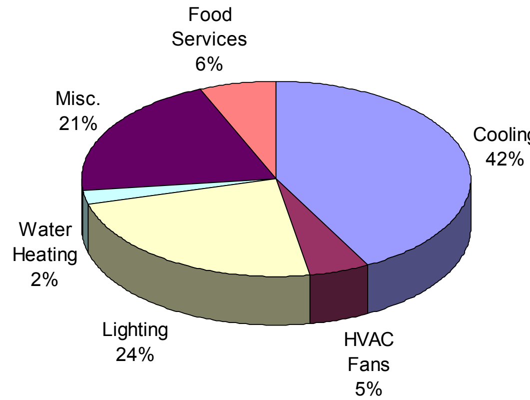



*Figure 1-6. Energy consumption for typical Hawaii hotel; total 16 kWh/yr-ft$^2$.*

Design for natural ventilation, allowing the guests to easily shut off cooling and rely on cross ventilation and ceiling fans for comfort. If air conditioning is installed, use magnetic switches on balcony doors to shut off cooling to a room when the door is open. Also consider an energy management system that reduces cooling demand by automatically raising the temperature in vacant rooms.

For ballrooms and meeting rooms, use controls to vary the amount of outdoor air ventilation depending on occupancy. See the HVAC Guidelines.

***Indoor Air Quality***

Moisture control is the primary air quality issue in hotels. Ventilation air delivered to guest rooms should be dehumidified.

***Other Savings Opportunities***

Hotels are an excellent application for using heat recovered from the cooling system to heat water. Heat rejected by water chilling equipment can be very effectively recovered using heat pump water heaters.

**Restaurants**

***Solar Control***

As with most other building types, attention to the windows and the roof is important for solar control. Consider operable exterior shades for east- or west-facing glazing.

***Daylighting and Visual Comfort***

For general ambient light, use full-size or compact fluorescent lighting. Limit the use of incandescent (including halogen) lamps to accent lighting.

***Thermal Comfort***

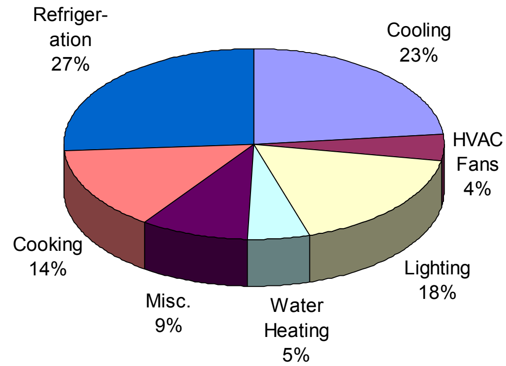



*Figure 1-7. Energy consumption for typical Hawaii restaurant; total 53 kWh/yr-ft$^2$.*

In many cases, cross ventilation and ceiling fans can provide comfort in dining rooms and cooling should not be necessary. Otherwise, it is important to pay attention to air conditioner sizing. A restaurant can have highly variable cooling loads because the number of occupants varies over the day. Therefore, good comfort requires that the system operate over a wide range of cooling loads while still providing good humidity control. Consider a dual-path system for humidity control and demand control for outside air volume. See the Dehumidification and HVAC Guidelines.

Kitchen comfort can be a significant energy issue. Providing air conditioning to the kitchen can be very costly due to the large heat sources and the large volume of exhaust air. Before providing air conditioning to the kitchen, it is important to carefully design the exhaust system so that the majority of air that is exhausted is drawn directly from outdoors and introduced to the space directly in front of the range hoods. See the Kitchen Exhaust Makeup section of the HVAC Guidelines.

***Indoor Air Quality***

Design and commission the kitchen exhaust system to ensure that the kitchen is negatively pressurized relative to the dining room. And, as described in the proceeding discussion of thermal comfort, design the cooling system to operate over a wide range of cooling conditions.

***Other Savings Opportunities***

Heat recovery from the cooling system or refrigeration system for water heating may be cost effective.

## Commissioning

Increasingly, building owners are recognizing that building commissioning is an important strategy for achieving lasting energy savings. Commissioning is a type of quality assurance program used to verify that building systems work together efficiently, effectively and as intended in the design specifications. Commissioning can give the building owner confidence that the designers and contractors have done the work the owner hired them to do. Without a formal commissioning process, building owners may find themselves dealing with costly and frustrating system problems well after construction is complete and the building contractors have moved on to other projects.

Not only does commissioning help ensure that a new building is performing optimally when delivered to the owner, it also improves the chances that the building will continue to operate as intended.

**Commissioning Agent**

The commissioning process starts with a commissioning agent (CA), who is engaged by the building owner to manage the commissioning and to act as an advocate for the owner. It’s important that the CA be independent and under direct contract to the owner, not under contract to other members of the design and construction team.

The owner should hire a commissioning agent as early as possible in the project. Part of the CA’s job is to identify the commissioning responsibilities of each member of the design and construction team so that this information can be included in each team member’s contract.

**Commissioning Plan**

In a written commissioning plan, the CA identifies the systems to be commissioned, describes the scope of the commissioning process, lays out a commissioning schedule, and defines the testing and reporting procedures that are integral to the commissioning process.

Most commissioning plans include the following important elements:

- *Installation checks.* Ensure that specified equipment and accessories are installed.
- *Performance checks.* Verify and document that systems are performing as intended, and that sensors and other control devices are properly calibrated.
- *Documentation.* Ensure that all required documentation has been provided, such as a statement of the design intent and operating protocols for all building systems.
- *Manuals and training.* Prepare operation and maintenance (O&M) manuals and provide training to the building operations staff.

- *Monitoring.* Conduct ongoing monitoring after the building is occupied to ensure that equipment and systems continue to perform as expected.

**Verification and Testing**

Although any building system can be commissioned, the most important systems that should be commissioned are the mechanical, electrical and life safety systems. Throughout the construction process, the CA verifies that the systems are being installed as specified, identifies any problems related to that particular system or its interaction with other systems, and makes recommendations to the owner for correcting those problems.

Functional tests, a key part of commissioning, help ensure that systems are working together as intended. The CA develops written protocols for these tests, ensures that they are properly conducted, documents the results, and reports the findings to the building owner.

**Commissioning Report**

The Building Commissioning Association recommends that every commissioning process be thoroughly documented with a commissioning report that includes:

- An assessment of the systems' operating condition when the functional tests are conducted;
- Problems discovered and the steps taken to correct them;
- Uncorrected operational problems that the owner decided to accept;
- Functional test procedures and results;
- Reports documenting all commissioning activities as they progress; and
- A description and estimated schedule of any deferred testing.

Properly implemented, commissioning will ensure that a new building starts its life at the highest performance level possible.

**Resources**

For more information about building commissioning:

U.S. Department of Energy, Office of Building Technology, State and Community Programs, www.eren.doe.gov/buildings/comm_energyeff.html

Building Commissioning Association, www.bcxa.org

# 2. NATURAL VENTILATION GUIDELINES



## Overview

From energy efficiency, indoor air quality and occupant comfort perspectives, natural ventilation is usually a better choice than air conditioning in a climate like Hawaii's. Natural ventilation can save substantial energy by decreasing or eliminating the need for mechanical cooling. It may also improve the building's indoor air quality, provided that dust and other pollutants in the air outside the building aren't a problem. And buildings with well-designed natural ventilation systems often provide very comfortable and pleasant environments for the occupants. People may even work more productively when they can open and close windows and vary the airflow in their workspaces.

For a successful naturally ventilated building, designers need to pay greater attention to the building's immediate surroundings. Obstructions, landscaping, nearby sources of noise or dust, and microclimate issues must all be considered.

**Thermal Comfort**

The choice between natural ventilation and air conditioning depends on whether natural ventilation can provide acceptable indoor conditions. One important consideration is occupant comfort.

The traditional definition of comfort published in ANSI/ASHRAE Standard 55–1992 (Thermal Environmental Conditions for Human Occupancy) does not distinguish between spaces with and without natural ventilation. But recent research by Gail Brager of the University of California–Berkeley shows that in naturally ventilated buildings, people adapt to changes in mean outdoor temperature and are comfortable in — and may even prefer — a broader range of thermal conditions. People in air-conditioned buildings, on the other hand, expect even and cool temperatures, and are quickly dissatisfied if thermal conditions differ from what they expect.

This difference in comfort expectations is partly the result of behavioral adaptations: people in naturally ventilated buildings wear appropriate clothes and open or close windows to adjust the airflow. Some of the difference may also be due to physiological factors, as the body's thermal expectations change over the course of a year.

An adaptive model of thermal comfort, instead of the narrow model recommended by ASHRAE Standard 55, allows buildings to be designed and operated to optimize thermal comfort and reduce energy use. Brager's research is at the heart of changes to ASHRAE Standard 55 that are currently under consideration.

For Hawaii, Brager's model means that people in naturally ventilated buildings can be comfortable at higher indoor temperatures as the outdoor air temperature increases[1] (see Figure 2-1). Based on this proposed new thermal comfort model, buildings in Honolulu can be naturally ventilated for most hours between the months of November through April (Figure 2-2). In Hilo natural ventilation can be adequate all year (Figure 2-3).

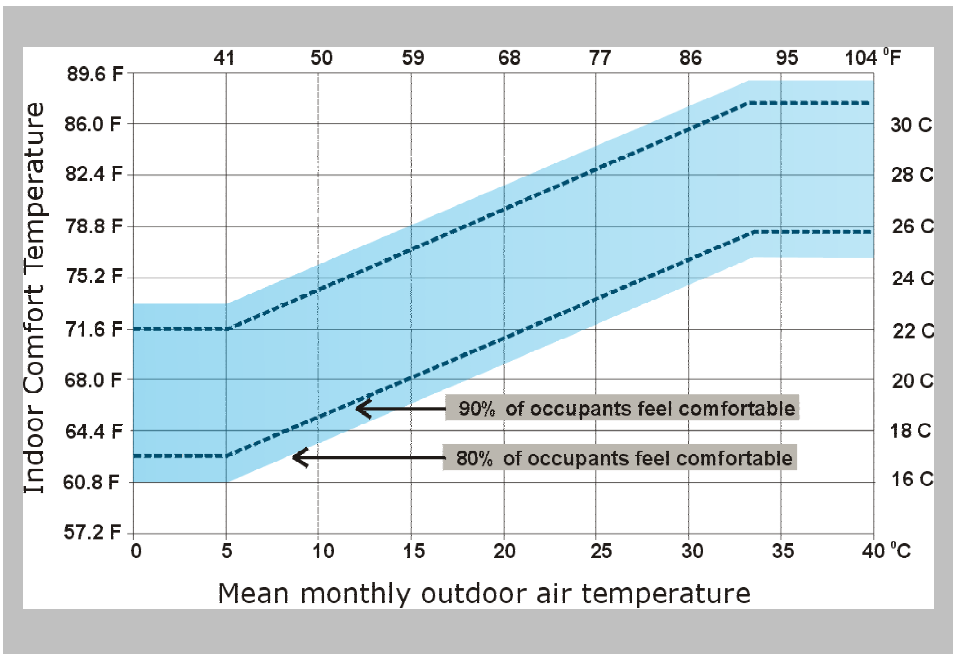



*Figure 2-1. Thermal comfort model proposed by Gail Brager. The shaded area shows indoor temperatures at which 80% of occupants feel comfortable as outdoor temperature varies. The area between the dotted lines shows the indoor temperatures at which 90% of occupants feel comfortable.*

[1] Gail Schiller Brager and Richard de Dear, "A Field-Based Thermal Comfort Standard for Naturally Ventilated Buildings," *Collaborative for High Performance Schools (CHPS) Best Practices Manual, Appendix C* (Eley Associates, 2001). Available at www.chps.net. Also, Gail Schiller Brager and Richard de Dear, "A Standard for Natural Ventilation," *ASHRAE Journal,* vol. 42, no. 10 (October 2000), p. 21-28.

*Figure 2-2. Indoor comfort range in naturally ventilated buildings in Honolulu (based on comfort model shown in Figure 2-1).*

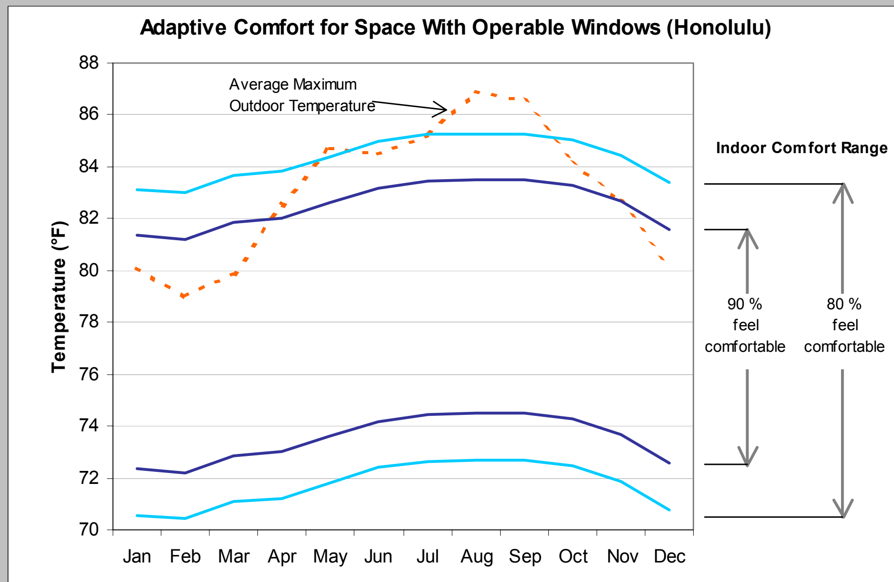



*Figure 2-3. Indoor comfort range in naturally ventilated buildings in Hilo (based on comfort model shown in Figure 2-1).*

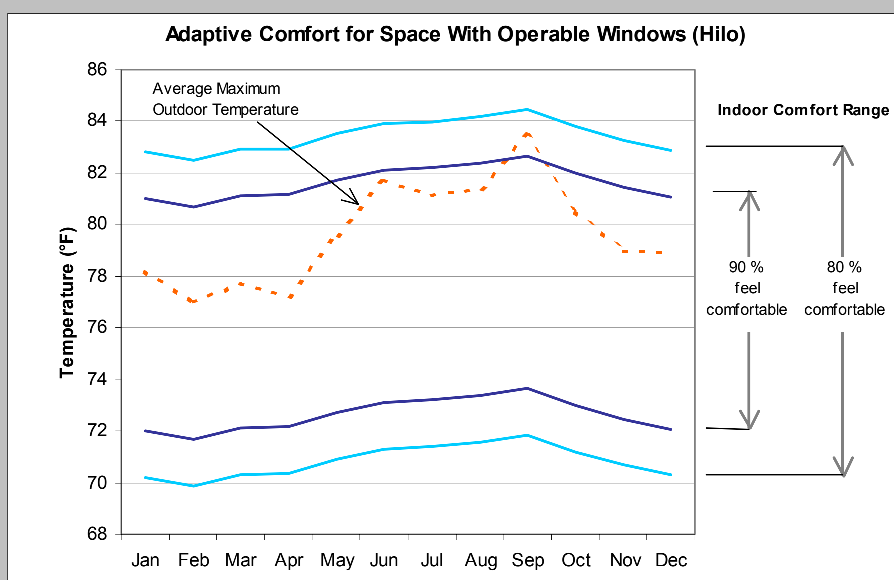



Table 2-1 and Table 2-2 show average hourly outdoor temperatures for Honolulu and Hilo and identify the times of year when outdoor air satisfies indoor comfort requirements. Table 2-1 shows that the majority of working hours fall within the comfort range, but that in Honolulu there are portions of the day in May through October that exceed the 90% comfort limit (outlined in the table with a dotted line). The less stringent 80% limit is exceeded only in August and September (indicated by shading in the table). Commercial buildings in warmer regions of Oahu might need measures like ceiling fans to provide air movement (see next section) and/or careful use of building mass and landscaping to reduce heat loads.

*Table 2-1. Average outdoor hourly temperatures (°F) for Honolulu. Dotted line marks the hours when outdoor temperature exceeds indoor comfort limits in naturally ventilated buildings for 10% of occupants. Source of temperature data: Typical Meteorological Year Data, U.S. National Climatic Data Center.*

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 69.3 | 68.2 | 70.2 | 71.1 | 72.7 | 75.4 | 75.4 | 77.2 | 76.4 | 75.6 | 72.9 | 69.7 | **72.9** |
| 2 | 68.8 | 67.9 | 69.6 | 70.8 | 72.3 | 75.1 | 74.9 | 77.1 | 76.0 | 75.1 | 72.4 | 69.4 | **72.5** |
| 3 | 68.4 | 67.6 | 69.1 | 70.1 | 71.8 | 74.7 | 74.5 | 76.7 | 75.6 | 74.9 | 72.1 | 69.4 | **72.1** |
| 4 | 68.1 | 67.6 | 68.8 | 69.9 | 71.4 | 74.3 | 74.3 | 76.3 | 75.3 | 74.4 | 71.9 | 69.2 | **71.8** |
| 5 | 67.8 | 67.3 | 68.2 | 69.9 | 70.8 | 74.0 | 73.9 | 76.1 | 74.9 | 74.2 | 71.7 | 69.2 | **71.5** |
| 6 | 67.6 | 66.6 | 69.3 | 69.6 | 70.5 | 74.0 | 75.3 | 75.8 | 76.1 | 75.3 | 71.8 | 69.4 | **71.8** |
| 7 | 67.3 | 66.5 | 70.4 | 70.5 | 73.4 | 75.1 | 76.8 | 76.6 | 77.4 | 76.3 | 71.7 | 69.6 | **72.7** |
| 8 | 69.1 | 67.5 | 71.5 | 73.9 | 77.0 | 77.5 | 78.2 | 78.5 | 78.6 | 77.5 | 74.1 | 69.8 | **74.5** |
| 9 | 73.3 | 71.2 | 73.6 | 76.1 | 79.3 | 79.3 | 80.0 | 80.4 | 80.6 | 79.2 | 77.2 | 72.7 | **76.9** |
| 10 | 76.3 | 73.7 | 75.9 | 78.5 | 81.3 | 80.9 | 81.7 | 82.5 | 82.8 | 80.9 | 79.6 | 75.4 | **79.2** |
| 11 | 77.7 | 75.9 | 78.0 | 79.9 | 82.5 | 82.4 | 83.5 | 83.8 | 84.8 | 82.6 | 80.7 | 78.3 | **80.9** |
| 12 | 78.5 | 77.1 | 78.5 | 81.0 | 83.3 | 82.9 | 83.9 | 85.4 | 85.2 | 82.8 | 81.4 | 78.7 | **81.6** |
| 13 | 78.7 | 77.5 | 79.3 | 81.4 | 84.0 | 83.5 | 84.2 | 85.7 | 85.9 | 83.5 | 81.6 | 79.2 | **82.1** |
| 14 | 79.0 | 77.9 | 79.9 | 81.0 | 83.4 | 83.5 | 84.6 | 86.2 | 86.3 | 83.7 | 81.7 | 79.6 | **82.2** |
| 15 | 78.1 | 77.5 | 79.2 | 80.9 | 82.8 | 83.4 | 83.7 | 85.6 | 85.4 | 82.9 | 81.1 | 78.8 | **81.6** |
| 16 | 77.3 | 76.3 | 78.6 | 80.5 | 81.5 | 82.7 | 83.0 | 84.4 | 84.3 | 81.9 | 79.7 | 78.0 | **80.7** |
| 17 | 75.6 | 75.4 | 77.9 | 78.5 | 79.8 | 81.6 | 82.1 | 83.4 | 83.4 | 81.1 | 78.2 | 77.2 | **79.5** |
| 18 | 73.5 | 73.9 | 76.5 | 76.2 | 78.0 | 80.0 | 80.4 | 81.2 | 81.8 | 79.9 | 76.0 | 75.8 | **77.8** |
| 19 | 72.2 | 72.2 | 75.1 | 73.6 | 75.9 | 78.4 | 78.9 | 79.5 | 80.1 | 78.6 | 75.2 | 74.5 | **76.2** |
| 20 | 71.5 | 71.5 | 73.6 | 72.7 | 74.9 | 77.2 | 77.3 | 78.7 | 78.5 | 77.5 | 74.3 | 73.1 | **75.1** |
| 21 | 71.2 | 70.5 | 72.9 | 72.6 | 74.5 | 76.9 | 77.0 | 78.3 | 78.3 | 77.2 | 74.2 | 72.2 | **74.7** |
| 22 | 70.5 | 69.5 | 72.2 | 72.3 | 74.1 | 76.7 | 76.5 | 78.1 | 77.6 | 76.8 | 73.6 | 71.4 | **74.1** |
| 23 | 69.9 | 69.0 | 71.6 | 71.8 | 73.9 | 76.4 | 76.3 | 77.8 | 77.4 | 76.5 | 73.4 | 70.5 | **73.7** |
| 24 | 69.7 | 68.7 | 71.0 | 71.4 | 73.6 | 75.8 | 75.8 | 77.7 | 77.0 | 76.0 | 73.1 | 70.2 | **73.4** |
| Avg. Outdoor Temperature (Dry bulb) | 72.1 | 71.7 | 73.8 | 74.3 | 76.1 | 78 | 78.8 | 78.9 | 78.9 | 78.2 | 76.3 | 72.9 | 75.8 |
| AVG. DAILY MAX. TEMP. | 80.1 | 79 | 79.9 | 82.5 | 84.7 | 84.5 | 85.2 | 86.9 | 86.5 | 84.2 | 82.6 | 80.1 | 83 |
| AVG. DAILY MIN. TEMP. | 66.1 | 65.4 | 67.7 | 68.8 | 70.2 | 73.5 | 73.7 | 75.5 | 74.8 | 73.8 | 70.8 | 67.5 | 70.7 |

10% feel uncomfortable

Typical occupied hours (7 am - 6 pm)

20% feel uncomfortable

Table 2-2 shows that temperatures in Hilo are a bit lower than in Honolulu and that average temperatures fall within the comfort range all year. Therefore, year-round natural ventilation should be feasible in Hilo and similar climates.

*Table 2-2. Average outdoor hourly temperatures (°F) for Hilo. Ninety percent of occupants will be comfortable in a naturally ventilated building during typical occupied hours. Source of temperature data: Typical Meteorological Year Data, U.S. National Climatic Data Center.*

| HOUR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 67.4 | 66.4 | 67.7 | 68.3 | 69.2 | 69.8 | 71.2 | 71.3 | 72.1 | 71.0 | 69.2 | 67.4 | **69.3** |
| 2 | 67.0 | 65.8 | 67.3 | 67.7 | 68.7 | 69.4 | 70.6 | 70.6 | 71.4 | 70.8 | 68.6 | 66.9 | **68.7** |
| 3 | 66.6 | 65.5 | 67.0 | 67.2 | 68.4 | 69.1 | 70.4 | 70.3 | 71.1 | 70.2 | 68.4 | 66.7 | **68.4** |
| 4 | 66.1 | 65.2 | 66.7 | 66.8 | 68.0 | 68.8 | 70.3 | 70.1 | 70.8 | 69.5 | 68.1 | 66.2 | **68.1** |
| 5 | 65.8 | 65.0 | 66.3 | 66.3 | 67.6 | 68.5 | 69.9 | 69.8 | 70.5 | 69.2 | 67.9 | 65.9 | **67.7** |
| 6 | 66.4 | 65.7 | 67.1 | 67.8 | 69.7 | 70.5 | 69.9 | 71.5 | 72.2 | 68.9 | 68.8 | 66.6 | **68.8** |
| 7 | 66.9 | 66.3 | 67.8 | 69.4 | 71.8 | 72.7 | 70.9 | 73.4 | 73.9 | 69.7 | 69.6 | 67.3 | **70.0** |
| 8 | 67.5 | 67.1 | 68.7 | 70.9 | 73.8 | 74.8 | 74.1 | 75.1 | 75.7 | 73.5 | 70.6 | 68.0 | **71.7** |
| 9 | 70.7 | 69.7 | 71.3 | 72.6 | 75.3 | 76.5 | 76.2 | 76.6 | 78.0 | 77.0 | 72.9 | 71.3 | **74.0** |
| 10 | 73.9 | 72.4 | 73.7 | 74.3 | 76.9 | 77.9 | 78.0 | 78.5 | 80.3 | 78.1 | 75.1 | 74.5 | **76.2** |
| 11 | 77.1 | 75.0 | 76.3 | 76.0 | 78.4 | 79.7 | 79.3 | 80.1 | 82.6 | 78.6 | 77.5 | 77.7 | **78.2** |
| 12 | 77.1 | 75.6 | 76.6 | 76.0 | 78.4 | 80.3 | 79.9 | 80.4 | 82.4 | 79.0 | 77.8 | 77.9 | **78.5** |
| 13 | 77.1 | 76.1 | 77.1 | 76.5 | 78.5 | 80.9 | 80.0 | 80.7 | 82.4 | 79.1 | 78.2 | 78.2 | **78.8** |
| 14 | 77.1 | 76.6 | 77.5 | 76.5 | 78.5 | 81.5 | 80.2 | 80.9 | 82.2 | 79.3 | 78.6 | 78.5 | **79.0** |
| 15 | 76.1 | 75.6 | 76.8 | 75.8 | 77.9 | 80.5 | 79.9 | 80.2 | 81.3 | 79.0 | 77.5 | 77.1 | **78.2** |
| 16 | 75.2 | 74.7 | 76.0 | 75.0 | 77.4 | 79.4 | 79.1 | 79.7 | 80.3 | 77.9 | 76.3 | 75.9 | **77.3** |
| 17 | 74.2 | 73.7 | 75.3 | 74.4 | 76.8 | 78.4 | 78.1 | 79.0 | 79.4 | 76.6 | 75.2 | 74.5 | **76.3** |
| 18 | 73.1 | 72.2 | 73.9 | 73.2 | 75.4 | 76.7 | 76.8 | 77.5 | 78.0 | 75.6 | 74.1 | 73.1 | **75.0** |
| 19 | 71.8 | 70.8 | 72.3 | 72.1 | 73.7 | 74.8 | 75.1 | 76.1 | 76.6 | 74.5 | 73.1 | 71.8 | **73.6** |
| 20 | 70.7 | 69.2 | 70.9 | 71.0 | 72.3 | 73.1 | 74.0 | 74.6 | 75.2 | 73.6 | 72.0 | 70.3 | **72.3** |
| 21 | 69.9 | 68.7 | 70.1 | 70.5 | 71.6 | 72.3 | 73.6 | 74.1 | 74.7 | 73.1 | 71.3 | 69.6 | **71.6** |
| 22 | 69.2 | 68.0 | 69.5 | 69.9 | 70.8 | 71.4 | 72.9 | 73.4 | 73.9 | 72.4 | 70.7 | 68.8 | **70.9** |
| 23 | 68.4 | 67.5 | 68.7 | 69.4 | 70.2 | 70.6 | 72.4 | 72.8 | 73.3 | 71.8 | 70.1 | 68.1 | **70.3** |
| 24 | 67.9 | 66.9 | 68.3 | 68.8 | 69.6 | 70.3 | 71.8 | 72.1 | 72.6 | 71.5 | 69.5 | 67.6 | **69.8** |
| Avg. Outdoor Temperature (Dry bulb) | 71.0 | 70.0 | 71.4 | 71.5 | 73.3 | 74.5 | 74.8 | 75.4 | 76.3 | 74.2 | 72.5 | 71.3 | 73.0 |
| AVG. DAILY MAX. TEMP. | 78.2 | 77.0 | 77.7 | 77.2 | 79.6 | 81.7 | 81.1 | 81.4 | 83.4 | 80.5 | 79.0 | 78.9 | 79.7 |
| AVG. DAILY MIN. TEMP. | 65.0 | 64.2 | 65.9 | 66.0 | 67.3 | 68.1 | 69.4 | 69.5 | 70.2 | 68.3 | 67.4 | 65.3 | 67.2 |

All hours fall within 90% comfort range

Typical occupied hours (7 am - 6 pm)

**Air Movement**

Air movement from open windows and fans also affects comfort. Air speeds up to 100 fpm are comfortable for most people, while air speeds between 100 and 200 fpm are often acceptable even though people will be aware of the air movement (Table 2-3). However, at 160 fpm, hair, loose paper and light objects may start to blow around and annoy people. Avoid velocities over 200 fpm because they create drafts and can be a nuisance.

*Table 2-3. Impact of air velocity on occupants.*[2]

| Air velocity (feet per minute) | Probable impact on occupants |
|---|---|
| Up to 50 fpm | Unnoticed |
| 50 to 100 | Pleasant |
| 100 to 200 | Generally pleasant but causing a constant awareness of air movement |
| 200 to 300 | From slightly to annoyingly drafty |
| Above 300 | Requires corrective measures if comfort and productivity are to be maintained |

**Utility Programs**

The utilities that serve Oahu, Maui, Molokai, Lanai and the Big Island (HECO, MECO and HELCO) have a rebate program called the Commercial and Industrial Customized Rebate (CICR) program. Under this program innovative technologies that save energy and demand would qualify for a rebate based on $125/kW of peak demand reduction and $0.05/kWh for a year of energy savings. Rebates are based on engineering estimates of energy and demand savings. In the case of unproven technologies the rebate may be paid over a period of five years based on metered savings.

**Resources**

G.Z. Brown, *Sun, Wind and Light* (New York: John Wiley & Sons, 1986).

Jeffrey Cook (editor), *Passive Cooling* (Cambridge, MA: MIT Press, 1989).

[2] Source: Victor Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (Princeton, NJ: Princeton University Press, 1963).

## Cross Ventilation

**Recommendation**

Provide equal area of operable openings on the windward and leeward side. Ensure that the windward side is well shaded to provide cool air intake. Locate the openings on the windward side at the occupied level.

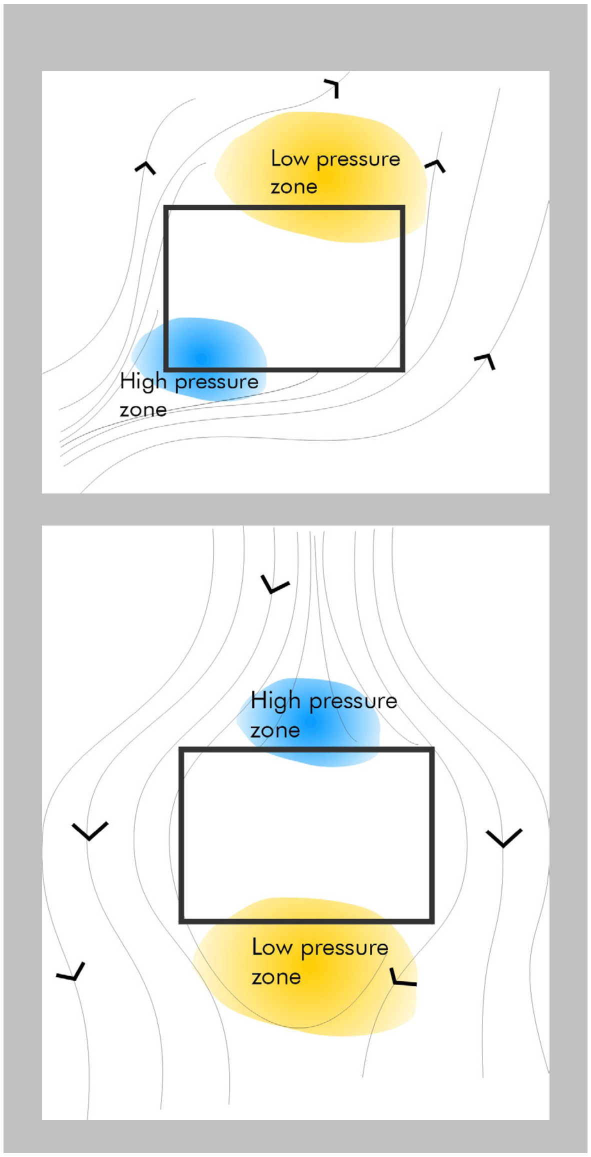



*Figure 2-4. Wind blowing against a building creates a high pressure zone on the windward side and a low pressure zone on the leeward side.*

**Description**

Wind-driven ventilation — or cross ventilation — is one of two methods of providing natural ventilation. (The other method, stack ventilation, is discussed in the next guideline.) All natural ventilation strategies rely on the movement of air through space to equalize pressure. When wind blows against a building, it is deflected around and above the building. The air pressure on the windward side rises above atmospheric pressure, creating a high pressure zone. The pressure on the leeward side drops, creating pressure stratification across the building. To equalize pressure, outdoor air will enter through available openings on the windward side and eventually be exhausted through the leeward side.

Pressure is not uniformly distributed over the entire windward face, but diminishes outward from the pressure zone. The pressure difference between any two points on the building envelope will determine the potential for ventilation if openings were provided at these two points. The airflow is directly proportional to the effective area of inlet openings, wind speed and wind direction.

**Applicability**

In Hawaii, a carefully designed cross ventilation system may eliminate the need for a mechanical cooling system. But in some spaces where special humidity control is required, cross ventilation cannot replace the moisture-removing capabilities of air conditioning.

Cross ventilation depends chiefly on two factors that may change continuously: wind availability and wind direction. Consequently, it is a somewhat unreliable source for providing thermal comfort. It may be necessary to supplement cross ventilation with ceiling fans to make the spaces more comfortable for people. Also, natural ventilation may not be applicable in locations where dirt, dust or noise is a problem.

**Codes and Standards**

The Hawaii Model Energy Code, Section 8.3(e), sets air leakage and comfort ventilation requirements. Comfort ventilation is required in hotel guest rooms; unconditioned commercial spaces must either comply with the same comfort ventilation requirements or must be sealed to prevent air leakage. Comfort ventilation requirements call for either minimum opening areas equal to at least 12% of the floor area or wiring for ceiling fans.

**Integrated Design Implications**

**Design phase:** Cross ventilation can (or should) very strongly influence building aesthetics and site planning. To maximize the effectiveness of openings, a building's long facade should be perpendicular to the prevailing wind direction. Narrow plans and other designs with more surfaces exposed to the outside will work better than bulky plans with concentrated volumes. Single-loaded corridors will provide better airflow than double-loaded ones. An open building plan with plenty of surface area exposed to the outside works well for cross ventilation. Architectural elements like fins, wing walls, parapets and balconies enhance wind speeds and should be an integral part of cross-ventilation design.

**Integration with daylighting and view windows:** The apertures for cross ventilation can also serve as view windows and can provide sidelighting. All architectural elements intended to enhance one strategy should also work for the other. However, an orientation that works for ventilation (openings on the windward side) may not be the ideal direction for bringing in daylight. For daylight, north- and south-facing windows are usually best. But for cross ventilation in Hawaii, windows ideally would be located to take advantage of the trade winds that typically come from the northeast. Prioritize the needs of the space based on function and climate.

**Integration with HVAC:** Natural ventilation may replace air conditioning entirely or may coexist with mechanical systems in a hybrid mode. For buildings that require air conditioning in some areas, the best solution is to divide the building into separate zones for natural ventilation and mechanical ventilation. The next best solution is a changeover system in which windows are shut when the air conditioning is on. Changeover controls should be used to automatically shut off the air conditioning if windows are open. Hybrid systems in which the air conditioning is on when windows are open are not recommended in Hawaii due to the humidity load from outside air. For information on air conditioning system selection, see the HVAC Guidelines.

**Costs**

Costs for cross ventilation are low to moderate. Buildings that use natural ventilation may have higher initial costs because operable windows typically cost 5% to 10% more than fixed glazing, but the savings from not using air conditioning will offset this added cost. Crossover systems will be more expensive because of the higher cost for operable windows and interlock controls for the HVAC system.

**Benefits**

Benefits vary significantly depending on climatic conditions and the natural ventilation design.

- In Hawaii, wind-driven ventilation can meet the cooling loads much of the time. In many cases, it can offset the need for an air conditioning system, eliminating the cost of the equipment and energy used to operate it. This will result in huge savings that will offset the cost of installing operable windows. The simple payback period may be as short as to 1 to 4 years.
- Cross ventilation can quickly exhaust odors and contaminants from indoor sources.
- Increased airflow in a space may result in higher thermal comfort levels and increased productivity.
- Operable openings at the occupied level give the occupants a sense of individual control over the indoor environment.
- An intangible benefit of natural ventilation is that it establishes a connection with the outdoors (both visual and tactile), weather patterns, and seasonal changes. This results in higher tolerances for variations in temperature and humidity levels.
- Natural ventilation systems are simple to install and require little maintenance.

**Design Tools**

Opening areas may be derived from simple spreadsheet-based calculations. These estimates use approximation techniques but are good numbers to start with. The following algorithm shows the rate of wind-induced airflow through inlet openings:

$$Q = C_4 C_v AV$$

where,

| | | |
|---|---|---|
| Q | = | airflow rate, cfm |
| $C_v$ | = | effectiveness of openings ($C_v$ is assumed to be 0.5–0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds) |
| A | = | free area of inlet openings |
| V | = | wind speed, mph |
| $C_4$ | = | unit conversion factor = 88.0 |

The following algorithm calculates the required airflow rate for removal of a given amount of heat from a space. (To estimate the amount of heat to be removed, see the information about load calculations in the Sizing AC Systems section of the HVAC Guidelines.)

$$Q = \frac{60q}{c_p \rho (t_i - t_o)}$$

where,

| | | |
|---|---|---|
| Q | = | airflow rate required to remove heat, cfm |
| q | = | rate of heat removal, Btu/h |
| $C_p$ | = | specific heat of air Btu/lb°F (about 0.24) |
| $\rho$ | = | air density, $lb_m/ft^3$ (about 0.075) |
| $t_i$-$t_o$ | = | indoor-outdoor temperature difference, °F |

Many computer software programs are available for predicting ventilation patterns. Programs that employ the zonal method may be used to predict ventilation rates (mechanical and natural), magnitude and direction of airflow through openings, air infiltration rates as a function of climate and building air leakage, pattern of airflow between zones, internal room pressures, pollutant concentration, and backdrafting and cross-contamination risks. These models take the form of a flow network in which zones or rooms of differing pressure are interconnected by a set of flow paths. This network is approximated by a series of equations that represent the flow characteristics of each opening and the forces driving the airflow process. Widely available codes include BREEZE and COMIS.

A Computational Fluid Dynamics (CFD) program is a more accurate and complex tool for modeling airflow through a space based on pressure and temperature differentials. These programs can simulate and predict room airflow, airflow in large enclosures (atria, shopping malls, airports, exhibitions centers, etc.), air change efficiency, pollutant removal effectiveness, temperature distribution, air velocity distribution, turbulence distribution, pressure distribution, and airflow around buildings.

- Fluent, Inc. is the largest provider of CFD code. Fluent is a sophisticated analysis technique that can, among other things, model and/or predict fluid flow behavior, transfer of heat, and behavior of mass.
- Flomerics authors the software Flovent, designed to calculate airflow, heat transfer, and contamination distribution for built environments. This software is particularly geared toward ventilation calculations, including natural and forced convection currents. It also accurately calculates air density as a function of temperature and predicts the resulting buoyancy forces that can give rise to important thermal stratification effects. Important outputs from Flovent are user variables such as the comfort indices of Predicted Mean Vote (PMV), Percentage of People Dissatisfied (PPD), Mean Radiant Temperature (MRT), Dry Resultant Temperature and Percentage Saturation, including a visualization of their variation through space. A summary of minimum, maximum, mean and standard deviation for all calculated variables is also available.

**Design Details**

An effective cross-ventilation design starts with limiting space sizes to facilitate inward flow of air from one face and outward flow from the other. Architectural elements can be used to harness prevailing winds.

- Orient the building to maximize surface exposure to prevailing winds.
- Provide the inlets on the windward side (pressure zone) and the outlets on the leeward side (suction zone).
- Use architectural features like wing walls and parapets to create positive and negative pressure areas to induce cross ventilation.
- Air speed inside a space varies significantly depending on the location of openings. The most effective strategy is to provide openings on opposite walls. Using single-loaded corridors makes it easier to provide openings on opposite walls. Limit room widths to 15 to 20 feet if openings cannot be provided on two walls.

- For small spaces where it's not possible to have openings on opposite walls, placing windows on adjacent walls may provide some cross ventilation. This should be limited to smaller spaces (less than 15 ft x 15 ft).
- Consider designing cross-ventilation openings that are secure enough to be left open at night, so that natural ventilation can provide additional nighttime cooling benefits.
- The openings must be easily accessible to and operable by the occupants.
- Equal inlet and outlet areas maximize airflow whereas outlets that are 25% larger than inlets produce higher air velocities.
- The inlet location affects airflow patterns far more significantly than outlet location. Inlet location should be a higher priority (if faced with a choice) as a high inlet will direct air toward the ceiling and may bypass the occupied level. Provide inlets for cross-ventilation openings at the occupied level.
- Stagger the outlet openings both vertically and horizontally by a few feet to achieve longer air paths. Concentrate ventilation openings in spaces most likely to require cooling.
- For natural ventilation to function properly, minimize solar gain. Direct sunlight penetration may make it difficult or impossible to achieve comfortable conditions with natural ventilation alone. Use shading devices like overhangs, awnings and fins to control solar gain. For details, see the Energy-Efficient Windows Guidelines.

- Use good site planning, landscaping and planting strategies to cool the incoming air. If a body of water is planned for the site, place it on the windward side to precool the incoming air through evaporative cooling. Planting tall deciduous trees on the windward side will lower the temperature of the inflow and shade the openings. Avoid locating large asphalt parking lots or other ground surface treatments that get hot on the upwind side of naturally ventilated buildings.

*Figure 2-5. The effectiveness of natural ventilation is reduced when a ground surface that heats the outside air — such as a parking lot — is located upwind of a cross-ventilated building. Photo: Erik Kolderup, Eley Associates.*

- Ground cover plantings can help prevent loose dirt and dust from blowing in through the windows. If excessive wind is a problem on the site, shrubs, trees or other landscaping can be situated to help reduce wind speed.
- Provide windows with sections or shutters that can be opened individually. This allows the occupants to vary the inlet and outlet areas according to seasonal variations.
- Use features like overhangs, awning windows, eaves and porches to protect the openings from rain. Awning windows work very well for cross ventilation because they provide more airflow than double-hung windows for the same glazed area and also provide protection from rain. Casement windows provide maximum airflow in both perpendicular and oblique wind conditions.
- Ensure that vents and windows are accessible and easy to use. Avoid blocking windows with exterior objects such as shrubs and fences, but do not eliminate shading.
- Ensure that openings can be tightly sealed when using an air conditioner.

- HVAC systems should be designed to work in harmony with natural ventilation. The objective of a concurrent natural ventilation system is to meet the outside air requirement using the smallest possible opening area. The objective of a changeover natural ventilation system is to meet the outside air requirement as well as provide cooling. The HVAC and natural ventilation system are mutually dependent.

**Operation and Maintenance Issues**

Cross ventilation is largely dependent on manual operation for its success. Automated operation may make sense for very large commercial buildings.

- Encourage occupants to open and close openings as needed to create more comfortable conditions.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Periodically clean windowsills, panes, fins and louvers to ensure healthy air intake for the space.
- Make sure that openings are shut when the mechanical system is operating, unless the HVAC and natural ventilation are designed to work concurrently.

**Case Study**

Most schools in Hawaii are naturally ventilated. The Pearlridge Elementary School's (Oahu) new administration building, for example, uses cross ventilation supplemented with ceiling fans in some spaces. The building is reported to be comfortable in winter, but a little hot in the summer.

## Stack Ventilation

**Recommendation**

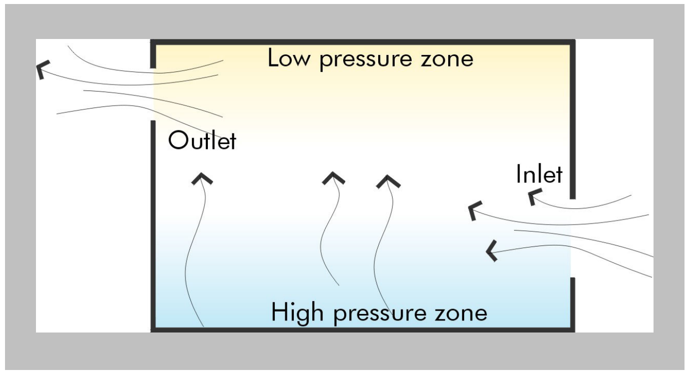
Use inlets and outlets of equal area and maximize the vertical distance between these two sets of apertures. Place inlets close to or in the floor or at the occupied level. Locate the outlets closer to the ceiling on the opposite wall.

**Description**

Stack ventilation is one of two methods of providing natural ventilation (the other — cross ventilation — is described in the previous guideline). Stack ventilation utilizes air density differences to provide air movement across a space. At least two ventilation apertures need to be provided — one closer to the floor and the other high in the space.

Warmed by internal loads (people, lights and equipment), the indoor air rises. This creates a vertical pressure gradient within the enclosed space. If an aperture is available near the ceiling, the warmer air at the upper levels will escape as the cool outside air is drawn in through the lower aperture.

*Figure 2-6. Stack ventilation requires two ventilation apertures, one closer to the floor and the other high in the space.*




In places like Hawaii, stack ventilation can be a challenge because the indoor temperature must be higher than the outdoor temperature for the stack ventilation to occur. Higher indoor temperatures cause a pressure difference so that the upper openings act as the outlet and cool air intake is induced at the lower opening.

The airflow induced by thermal force is directly proportional to the inlet-outlet height differential, the effective area of the aperture, and the inside-outside temperature differential.

**Applicability**

To get any cooling benefit from stack ventilation, you need access to cool outdoor air. The cool air may be drawn from a shaded or landscaped space or from over a body of water. Stack ventilation works best in spaces with high ceilings and where cross ventilation is not feasible because of security, privacy, noise or other reasons.

**Codes and Standards**

Stack ventilation can be used to meet the Hawaii Model Energy Code's comfort ventilation requirements, Section 8.3(e), using the exception for innovative ventilation design.

**Integrated Design Implications**

**Design phase:** Using the stack effect for ventilation requires an integrated design approach. Stack ventilation will affect building mass and aesthetics. Vertical airshafts for providing stack ventilation also need to be considered early in the design phase.

**Integration with daylighting and view windows:** Apertures for stack ventilation need to be located close to the floor and ceiling for best results. The high apertures can work as clerestories for sidelighting. The benefits of daylighting and natural ventilation need to be considered in conjunction with each other to arrive at the ideal location and size for the openings.

**Integration with HVAC:** Stack ventilation can be used to meet the outside air requirement in most climates other than hot-dry (where stack ventilation will also be used for nighttime cooling).

Carefully integrating this strategy with HVAC system selection and operation will maximize its benefits.

**Costs**

Costs are low to moderate. Stack ventilation may not add to overall costs significantly if it is integrated with view windows, high sidelighting, and other daylighting strategies. However, an additional cost of $2/ft$^2$ may be associated with ensuring that all openings are operable. Adjustable frame intake louvers may cost up to $25/ft$^2$ (this includes installation costs). Additional cost of installing windows high in the space will range from $15–$30/ft$^2$.

**Benefits**

The benefits of stack ventilation are low to moderate, depending largely on weather conditions (indoor-outdoor temperature differential) and the design of openings.

- Stack ventilation apertures can double as sidelighting.
- Stack ventilation effectively removes contaminants and pollutants from a space.
- Compared to cross ventilation, it's easier to design stack ventilation openings so that they are secure from intruders and less susceptible to noise and dust infiltration.

**Design Tools**

The airflow (cfm) required can be reasonably estimated using spreadsheet-based calculations. The following algorithm defines the airflow as it varies with the area of openings, indoor temperature, outdoor temperature, and location of the inlet and outlet:

$$Q = 60 C_D A \sqrt{2g \Delta H_{NPL} (T_i - T_o) / T_i}$$

$Q$ = airflow rate, cfm
$C_D$ = discharge coefficient for opening
$\Delta H_{NPL}$ = height from mid-point of lower opening to NPL, ft
$T_i$ = indoor temperature, °R
$T_o$ = outdoor temperature, °R

Use this algorithm to estimate the aperture area for a particular hour of a day (with Q equal to 15 cfm).

A number of computer tools are available for simulating pressure driven airflow. Refer to the Cross Ventilation Guideline in this chapter for details.

**Design Details**

An effective stack ventilation design starts with inlet and outlet openings of equal area. Architectural elements can be used to harness prevailing winds and exhaust indoor air.

- Provide equal inlet and outlet areas to maximize airflow. If they are not equal, then airflow will be dictated by the smaller of the inlet or outlet areas.
- The width-to-height ratio of openings should be more than 1, as far as possible (in other words, orient the openings horizontally).
- Allow for at least a 5 ft (center-to-center) height difference between the inlet and the outlet. Increasing the height differential further will produce better airflow.
- Provide adequate apertures in stairwells or other continuous vertical elements so that they can work as stack wells. Such spaces may be used to ventilate adjacent spaces because their stack height allows them to displace large volumes of air.
- Carefully control and minimize solar gains. For details, see the Energy-Efficient Windows Guidelines.
- Use louvers on inlets to channel air intake. Use architectural features like solar chimneys to effectively exhaust the hot indoor air.
- HVAC systems should be designed to work in harmony with stack ventilation. Consider a displacement ventilation design for the air conditioning system to supplement the stack ventilation during hot periods.
- For buildings with crawl spaces, consider using inlet openings in the floor to draw air from the cool space below.

**Operation and Maintenance Issues**

This strategy is largely dependent on manual operation for its success.

- Openings should be appropriately operated according to indoor-outdoor temperature differentials.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Periodically clean windowsills, fins and louvers to ensure healthy air intake for the space.
- Make sure that openings remain shut when the mechanical system is operating.

**Commissioning**

During construction, ensure that the airflow meets the design intentions. Before applying interior finishes, check the cross ventilation to determine if the opening areas provide the expected level of ventilation. If they don't, it may be necessary to increase or decrease the opening areas.

**Case Study**

Stack ventilation is less commonly used than cross ventilation in Hawaii. However, there are some successful stack ventilation projects. The office of Dr. Lee-Ching in Hilo employs low inlets and uses vented skylights as outlets for stack ventilation. More information about this building and other stack ventilation designs by architect Virginia Macdonald, FAIA, can be found in the *Guide to Resource-Efficient Building in Hawaii* (First Edition, Revision B, June 2000), produced by the Hawaii Advanced Building Technologies Training Program.

## Ceiling Fans

**Recommendation**

Use ceiling fans instead of air conditioners to make occupants more comfortable by increasing the air velocity in a space.

**Description**

A ceiling fan is a permanent fixture mounted on the ceiling and operated by a switch or a pull string. In warm climates, ceiling fans are used to move interior air, which cools people and makes them feel more comfortable by increasing the evaporation of moisture from their skin. As long as there is some air movement, people can generally tolerate higher temperatures. Generally, for speeds above 30 fpm, most people will perceive a 15 fpm increase in air to be equal to 1°F decrease in temperature (this is commonly called "chill factor").

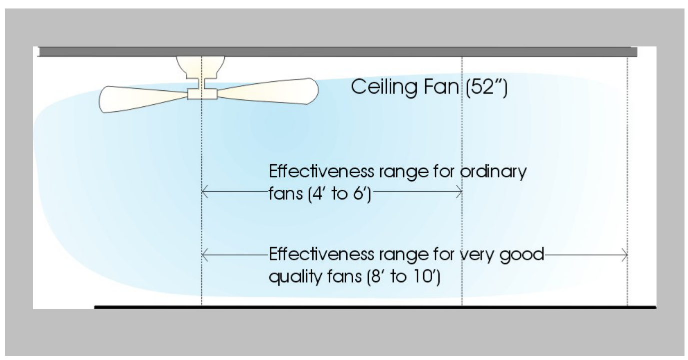



*Figure 2-7. Ceiling fans increase air velocity to provide greater comfort for occupants.*

A ceiling fan can be used to draw outside air into a space when the air cannot enter the space on its own because it's either too humid or too hot. A fan can also recirculate air within a space.

*Figure 2-8. Ceiling fans cool people, not spaces. They enhance comfort by increasing the evaporation of moisture from skin. Photo: Erik Kolderup, Eley Associates.*

The interior air motion cause by ceiling fans varies as a function of fan position, power, blade speed (measured in rpm), blade size, and the number of fans within the space. Moreover, air speeds within a space vary significantly at different distances from the fan.

The normal current draw will range from approximately 15 W at low speed to 115 W at high speed.

**Applicability**

Ceiling fans are appropriate for many types of spaces, including offices and classrooms. They may not be appropriate small spaces such as restrooms. Noise produced by ceiling fans may be an issue in auditoriums.

Ceiling fans are suitable for most climates that require cooling. Combined with other natural ventilation strategies they may eliminate the need for air conditioning.

They may not be applicable in spaces where the air movement may cause problems or spaces where you want temperature stratification to occur (such as when using stack ventilation).

**Codes and Standards**

In the Hawaii Model Energy Code, the comfort ventilation requirements in Section 8.3(e) can be met by supplying wiring for ceiling fans as an alternative to providing cross-ventilation openings.

**Integrated Design Implications**

Ceiling fans need to be integrated with the lighting system design.

A minimum ceiling height of 9 ft must be provided to accommodate a fan so that its blades are at least 8 ft from the floor and 1 ft from the ceiling.

Ceiling fans should be combined with natural ventilation strategies for best results.

**Costs**

Ceiling fans cost between $75 and $200. The typical cost with professional installation is about $250. Fans with features such as light fixtures, reverse or multiple speed settings, and extended warranties may cost more. Ceiling fans are economical to operate because they consume very little energy.

**Benefits**

Moving air extends the comfort range and allows occupants to feel comfortable at higher temperatures. It also helps occupants feel dry.

When ceiling fans are used, air conditioners can be set at a higher temperature. The resulting energy savings will more than offset the fans' energy consumption. According to the Texas Energy Extension Service, for a 3-ton cooling system costing $550 per season, raising the thermostat from 75°F to 80°F can reduce the operating cost by $151. Operating a ceiling fan 10 hours a day or more may cost less than $3 per month. A typical fan operating at high speed, for example, uses approximately 100 watts of power. If the fan is operated 5 hours per day with an energy cost of $0.08/kWh, the operating cost will be $0.04/day. At lower speeds this operating cost will be even less. This low operating cost, combined with the potential reduction in HVAC costs, makes the ceiling fan one of the better energy-saving devices on the market.

As a rule of thumb, each degree rise in a thermostat setting (beyond 78°F) results in a 3–5% saving on cooling energy. If the ceiling fan is supplementing air conditioning, the thermostat of the AC unit may be raised a full 4°F above the standard 78°F setting while still maintaining comfortable space conditions.

**Design Tools**

Use the following charts to size ceiling fans according to the largest room dimension and room area:

*Table 2-4. Fan diameter selection based on space dimensions.*

| Largest Dimension of Room | Minimum Fan Diameter |
|---|---|
| 12 ft or less | 36 in. |
| 12 – 16 ft | 48 in. |
| 16 – 17.5 ft | 52 in. |
| 17.5 – 18.5 ft | 56 in. |
| 18.5 ft or more | 2 fans needed |

*Table 2-5. Fan diameter selection based on space area.*

| Room Area | Minimum Fan Diameter |
|---|---|
| 100 ft² | 36 in. |
| 150 ft² | 42 in. |
| 225 ft² | 48 in. |
| 375 ft² | 52 in. |
| 400+ ft² | 2 fans needed |

Source: *Consumer Guide to Home Energy Saving,* American Council for an Energy Efficient Economy (1995).

**Design Details**

Ceiling fans should be considered in the design development stage due to electrical wiring issues, although adding fans to existing spaces is also feasible.

- Use ceiling fans in frequently occupied spaces. Fans should be on only when the space is occupied; otherwise the movement of the motor in introducing heat in the room without any cooling benefits. Remember that ceiling fans cool people, not spaces. Consider using an occupancy sensor to control the fans.
- A larger fan provides a greater range of airflow settings and ventilates a larger area at lower velocities, with less noise, and only slightly more power than similar smaller units.
- Ceiling fans work best when the blades are 8 ft to 9 ft above the floor and 10 in. to 12 in. below the ceiling. Placing fans so the blades are closer than 8 in. to the ceiling can decrease the efficiency by 40%. Fans also require at least 18 in. of clearance between the blade tips and walls.

- Two types of mountings are available for ceiling fans: rod and hugger. In rod fans, the motor housing is suspended from the mounting bracket by a rod. With hugger fans, the motor housing is mounted directly to the ceiling box. Hugger fans are not as efficient as rod fans in the down motion, especially at higher speeds. The blades will starve themselves for air when they are too close to the ceiling.
- Generally speaking, the larger the blades of the fan, the greater the air movement (also such fans are less noisy). Use larger blade pitches (note that as the pitch or blade surface increases, the motor size must be increased or the rpm of the motor will drop). A good ceiling fan should create enough air movement to make the occupant comfortable at 82°F with 80% relative humidity.
- Select a fan with at least a 2-speed control for better regulation of air movement.

**Operation and Maintenance Issues**

Operation and maintenance issues for ceiling fans include:

- Ensure that all blades are screwed firmly into the blade holder and that all blade holders are tightly secured at the fan. This should be checked from time to time (once a year).
- Periodically clean the fan because the blades tend to accumulate dust on the upper side. An anti-static agent can be used for cleaning but don't use cleaning agents that can damage the finish. Never saturate a cloth with water to clean a ceiling fan; water introduces the possibility of electrical shock.
- For a fan to perform efficiently it is very important that the blade be flat throughout. Most manufacturers have programs to keep warpage to a minimum. "Balanced" blades — that is, blades that are electronically matched at the factory — are sold as a balanced four- or five-blade set depending on the design of the fan. For this reason, never interchange blades between fans.

**Commissioning**

Specify durable fans with longer warranties. Use fans with metal motor housings; these may require annual oiling (while plastic motor housings will not) but may have better warranties and be worth the added maintenance. During building commissioning, ensure that the specified equipment is what actually gets installed.

**Resources**

*ASHRAE Standard 62—Ventilation for Acceptable Indoor Air Quality*. Web site: www.ashrae.org.

*Oikos/Green Construction Source* (Eugene, OR: Iris Communications). Features REDI, an online directory of products, including ventilation fans, devices and controls. Web site: http://oikos.com.

# 3. DAYLIGHTING GUIDELINES



## Overview

**Description**

Daylighting is the use of transparent or translucent panels located in the building envelope to let natural light into interior spaces. To provide balanced, glare-free illumination, daylight can be diffused in a variety of ways, such as by using louvers or translucent glazing panels, designing apertures to bounce daylight into the space, and using shading devices to block direct sun penetration.

There are two forms of daylighting: toplighting and sidelighting. With toplighting, the daylighting openings — or *apertures* — are located in the ceiling plane to provide uniform, glare-free illumination. Daylight is diffused using translucent glazing, reflective fixed or operable baffles, or deep skylight wells. Several configurations — such as vertical and splayed skylight wells, clerestory windows, light boxes and sawtooth roof monitors — can be used successfully in toplighting designs. Daylight levels are highest directly under the aperture and drop off as you move away from it. The spacing of the daylight aperture depends on the ceiling height.

Sidelighting allows daylight to enter through windows in vertical walls. With sidelighting, uniform illuminance is more difficult to provide, as there is always more light next to the window. Glare is also more difficult to control. But there are design techniques that can substantially reduce problems associated with sidelighting.

**Benefits of Daylighting**

Daylighting is at the heart of sustainable design for most buildings. A well-designed daylighting system can significantly reduce or even eliminate the need for electric lighting during the day, which can save a substantial amount of lighting energy and air conditioning energy.

Energy savings are only one aspect of the benefits of good daylighting. Productivity can be another compelling benefit. Recent studies have shown improved learning rates in schoolchildren in daylit classrooms and improved sales in daylit retail stores.[1] Further studies are underway to verify these findings.[2] In commercial buildings in industrialized countries where labor costs are high, the investment cost for better daylighting design and controls can typically be readily offset by the value of likely increases in occupant productivity. Even if better daylighting were to result in a mere 1% increase in employee productivity, the value of that increase would far outweigh the added costs for the daylighting and controls.

Daylight affects us in both obvious and subtle ways: it provides light to see our environment, go about our lives and do our work; it determines the cycles of our days and seasons; and on a biological level it stimulates hormones that regulate our body systems and moods. Daylight also affects certain physiological functions. For example, it stimulates the assimilation of Vitamin D, which is important for healthy bone formation, and it affects sleep cycles.

**Daylighting Strategies**

Daylighting uses natural light to provide adequate interior illumination for doing various tasks. Illumination may be provided completely through daylighting or through a combination of daylight and electric light.

Daylighting can be provided through an opening in the wall, roof or ceiling via transparent or translucent panels such as windows, glazed doors, skylights and other sources. These glazed apertures are referred to as fenestration.

The availability of sunlight depends primarily on the daily and seasonal path of the sun, while the intensity of daylight depends on the presence of clouds and moisture in the air. To successfully daylight a building it's important to understand the basic principles of solar orientation, climatic conditions and shading systems.

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[1] Heschong Mahone Group, "Daylighting in Schools," and "Skylighting and Retail Sales," (Pacific Gas & Electric Company, 1999). Available at www.pge.com/pec/daylight.

[2] "Productivity and Interior Environments" studies now being conducted by Heschong Mahone Group for the New Buildings Institute's Integrated Energy Systems: Productivity & Building Science Program, a project of the State of California PIER Program. For more information, go to www.newbuildings.org/pier.

These Daylighting Guidelines provide an overview of daylighting and fenestration design, including basic principles for good daylighting design and general and specific guidelines for toplighting and sidelighting strategies. For more information about optimum glazing areas, choice of glazing types and thermal comfort issues, see the Energy-Efficient Windows Guidelines. For information about energy-efficient electric lighting systems, refer to the Electric Lighting and Controls Guidelines.

The daylighting strategies listed here are discussed in detail in the subsequent Guidelines in this chapter:

- Provide uniform illumination using **GOOD DAYLIGHT DESIGN**
- Provide access to exterior views through **VIEW WINDOWS**
- Use **CLERESTORIES** for deeper daylight penetration
- Add **LIGHTSHELVES TO CLERESTORIES** to improve daylight distribution
- Balance daylight from window walls with **WALL-WASH TOPLIGHTING**
- Provide even daylight with **CENTRAL TOPLIGHTING**
- Use **PATTERNED TOPLIGHTING** to provide even illumination across a large area
- Use **LINEAR TOPLIGHTING** to direct movement or provide visual orientation in a linear space
- Employ **TUBULAR SKYLIGHTS** for toplighting areas with deep roof cavities and for low-cost retrofits

These daylighting strategies each have their own advantages and disadvantages, as shown in Table 3-1. Most spaces will need to include more than one daylighting strategy if they are to be fully daylit.

*Table 3-1. Selection criteria for daylighting strategies.*

| Design Criteria | View Windows | High Sidelighting | Wall-wash Toplighting | Central & Patterned Toplighting | Linear Toplighting | Tubular Skylights |
|---|---|---|---|---|---|---|
| View | + | - | - | - | - | - |
| Uniform Light Distribution | - | +/- | + | ++ | * | * |
| Low Glare | - | + | + | + | + | +/- |
| Reduced Energy Costs | - | + | + | ++ | + | + |
| Cost Effective-ness | + | + | + | + | + | ++ |
| Safety/ Security Concerns | - | +/- | + | + | + | ++ |
| Low Mainten-ance | - | + | + | + | + | + |

Notes: **+** Good application. **-** Poor application. ***** Depends on space layout and number and distribution of daylight apertures.
Source: Eley Associates. *Collaborative for High Performance Schools Best Practices Manual, Vol. II — Design,* 2001. Web site: www.chps.net.

## General Principles for Daylighting Design

**Recommendation**

Provide daylighting for uniform and low glare illumination wherever possible. In locations that have predominantly clear days, provide daylight using vertical glazing. In locations with predominantly cloudy days, use horizontal glazing to provide daylight.

Provide toplighting in single-story structures or in the top floor of multistory buildings. Use sidelighting to provide illumination in areas near the walls and to provide views. Use high sidelighting to deliver daylight deeper into the space.

**Description**

Daylighting provides uniform interior illumination through transparent or translucent panels located in the building envelope that let in natural light. Daylight can be diffused by using louvers or translucent glazing panels or by articulating the aperture.

**Applicability**

Daylighting can provide uniform illumination in many types of spaces — including classrooms, offices, restaurants, retail stores, cafeterias, corridors, multipurpose spaces, hospitals, assembly areas, warehouses, and light industrial spaces — to save lighting energy, reduce cooling loads and increase productivity.

**Codes and Standards**

The Hawaii Model Energy Code does not require that view windows or skylights be installed.

The code limits the maximum Relative Solar Heat Gain factor (RSHG) for various window-wall ratios for vertical glazing for windows (there are different limits for north-facing and non-north facing windows). The RSHG factor is a function of the shading coefficient of the glazing and exterior shade screens and/or louvers, interior shading devices, overhangs and fins. Individual windows may exceed the maximum RSHG limit as long as the area-weighted average RSHGs for both north and the combined east, west and south orientations are less than or equal to the maximum limit. Most buildings require window shading or tinted glass.

The skylight shading coefficient limits the skylight area. The maximum effective aperture (which is defined as a product of the horizontal glazing area and the fraction of the roof area covered by skylights) cannot exceed 0.025.

**Benefits**

***Energy Savings***

Turning off or dimming electric lights in response to the amount of available daylight can result in electric light savings of 40% to 80% during daylight hours. However, if the total glazing area is not optimized, these savings can be offset by increased solar gain. The Electric Lighting and Controls Guidelines address the design of supplementary electric lighting systems and controls, while the Energy-Efficient Windows Guidelines address solar control.

***Indoor Air Quality***

When the outside temperature is within a comfortable range — which is a considerable portion of the time in Hawaii — operable skylights, clerestories or roof monitor glazing can be used to naturally ventilate a space by drawing fresh air in through a lower aperture and exhausting it through the upper aperture. This can save energy by eliminating or reducing the need for mechanical ventilation, and may help improve indoor air quality by increasing the fresh air supply.

In addition to energy benefits, natural ventilation may help improve productivity. Studies have shown a positive correlation between higher student scores on standardized tests and an increase in natural ventilation.[3]

Refer to the Natural Ventilation Guidelines for more about natural ventilation strategies.

***Indirect Impacts on HVAC***

The appropriate sizing of daylighting apertures and the appropriate design of shading and glazing can minimize cooling loads because daylight contributes less heat to a space than electric lighting does for the same illumination level. (See the Energy-Efficient Windows Guidelines for optimum aperture sizes for different glazing types.) Lower cooling loads may potentially reduce investment costs for air conditioning equipment by reducing equipment size. And lower cooling loads may also provide the opportunity to increase the allowable window head height if smaller air conditioning ducts can be used in the ceiling plenum.

Using operable fenestration systems to naturally ventilate the building also reduces HVAC energy consumption by reducing the number of hours during which the HVAC system operates. In Hawaii, a carefully designed natural ventilation system may eliminate the need for a mechanical cooling system (see the Natural Ventilation Guidelines for details).

The building energy simulation tools mentioned in the section on Whole Building Energy Simulation Software later in this chapter can aid in evaluating overall loads and performance.

***Other Benefits***

There are additional benefits to daylighting, including increased employee productivity. With good diffusion, toplighting effectively provides even, balanced and glare-free illumination across the space. This has been correlated with higher standardized test scores for students. However, uncontrolled toplighting with direct sun penetration in classrooms has been associated with lower standardized test scores.[4]

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[3] Heschong Mahone Group, "Daylighting in Schools." Also, Norris and Tillett, "Daylight and productivity: Is there a causal link?", *Glass Processing Days Conference,* (Tampere, Finland, Sept. 1997).

[4] Heschong Mahone Group, "Daylighting in Schools."

Windows serve a range of important functions including providing views, opportunities for social communication and connections with nature.

Additional benefits of daylighting include:

- Providing better color rendition for visual tasks than electric lighting;
- Making a space look brighter and larger; and
- Producing a positive impact on people, and perhaps indirectly increasing their productivity.

**Integrated Design Implications**

**Design phase:** Daylighting design is integral to a building's architecture and is best started early in the design phase. It can be difficult and expensive to add apertures for daylighting once the building is built. Orientation is a critical factor for determining the placement of toplighting, view windows and clerestories.

**Horizontal vs. vertical glazing:** The glazing may be either horizontal or vertical depending on the orientation of the aperture, sky conditions, and cost considerations. Use vertical glazing for south and north orientations with predominantly clear skies. Use horizontal glazing for locations with predominantly cloudy skies that generally have east or west orientations. Horizontal glazing is typically cheaper than vertical glazing and is recommended for projects with greater budget constraints. See the Energy-Efficient Windows Guidelines for a lifecycle cost analysis of various window orientations, window-wall ratios and glazing types.

**Integration with electric lighting:** For the same level of illumination, daylight has a lower impact on cooling loads than electric lighting. To maximize the energy benefits of daylighting, circuit and control the electric lighting so that the lights can be turned off in areas where there is adequate daylight and kept on where daylight is insufficient.

**Integration with structural system:** The size and location of skylights and roof monitors are limited by the roof diaphragm and the structural system, and must be coordinated with the building's structural system to maintain strength and integrity.

Coordinate the size and location of windows with the location of columns and studs. Clerestory sidelighting requires ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by careful integration of the structural system, HVAC ducts and electric lighting in the plenum.

**Integration with HVAC:** Coordinate the placement of daylighting apertures and their associated lightshelves or light wells with the location of rooftop HVAC equipment and interior ducts.

View windows can decrease cooling loads on the building if they are oriented, glazed and shaded correctly. Toplighting and high sidelighting glazing is vulnerable to solar gains during the cooling season; appropriate orientation, size, glazing materials, shading and photocontrol of electric lights can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs.

To maximize lighting and HVAC energy benefits, conduct a whole building simulation to evaluate the total glazing area used for daylighting before finalizing a daylight scheme (see Design Analysis Tools later in this section).

**Integration with natural ventilation:** If the building has operable high sidelighting or toplighting fenestration, it can be used in combination with operable windows to naturally ventilate the space when the outside air temperature falls within a comfortable range, which is a significant portion of the time in Hawaii. Natural ventilation can have a positive impact on indoor air quality and can eliminate or significantly reduce the need for mechanical ventilation for a significant portion of the time in Hawaii.

For more information, see the Natural Ventilation Guidelines.

**Design Details**

The following principles, which are discussed in detail below, are fundamental elements of good daylighting design.

- Prevent direct beams of sunlight from penetrating the space
- Provide uniform illumination
- Avoid glare
- Provide methods of controlling daylight
- Integrate daylight with electric lighting
- Lay out the interior spaces so that they benefit from daylighting opportunities
- Optimize the aperture size
- Consider safety and security issues when designing daylighting apertures

### *Prevent Direct Sunlight Penetration*

Direct sunlight can make people uncomfortable because it is so bright — up to 10,000 footcandles — and hot. Daylight that is diffused and reflected by, for example, clouds, moisture and other particulate matter, is much gentler. When properly utilized, daylight can provide excellent illumination without causing thermal or visual discomfort.


*Figure 3-1. Overhangs help control direct sun penetration. To maximize daylight availability and reduce direct sun penetration, it's critical to properly orient the building. Photo: Erik Kolderup, Eley Associates.*

Here are some recommendations for maximizing the use of daylight and minimizing the penetration of direct beam sunlight:

- Use sunlight in small quantities to introduce brightness and accents in non-task dominant zones, such as lobbies and cafes.
- Begin daylight design early in the design process. A building's orientation is critical for maximizing the use of diffused daylight and reducing direct solar penetration. The best orientation for daylight sources is north, since the sun strikes a north-facing window only early in the morning and late evening during midsummer. South-facing windows are the next best option. The high angle of the south sun is easy to control with a horizontal overhang.
- Avoid east- and west-facing windows for daylighting. The low angle of the sun makes it difficult to control direct sunlight penetration via overhangs or other fixed shading devices. Any window orientation more than 15 degrees off of true north or south requires careful assessment to avoid unwanted sun penetration.
- The ideal orientation may not be possible in urban situations where plot sizes may be constrained. In such cases increase the surface area of exposure toward the south and north. This may be done by using light shafts, light wells or light courts such that the west- and east-facing walls are shaded and receive diffused light.

- For toplighting, use glazing that diffuses the sunlight, or use baffles, louvers or light well walls to reflect it.

***Provide Uniform Illumination***

Evenly diffused daylight provides maximum energy savings and the most comfortable visual environment. Daylight can be used to provide a base level of illumination throughout a space, referred to as the ambient illumination. This is often on the order of 20 to 30 footcandles. Electric task lights can be used in specific work areas to bring the illumination levels to higher task level requirements, such as 50 or 75 footcandles. Here are some strategies for providing uniform illumination with daylighting (see the guidelines for specific daylighting strategies in this chapter for details):

- Use repetitive toplighting strategies, such as a uniform distribution of unit skylights.
- If uniform toplighting is not possible, use a combination of view windows and high sidelighting to provide daylight from two sides of a space.
- Use a combination of sidelighting and toplighting in areas where only one wall has windows.
- Paint walls, ceilings and other reflective surfaces white or a very light color. Even pastel colors absorb 50% of the light falling on the surface, reducing the amount of light reflected back into the room. Use saturated colors only in small quantities for accents or special effects.
- Exterior elements such as walkways and overhangs near the apertures also help to reflect daylight into the space. These are most effective when they are light colored.
- A series of reflective or refractive surfaces (such as mini-louvers) built into the glazing itself can redirect sunlight onto the space's ceiling.
- Use lightshelves to bounce daylight deeper in the space (see High Sidelighting with Lightshelves Guideline).
- Baffles, fins or other reflective surfaces next to the daylight aperture can be used to distribute light uniformly through the space. Due to variations in sun angles, the best design solution for each orientation is unique. For example, a space may have lightshelves on the south side of the building, but none on the north.

### *Avoid Glare*

Direct glare (the presence of an extremely bright surface or light source in the field of view) and reflected glare (light hitting a reflective surface) can make people uncomfortable and can make it difficult for them to perform certain tasks. Glare reflecting off a computer screen, for example, may make it difficult or impossible to view the images on the screen. The following are some strategies for reducing or eliminating glare caused by daylighting:

- Use devices such as blinds, louvers, reflectors or overhangs to block views of bright daylight sources and bright surfaces.

*Figure 3-2. An overhang shades south windows from direct sun, while daylight reflects into the space from the light-colored concrete walkway and overhang. North windows are large and unshaded. Photo: Lisa Heschong.*

- Place daylight apertures next to reflective (light-colored) surfaces to distribute daylight more uniformly and to brighten interior surfaces, reducing their contrast with the bright glazing surface.
- Use blinds or drapes to control brightness at the windows, diffuse the light and reduce glare.
- Avoid punched windows, which are simple holes in the middle of a wall or ceiling. Splay window reveals and skylight wells to reduce glare.
- Orient extremely shiny surfaces such as computer screens or white boards so that glare is avoided, or redesign the daylighting apertures to eliminate reflections on those surfaces.

- Locate computer screens so that the screen viewing orientation is parallel to or 45 degrees to the windows. Reflected glare will then pose less of a problem and, if present, can usually be reduced by using polarizing filters or meshes attached directly to the screen.

*Figure 3-3. Deeply coffered ceiling helps to diffuse light from skylights. White ceilings and walls help reflect light into the space. Photo: SunOptics.*

***Provide Control of Daylight***

The quantity and quality of daylight varies through the day and year, making it challenging to design an ideal aperture that provides adequate illumination for the maximum number of hours with minimal impact on cooling load. The most practical method of daylighting control is to provide shades or blinds on the apertures. Here are some guidelines:

- Provide shades or blinds inside or outside the window that are easily accessible to the occupants. These systems should be durable, easy to use, and economic to maintain.
- Manually operated controls are slightly less convenient than automatic controls but they are also less expensive and less likely to need repairs.

- Moveable exterior shades are exposed to weather conditions that may damage them over time. Use fixed exterior shades instead. Make sure that fixed exterior shades are sloped slightly so that water drains off them.

*Figure 3-4. Horizontal blinds allow control of brightness from lower view windows. Note that high clerestory windows have no blinds so that daylight can reach deep into the space. Photo: Barbara Erwine.*

- Skylights with clear glazing should use some form of shading device. Exterior shading devices for skylights are available, but not recommended because of maintenance problems. Rooftop devices are usually exposed to more severe weather, dust and debris. Sturdy, dependable performance is essential. If possible, position shading or operable equipment for skylights below at least the first layer of skylight glazing.
- Some skylight manufactures offer fixed or operable louver options for sun and daylight control, to reduce both solar gain and excessive daylight. Others offer movable insulation devices that can be operated, either manually or automatically, to reduce both solar gain and nighttime heat losses.

***Integrate with Electric Lighting Design***

Daylighting is thermally more efficient than electric lighting. For the same level of illumination the cooling load created by daylighting illumination is much lower than that created by electric lighting. Substituting daylighting for electric lighting where possible reduces both cooling and lighting costs. But these energy savings can be achieved only if the electric lights are turned off or dimmed in response to the daylight, using either manual or automatic controls.

The Design and Analysis Tools section below discusses tools to help visualize the overall light distribution in the space. Also the see the Electric Lighting and Controls Guidelines for more information. Here are some general guidelines for integrating daylighting with electric lighting design:

- Align the lighting fixtures with the daylight apertures so as to avoid blocking daylight penetration or casting undesirable shadows in the workspace.
- The light well connecting the toplighting aperture with the space below may intersect electric lighting layouts and fire sprinkler systems. Careful coordination will ensure compatibility among these systems.
- Daylight provides “bluer” light than most electric lighting. When combining electric light and daylight in a space, consider using fluorescent lamps with a color temperature of 3500°K to 4100°K or higher. (Color temperature describes a light source’s relative blueness or yellowness.)

- Automatic daylighting controls, which use photosensors to respond to light levels, cost more than manual controls but ensure savings. If using manual controls, make sure that they are accessible and well labeled so that they are easy to use. See the Electric Lighting and Controls Guidelines for more information.

***Plan the Layout of Interior Spaces***

Daylight can be provided through toplighting or sidelighting. Sidelighting can be used on all floors, but the extent of daylight penetration is limited because the illumination level drops off sharply as the distance from the window increases. Daylight penetration is roughly equal to twice the window head height.[5]

Here are some general guidelines for designing the interior space to best take advantage of daylighting opportunities:

- Since daylighting illuminance can vary considerably within the space, especially with sidelighting, locate work areas where there is adequate daylighting most of the time.
- To provide uniform illumination, balance the daylight from one side by providing apertures on the opposite side of the space. Where this is not possible, the space should ideally be only as wide as the daylight can penetrate, if daylight is to be provided in the entire space. If the space needs to be deeper than the extent of daylight penetration, balance the natural light by providing electric lights with controls to maintain the desired illumination level.
- Locate areas for predominantly visual tasks — such computer screens — to reduce the probability of glare. Orient these work areas so that daylighting is available from the side or from above. Facing a window may introduce direct glare into the visual field, while facing away from a window may produce shadows or reflected glare.
- Unlike sidelighting, where the width of the space is an issue, toplighting can be used to provide uniform daylight in a large space, but it can only be used in single-story buildings or on the top floor of a multistory building. Locate large spaces that require daylighting on the top floor. Spaces that are less deep, such as classrooms, conference rooms and private offices, can be located on the periphery of the building envelope to take advantage of daylight through sidelighting strategies.

[5] The window head height is the height from the floor level to the top of the aperture.

- At the space planning stage, allot functions that would benefit most from daylighting — such as spaces with maximum operating hours during the day — to the areas that can have some toplighting. Tasks that make use of self-illuminating sources (such as computer rooms) can be located in those areas of the building where you may not be able to provide daylighting.

***Optimize Aperture Size***

The optimum size of the daylighting aperture depends on a number of factors, including the aperture pattern (lightshelves, sawtooth roof monitor, etc.), the desired illuminance level of the space that is being daylit, and the type of glazing material used.

For a given daylighting pattern, glazing material, occupancy pattern, lighting level, electric lighting control system, and climate, the total operating costs can be calculated and plotted for various window areas. As the glazing area increases, the energy use for lighting is steadily reduced until the window area is about 25% of the exterior wall. After that, daylight saturation is achieved for much of the time, and lighting energy savings are much smaller with increased window area. However, both cooling load and fan energy increase steadily throughout the entire range of window-wall ratios.

For more information about sizing daylighting apertures, see the Energy-Efficient Windows Guidelines.

***Design for Safety and Security***

Design operable apertures to minimize security risks such as intruders entering a building.

In hurricane-prone areas, there is a risk of damage to glazed panels. Exposed toplighting devices such as skylights may need to meet impact standards. A perforated metal panel or metal grill could be installed below the skylight to provide protection, although this may reduce the amount of daylight penetration To compensate, increase the number of skylights or the visible transmittance of the skylight’s glass. Another alternative is to use laminated glass. Check with local building department officials and your insurance company for current requirements on hurricane safety.

**Design and Analysis Tools**

Daylighting designs can be evaluated with physical models, lighting computer simulation software or whole building energy simulation software.

### *Physical Scale Models*

Physical scale models accurately illustrate the daylighting conditions and lighting quality issues created by any given design, and help to understand why one design might work better than another. The interior of physical models can be photographed to record the lighting impacts of various design options, including issues such as uniformity and glare.

Daylighting models can be tested outdoors under real sky conditions or in simulators constructed to reproduce overcast sky and direct sun conditions. Photocells can be used to record light levels within the model. These sun simulators — which are called heliodons — can be set to correspond to the actual sun angle at specific times of the day for a particular site's latitude, and are used to study shading patterns during a typical day. A heliodon is available at the University of Hawaii at Manoa campus.[6] Daylighting textbooks provide information about constructing and testing daylighting models.

### *Lighting Simulation Software*

Electric lighting and daylighting software can generate light level values and gradients for electric light and daylight from windows and skylights in a space. Simulation programs include Desktop Radiance, Lightscape, LumenMicro and Superlite. Because these programs produce results for a single point in time, numerous simulations must be performed to study daylight distribution for varying sun and sky conditions.

Setting up the basic computer model can take more time than constructing a physical model, but once the basic model exists, simulating various design options can be quicker and easier than with a physical model. Some of these programs have another advantage: they generate realistic renderings of the lighting in the space, which can be linked together to simulate the changes in daylighting over the course of a day. These programs vary in their ease of use, the time required to create a model, and in the range of materials and room shapes they can simulate.

### *Whole Building Energy Simulation Software*

Unlike lighting simulation programs, which just model electric lighting and daylighting conditions, whole building energy simulation programs help to evaluate the effects of daylighting on

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[6] For more information, contact Steve Meder: smeder@hawaii.edu.

whole building energy use. Programs such as BLAST, DOE-2.1E, Energy 10 and EnergyPlus take into account the impact of daylighting fenestration on issues such as solar gain, HVAC equipment size, and reduced electric lighting energy use. Programs that interface with these whole building simulation tools have been developed to make it easier to create models and analyze results. To accurately evaluate complex daylighting designs, it may be necessary to use one of the lighting simulation program discussed above in conjunction with a whole building energy simulation tool.

**Operations and Maintenance**

Horizontal glazing needs more frequent cleaning than vertical glazing in areas and times of the year with low rainfall, and must be on a cleaning schedule for maximum daylight benefit.

The mechanisms for operable louvers and blackout shades should be robust, accessible to the occupant and easily repairable.

Horizontal reflecting members such as lightshelves should also be on a cleaning schedule.

Daily janitorial service should check all operable windows and skylights to make sure that they are closed when appropriate.

**Commissioning**

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

It's critical to test and adjust automatic lighting controls to ensure that expected energy savings are achieved with daylighting systems. For a daylighting system with automatic controls to work properly, several commissioning steps are important:

- Clearly specify the intended control operation;
- Carefully specify the control equipment to ensure that the installed equipment has the necessary capabilities;
- Provide the contractor with a detailed testing protocol; and
- Require that the contractor certify proper operation.

See the Electric Lighting and Controls chapter for more information about commissioning daylighting controls.

**Utility Programs**

To take advantage of any existing opportunities for daylighting design incentives, contact your utility company representative as early as possible in the design process.

**Products**

Refer to the Energy-Efficient Windows Guidelines for information about glazing characteristics and high performance glazing products.

**Resources**

*Advanced Lighting Guidelines.* White Salmon, OR: New Buildings Institute, 2001. Web site: www.newbuildings.org.

Ander, Gregg. *Daylighting Performance and Design.* NY: John Wiley & Sons, Inc., 1997.

*Daylighting Initiative Case Studies and Project Reports.* San Francisco: Pacific Gas & Electric Company, 1999. Web site: www.pge.com/pec/daylight.

*IESNA Lighting Handbook, 9th edition.* NY: Illuminating Engineering Society of North America (IESNA), 2000. Web site: www.iesna.org.

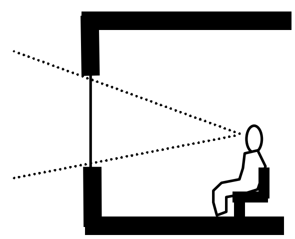
*SkyCalc.* A Microsoft Excel-based spreadsheet used to determine the optimum skylighting strategy for a building. Available from www.energydesignresources.com.

*Skylighting Guidelines.* California: Energy Design Resources. Web site: www.energydesignresources.com.

## View Windows

**Recommendation**

Provide access to exterior views through view windows for all interior spaces where occupants are present for extended periods of time.[7]



**Description**

A view window is vertical glazing at eye level that provides a view to the exterior or interior adjacent spaces.

**Applicability**

Use view windows in all spaces except those requiring visual privacy. They should be planned for in the schematic design phase.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

[7] Cross-section drawings in this and subsequent Daylighting Guidelines are courtesy of *CHPS Best Practices Manual* (Eley Associates, 2001).

**Benefits**

In addition to providing daylight, view windows offer many other benefits, including providing building occupants with connections to outdoor conditions and to nature, and allowing people outside of a space to view what's taking place inside the space.

Stimulating views may increase occupant productivity and may help to reduce stress. Access to views can also promote eye health: optometrists encourage people who spend much time on close-up activities such as computer work to frequently shift their focus to a longer view.

If view windows are operable, they can allow for emergency egress and natural ventilation.

Also, north-facing view windows can provide enough daylight to reduce electric lighting loads, if manual controls or photocontrols are provided. But view windows on the other orientations will often have to have their blinds or curtains drawn to reduce glare, and so should not be counted on to provide adequate daylight or to predictably reduce a space's electric lighting use.

**Integrated Design Implications**

**Design phase:** Identify the location and design objectives of view windows early in the schematic design phase. View windows need to be at eye level, they should not produce glare, and they should be oriented and designed to reduce building energy loads.

**Interior layout of space:** If some view windows cannot be optimally oriented, it may be possible to allot time-specific activities to certain spaces to make best use of the window orientation. For example, a space with a west-facing view window can be comfortably used

*Figure 3-5. The light-colored wall perpendicular to the windows helps to reduce contrast and reflect daylight into the space. Blinds provide control over brightness and direct sunlight penetration. Photo: Erik Kolderup, Eley Associates.*

from morning to early afternoon, but will need to be protected from direct solar penetration with blinds in the late afternoon. Activities that require daylight in the late afternoon should be avoided in this space.

Orient view windows relative to the location of stationary tasks, such as desks, computer workspaces and reading areas. Avoid reflected glare from windows in computer screens or surfaces such as whiteboards.

**Balance with other daylighting strategies:** Although view windows offer many benefits, they are not the most effective daylight delivery system. For better daylight delivery, combine view windows with high sidelighting, toplighting or both.

**Integration with electric lighting:** See the General Principles for Daylighting Design Guideline for an overview of integrating daylighting with electric lighting.

If view windows are the only daylight apertures in a space, and they appear on only one wall of the space, balance their brightness by washing other interior walls with electric light.

With view windows the illuminance level quickly drops off as we move away from the windows (see Figure 3-6). They do not significantly lower electric lighting energy consumption unless integrated with other daylighting strategies such as high sidelighting or balancing daylight from two or more directions. To maximize the energy benefits of daylighting, circuit and control the electric lighting so that at least one row of lights can be turned off near the view windows and the rest of the rows can be left on away from the windows where there is less daylight.

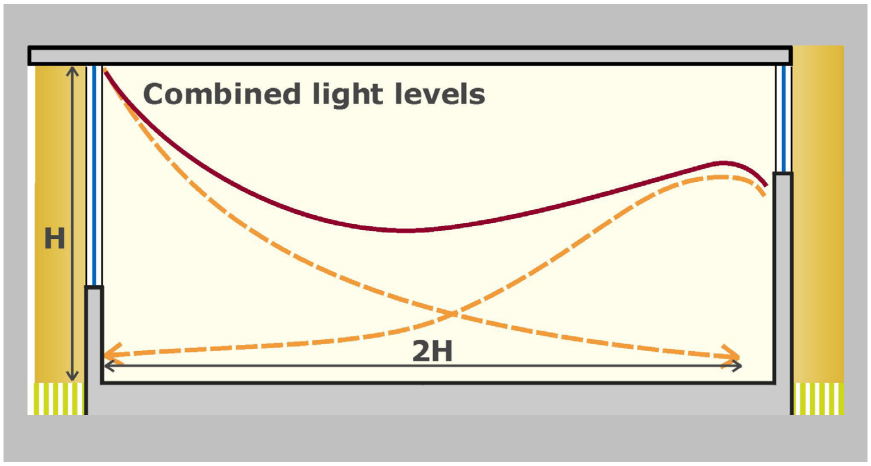



*Figure 3-6. Daylight levels drop rapidly as you move away from a window. Daylight penetration is approximately two times the window head height. The solid line represents combined light levels from the two windows shown here.*

**Integration with structural system:** Coordinate the size and location of windows with the location of columns and studs.

**Integration with HVAC:** If they are oriented, glazed and shaded appropriately, view windows can reduce a building's overall heating and cooling loads, which in turn can reduce the required size of the HVAC system and yearly energy costs.

**Integration with natural ventilation:** Operable view windows in combination with operable skylights, or operable windows in combination with high sidelighting apertures located on the opposite wall, can be used to naturally ventilate the space when the outside air temperature falls within a comfortable range. This can eliminate or significantly reduce mechanical ventilation needs for a significant portion of the time in Hawaii. Evaluate prevailing wind conditions to assess the feasibility of this approach. See the Natural Ventilation Guidelines for details.

**Design Details**

**Orientation:** Orient view windows toward the north or south to avoid the low-angle east and west sun. See the Energy-Efficient Windows Guidelines for information about the impact of window orientation on building energy performance.

*Figure 3-7. Exterior fins help to reduce brightness and direct sun penetration. Photo: Erik Kolderup, Eley Associates.*

**Diffusion:** Since view windows are within the occupants' normal field of view, the contrast between the bright window area and other interior surfaces can create glare. Use exterior shading devices such as overhangs or fins, or use landscaping, to eliminate direct sun penetration and reduce brightness. Deeply splayed walls or mullions will also reduce glare.

On south, east and west orientations, an interior shade such as a shade screen, blinds or drapes, will provide control over brightness and sun penetration.

**Blackout capability:** If blackout capability is required, add louvers.

**Glazing area:** Refer to the Energy-Efficient Windows Guidelines for information about appropriately sizing the glazing areas.

**Visible transmittance:** If it is not possible to use a shading device to cut off direct solar penetration, use a lower transmission glazing according to the aperture's orientation. If tinted glazing is used, evaluate its effect on color distortion with both overcast and clear skies. See the Energy-Efficient Windows Guidelines for details.

**Reflectance:** Paint all surfaces near windows white or off-white to reduce contrast between the brightness of the window and its surrounding wall. Place view windows adjacent to a perpendicular surface that can reflect daylight onto adjacent surfaces. Avoid windows that are merely punched holes in walls, as these create glare.

**Exterior reflective surfaces:** Reflective surfaces outside the view window may create glare. Reflected sun off a car windshield, for example, can create annoying glare, as can light-colored exterior walls that are within view. Landscaping such as hedges or trees can help reduce glare from these outdoor sources.

**Computer screen location:** Orient computers at a 45-degree angle from view windows to avoid glare from reflections of the window in the computer screen. Flat-screen computers and adjustable-angle LED screens also help to reduce glare.

**Safety and security:** There are safety and security issues associated with view windows, especially those located on the first floor. Operable interior shades, laminated glass, or both can make view windows more secure.

**Noise transmission:** If noise is expected to be a problem, use double-glazing or laminated glass to reduce noise transmission.

**Design and Analysis Tools**

The physical models or daylight simulation tools noted in the General Principles for Daylighting Design Guideline can be used to evaluate the potential daylight levels of a particular design that includes view windows. The energy simulation programs can be used to understand the building energy use associated with a particular design.

In spaces where a particular view is a critical element of the design, use scaled drawings or a scale physical model to evaluate views and view angles from various positions in the space, or use simulation programs such as Desktop Radiance or Lightscape. A "lipstick"-type video camera head can be used inside a physical model to record the views from various positions.

**Costs**

Costs for view windows are typically low. The incremental cost of energy-efficient glazing can vary widely, from $0.70 to $12 per square foot of glass.

**Cost Effectiveness**

Although there are many excellent reasons for including view windows in buildings, it is difficult to place a value on view windows in terms of cost effectiveness. Where view windows are used, it is often cost effective to use energy-efficient glazing to reduce cooling loads and increase occupant comfort.

**Operation and Maintenance Issues**

Wash view windows on a regular schedule. Clean, repair and replace as necessary any shading devices such as blinds, louvers, drapes and shades. Use shading devices with mechanisms that are sturdy, easy for the occupants to operate, and easy to repair.

Make sure that operable windows are designed to prevent physical entry and water penetration.

**Commissioning**

View windows typically do not require commissioning.

**Utility Program**

Energy-efficient windows that exceed the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

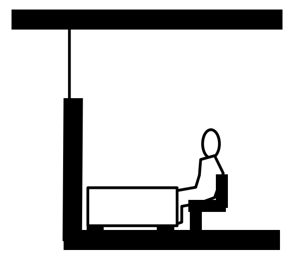
**Case Study**

The HMSA Building in Honolulu uses lightshelves to shade view windows and bounce daylight deeper into the space. In some spaces, the glazing below the lightshelf is tinted to reduce glare, while the glazing above the lightshelf is clear. In other areas, the view windows have clear glazing, but the exterior lightshelves shade the windows.

*Figure 3-8. HMSA Building. Windows provide occupants with views and daylight. Lightshelves shade the view windows. Photos: Erik Kolderup, Eley Associates.*

*Figure 3-9. HMSA Building. Exterior lightshelves shade the view windows and bounce light onto the ceiling.*

## High Sidelighting — Clerestory



**Recommendation**

Use high sidelighting clerestories in perimeter walls to deliver daylight deeper in spaces such as offices, classrooms, warehouses, industrial spaces, gymnasiums, and many other building types.

**Description**

High sidelighting is characterized by vertical glazing in an exterior wall above eye level, typically above 7 ft. The penetration of usable daylight into a space from vertical glazing is roughly 1.5 to 2.5 times the window head height. Therefore, placing the window higher on the wall increases daylight penetration in the space.

For all orientations except perhaps north, clerestories generally require some type of shading to prevent the direct penetration of sunlight. The Design Details section of this Guideline lists various shading options, while lightshelves and louvers are discussed in depth in the next Guideline, High Sidelighting — Clerestory with Lightshelves or Louvers.

**Applicability**

High clerestory windows can be used in many types of commercial buildings to provide deep penetration of daylight.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

Refer to the General Principles for Daylighting Design Guideline in this chapter for a discussion of the energy saving, productivity and visual comfort benefits of daylighting.

Clerestory sidelighting can save energy by reducing electric lighting energy use, assuming that appropriate manual or automatic controls are used for the space's electric lighting system. Clerestory sidelighting improves lighting quality by distributing daylight more uniformly across the space.

**Integrated Design Implications**

**Design phase:** High sidelighting must be planned for in the schematic design phase. High ceilings and perimeter walls are required. The best orientations for high sidelighting are north and south (if shaded). East and west orientations may be acceptable if diffusing glazing is used, or if low-angle sun penetration will not be a problem in the space.

**Interior layout of space:** An open-plan interior layout works best with high sidelighting because it doesn't obstruct daylight penetration.

**Balance with other daylighting strategies:** Used on one wall, this approach creates a decreasing gradient of useable daylight of roughly 1.5 to 2.5 times the clerestory head height into the space. For spaces 20 to 40 ft wide, balance high sidelighting with a daylighting scheme on the opposite wall to distribute daylight evenly across the space.

When combining view windows and high sidelighting in a space, the clerestories should be continuous along the whole area to be daylit, but view windows can be selectively spaced as needed.

*Figure 3-10. Clear glazing on the high sidelighting and tinted glazing on the view windows. HMSA building, Honolulu. Photo: Erik Kolderup, Eley Associates.*

**Integration with electric lighting:** Circuit electric lighting parallel to the linear zones of daylighting created by high sidelighting. Use manual controls or photocontrols to regulate electric light in response to daylighting conditions.

See the General Principles for Daylighting Design Guideline for an overview of integrating daylighting with electric lighting.

**Integration with ceiling plenum:** Clerestory sidelighting requires ceiling heights of at least 9.5 ft at the window wall. There are a variety of ways to achieve this extra ceiling height without significantly increasing the building's floor-to-floor height. For example, the ceiling can be sloped or stepped upward at the perimeter, as shown in Figure 3-11, which reduces the plenum near the window wall. A careful integration of the structural system, HVAC ducts and electric lighting in the plenum can also provide additional perimeter ceiling height. In spaces with HVAC ducts in the ceilings, the ducts should be located away from perimeter walls.

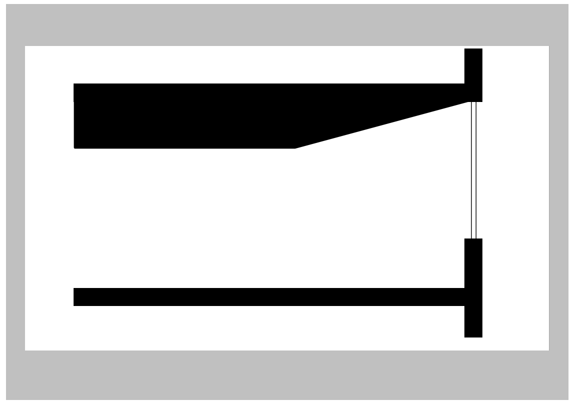


*Figure 3-11. Sloped ceiling at perimeter increases window head height by reducing the plenum height.*

**Integration with HVAC:** High sidelighting can affect a building's overall HVAC loads because it is susceptible to solar gain in the cooling season and heat loss in the heating season. Reduce HVAC loads by correctly orienting the glazing, designing appropriately sized windows, selecting appropriate glazing materials, providing shading, and controlling the electric lighting system. In addition to saving energy, these measures may help to reduce the size and first cost of the HVAC equipment.

Locate ductwork away from clerestory windows to avoid blocking daylight.

**Integration with natural ventilation:** Operable clerestories that allow warm air to escape near the ceiling level can be part of a natural ventilation scheme (see the Stack Ventilation Guideline in the Natural Ventilation chapter for details). Locate operable clerestory windows on a building's leeward side for more effective natural ventilation.

**Design Details**

**Orientation:** Clerestories are most effective on south and north orientations. For east and west orientations, evaluate the design to reduce low sun angle penetration. With east, west and south orientations, reduce solar gain by shading the glazing with an overhang or use a selective low-e coating (SHGC less than .45).

**Glazing materials:** There are some new glazing materials that can help deliver daylight deeper into the space by redirecting it from the clerestory window to the ceiling. These include prismatic, lensed, holographic and laser-cut acrylic materials. Before selecting these glazing materials, test them to see if they will result in excessive bright spots or glare.

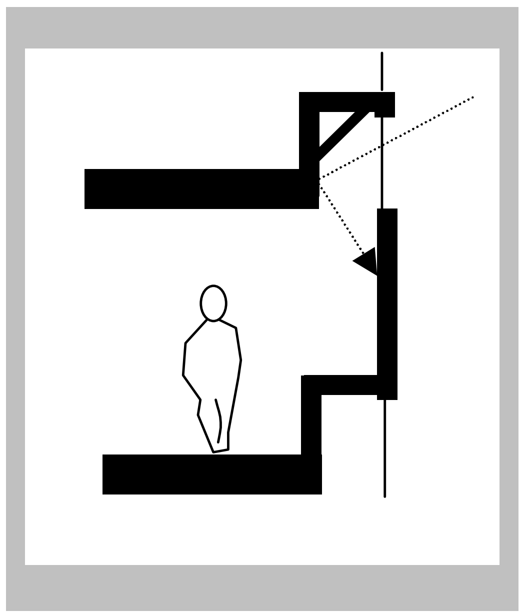
**Visible transmittance:** Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Reflectance:** Surfaces near the clerestories should be white or off-white to reduce contrast between the brightness of the windows and their adjacent walls. The adjacent ceiling should have a white or off-white surface with a reflectance of 70% or more to help direct daylight into the space. High-reflectance ceiling tiles may be an option if the budget allows.

**Ceiling design:** For high sidelighting designs, a minimum perimeter ceiling height of 9.5 ft is recommended. Generally, the higher the ceiling height, the better.

The wall area directly below a clerestory may be darker than other nearby surfaces. In a multistory building, the ceiling can be stepped so that reflected daylight from the clerestory brightens the perimeter wall area, as shown in Figure 3-12.

*Figure 3-12. Clerestories in multistory buildings can redirect daylight onto the perimeter wall to brighten it.*



**Shading devices:** Use exterior shading devices, diffusing glazing, operable blinds, lightshelves or louvers to reduce or eliminate direct sun penetration. The following guideline, High Sidelighting — Clerestory with Lightshelf or Louvers, discusses the lightshelf and louver strategies. The Energy-Efficient Windows Guidelines provide information about the appropriate depth of exterior shading devices.

Dedicated blinds or shades for clerestory and view windows allow them to be controlled separately for glare. One low-maintenance option is a product that has miniblinds positioned between the panes of glass in a double-glazed window. Blackout shades may be necessary in certain spaces.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings.

For high sidelighting designs that include sloped surfaces, make sure that the simulation program can accommodate them. Evaluate daylight levels in the space under both clear and overcast sky conditions. It's important to assess sun penetration through the clerestory glazing for the lowest anticipated sun angles, because occupants may block a window if they are annoyed by even occasional glare.

**Costs**

Costs for high sidelighting are low to moderate. A balance of view and clerestory windows can be provided with minimal increase to the overall glazed area.

Refer to the Energy-Efficient Windows Guidelines for information about the relative costs of different types of glazing. As long as the clerestories are properly shaded, it is generally not necessary to use more expensive high-performance glazing.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

Clerestories are generally more cost effective than view windows because they can be substantially smaller and yet they do a better job of providing daylight.

**Operation and Maintenance Issues**

Wash clerestory windows on a regular schedule. Clean, repair and replace as necessary any shading devices such as blinds, louvers and shades. Use shading devices with mechanisms that are sturdy, easy for the occupants to operate, and easy to repair.

Make sure that operable clerestory windows are designed to prevent water penetration.

**Commissioning**

Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

**Utility Programs**

Energy-efficient sidelighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

**Case Study**[8]

At the Ross Middle School in Ross, California, clerestories bring daylight into the classrooms and can be opened to provide natural ventilation. View windows on the opposite side of the room provide additional daylight, and have miniblinds for glare control when needed. White ceilings and walls help to reflect daylight deeper into the space.

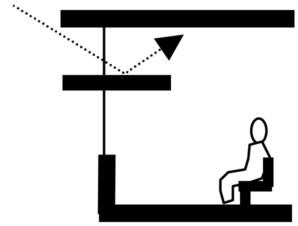
The direct/indirect pendant luminaires include two fluorescent lamps that can be switched separately by the teacher to control light levels. This system uses only 1 W/ft² of electricity. In addition, the electric lighting system includes dimming ballasts and photocontrols, which can reduce lighting energy use by up to 60%.

Occupancy sensors are used in some area to shut off lights when the space is not occupied, and building-level automatic controls turn off lights when the building is not in use.

*Figure 3-13. Ross Middle School, Ross, CA. The clerestories on the right allow daylight into the classroom, while white ceilings and walls reflect the daylight deeper into the space. Photo: Eley Associates.*

[8] Source: Eley Associates. *Collaborative for High Performance Schools Best Practices Manual, Vol. I — Planning,* 2001. Web site: www.chps.net.

## High Sidelighting — Clerestory with Lightshelves or Louvers



**Recommendation**

Use lightshelves or louvers with high clerestory glazing to improve daylight distribution, reduce glare and prevent direct sun penetration.

(Note: The previous Guideline, High Sidelighting — Clerestories, discusses clerestories in general. You may wish to familiarize yourself with that material before continuing with this Guideline.)

**Description**

A lightshelf is a horizontal panel separating a high clerestory window from a lower view window. Daylight reflects off the top of the lightshelf or louver onto the ceiling, improving light distribution.

A series of smaller horizontal louvers can replace a large lightshelf. Performance will be reduced slightly with louvers, but they may provide better illumination on the wall directly beneath the clerestory. Larger louvers deliver daylight deeper into the space. Louvers can either be fixed or adjustable. If louvers are used instead of lightshelves, they should be designed with the same cutoff angle as the lightshelf. In Hawaii, because louvers help to reduce the size of exterior shading devices, a larger floor area may be allowed.

Lightshelves and louvers can be located on the exterior of a building, the interior or both. Exterior lightshelves (see Figure 3-14) bounce the high-angle summer sun into the space, and also shade the lower window, which helps to stop solar heat gain before it enters the building. Interior lightshelves reflect the low-angle winter sun into the space, block direct sun penetration, and reduce glare from the upper glazing. Figure 3-15 shows the effect of interior and exterior lightshelves.


*Figure 3-14. Exterior lightshelves improve light distribution and help stop heat gain before it enters the building. Photo: Erik Kolderup, Eley Associates.*

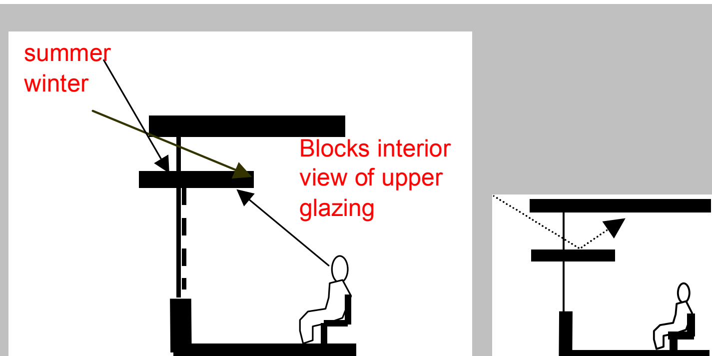



*Figure 3-15. Exterior lightshelves shade lower window and reflect summer sun into room. Interior shelves reflect winter sun while reducing glare.*

**Applicability**

High clerestory windows with lightshelves or louvers can be used in many types of commercial buildings to provide deep penetration of daylight.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

For general information about the benefits of daylighting, see the General Principles for Daylighting Design Guideline earlier in this chapter.

Clerestories with lightshelves or louvers provide numerous benefits. They can save energy by both reducing solar heat gain through shading and by reducing lighting energy use.

They also improve lighting quality by delivering daylight deeper into the space and distributing daylight more evenly. Interior lightshelves and louvers reduce or eliminate glare by blocking the occupants' view of the bright upper glazing.

**Integrated Design Implications**

**Design phase:** High sidelighting with lightshelves or louvers should be planned for early in the schematic design phase. High ceilings and perimeter walls are required. Clerestories with lightshelves are most effective with a south-facing orientation. The size and cutoff angles of the lightshelf or louver system must be carefully calculated. See the Energy-Efficient Windows Guidelines for information about interior and exterior shading devices.

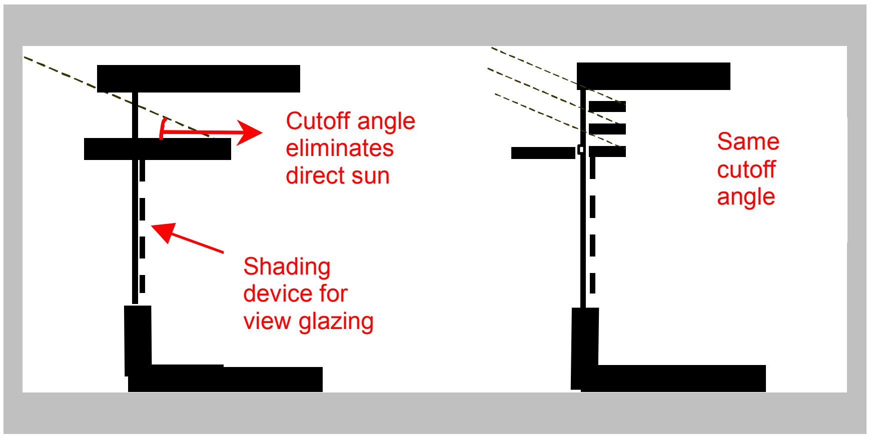



*Figure 3-16. Set the cutoff angle of lightshelves or louvers to eliminate direct sun penetration during normal operating hours.*

**Interior layout of space:** An open-plan interior layout works best with high sidelighting because it doesn't obstruct daylight penetration.

**Balance with other daylighting strategies:** Used on one wall, this approach creates a decreasing gradient of useable daylight of roughly 2.5 times the clerestory head height into the space. For spaces that are 20 to 50 ft wide, balance high sidelighting with a daylighting scheme on the opposite wall to distribute daylight evenly across the space.

When combining view windows and high sidelighting in a space, the clerestories should be continuous along the whole area to be daylit, but view windows can be selectively spaced as needed.

**Integration with electric lighting:** Circuit electric lighting parallel to the linear zones of daylighting created by high sidelighting. Use manual controls or photocontrols to regulate electric light in response to daylighting conditions.

Lightshelves and louvers work well when combined with a direct/indirect pendant electric lighting system. The first row of electric lighting is sometimes incorporated into the lightshelf itself.

**Integration with ceiling plenum:** Clerestories with lightshelves require ceiling heights of at least 9.5 ft at the window wall. There are a variety of ways to achieve this extra ceiling height without significantly increasing the building's floor-to-floor height. For example, the ceiling can be sloped or stepped upward at the perimeter, as shown in Figure 3-11, which reduces the plenum height near the window wall. A careful integration of the structural system, HVAC ducts and electric lighting in the plenum can also provide additional perimeter ceiling height. In spaces with HVAC ducts in the ceilings, the ducts should be located away from perimeter walls.

**Integration with HVAC:** Glazing above a lightshelf can affect a building's overall HVAC loads because it is susceptible to solar gain in the cooling season and heat loss in the heating season. Reduce HVAC loads by correctly orienting the glazing, designing appropriately sized windows, selecting appropriate glazing materials, providing shading, and controlling the electric lighting system. In addition to saving energy, these measures may help to reduce size and first cost of the HVAC equipment.

Design lightshelves so they don't interfere with air circulation from the HVAC system. Locate ductwork away from clerestory windows to avoid blocking daylight.

For spaces with the potential to be naturally ventilated, consider using operable clerestories. See the Natural Ventilation Guidelines.

**Integration with other mechanical systems:** Design lightshelves so they don't interfere with the fire sprinkler system operation.

**Design Details**

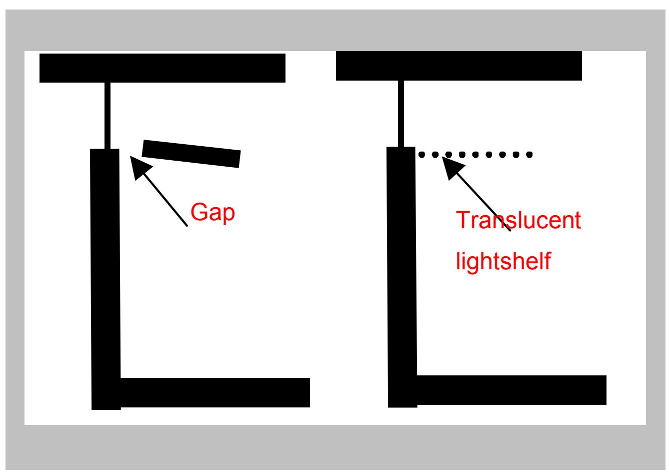
**Orientation:** Lightshelves are most effective on south orientations. For north orientations, they are occasionally useful for reduce glare from the upper glazing. Avoid them on east and west orientations.

**Materials:** Lightshelves can be made of wood, metal, glass-fiber reinforced concrete (GFRC), plastic, fabric or acoustic ceiling materials. Issues to consider when selecting an appropriate material include reflectivity, structural strength, cost, maintenance requirements and durability. Some curtain wall or window manufacturers provide assistance with the design of lightshelves.

The top surface of casework along a perimeter wall can also be used as a lightshelf if its reflectivity and size are appropriate. The top should be sloped so that it won't be used for storage, which would interfere with its ability to reflect daylight into the space.

**Opaque vs. translucent shelves:** Lightshelves and louvers may be opaque or translucent. If opaque lightshelves are not combined with a lower view window, there may be a dark space on the wall directly under them. To address this, leave a gap between the lightshelf and the wall or use electric lighting to brighten this wall. Translucent shelves provide a soft light under them but must be designed carefully so that occupants with a view of their underside aren't bothered by glare. See Figure 3-17.

*Figure 3-17. A gap between an opaque lightshelf and the perimeter wall beneath creates a wall wash. A translucent lightshelf provides a soft light.*




**Visible transmittance:** Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Reflectance:** The top surface of the lightshelf or louvers should have a reflectance of greater than 80%, with a diffuse, not mirrored, surface. Surfaces near the clerestories should be white or off-white to reduce contrast between the brightness of the windows and their adjacent walls. The adjacent ceiling should have a white or off-white surface with a reflectance of greater than 70% to help direct the maximum amount of daylight into the space. High-reflectance ceiling tiles may be an option if the budget allows.

**Ceiling design:** For high sidelighting designs, a minimum perimeter ceiling height of 9.5 ft is recommended. Generally, the higher the ceiling height, the better. Position the lightshelf at 7 ft or more above the floor. Coordinate shelf position with pendant electric lighting, door headers, shelving, fire sprinklers and other interior features.

**Cutoff angle:** Set the cutoff angle of the lightshelf or louvers (see Figure 3-16) to eliminate direct sun penetration during normal operating hours. See the Energy-Efficient Windows Guidelines for details about shading devices.

**Sloped shelves:** Slope exterior lightshelves at least ¼ inch per foot so that rain can wash dirt off the shelves and so that water won't pool on them. Slope interior shelves (or use fabric lightshelves) so they are not used for storage.

**Maintenance:** Design the lightshelves or louver systems so it is easy to clean the glass above them, both inside and outside. Large lightshelves may need to be positioned away from the window by about 6 in. so that window-cleaning equipment can be inserted from below the shelf.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings.

For high sidelighting designs that include sloped surfaces, make sure that the simulation program can accommodate them. Evaluate daylight levels in the space under both clear and overcast sky conditions. It's important to assess sun penetration through the clerestory glazing for the lowest anticipated sun angles, because occupants may block a window if they are annoyed by even occasional glare.

**Costs**

Lightshelves or louvers are an added expense, but some of this cost may be offset if the building's cooling load can be reduced and the HVAC system downsized.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

Energy savings from reduced lighting and cooling energy are adequate to recover the initial investment in about 8 to 12 years. Also, high sidelighting with lightshelves and louvers helps provide a better indoor environment, and may even increase occupant productivity by enhancing visual comfort. For many tenants and building owners, the value of any increase in productivity would be an even more attractive benefit than the long-term energy savings.

**Operation and Maintenance Issues**

Glazing, lightshelves and louvers must be kept clean to provide maximum daylight to the space. Clean the top surface of the shelf or louvers each time the windows are washed. Make sure lightshelves or louvers are detailed correctly to allow easy window cleaning. For operable louvers, it is preferable to have preset angles that can be seasonally adjusted by the building maintenance staff so the louvers are not inadvertently left at a non-optimal angle.

**Commissioning**

Unless the lightshelf or louvers are moveable, commissioning should not be necessary. Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

**Utility Programs**

Energy-efficient sidelighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

**Case Study**

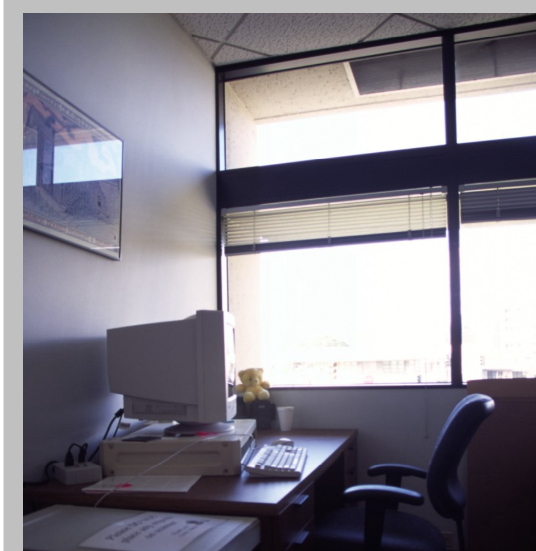
Overhangs and lightshelves shade the windows of the Kaiser Permanente Honolulu building pictured here. Windows on the east façade are angled southeast (a sawtooth pattern in plan view) to provide additional shading. Because the exterior surfaces are buff colored, they do not reflect as well as white surfaces would.

Interior miniblinds below the lightshelves provide some glare control (Figure 3-20), but the high sidelighting above the lightshelf is a potential source of glare because the lightshelves do not extend inside the building. The glass is tinted a neutral color.

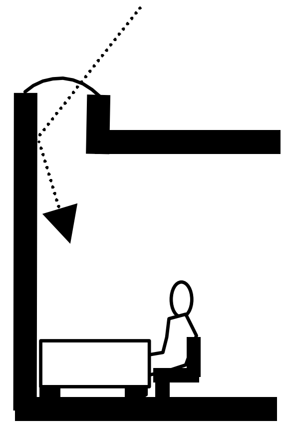
*Figure 3-18. Kaiser Permanente, Honolulu Clinic. Photos: Erik Kolderup, Eley Associates.*

*Figure 3-19. Exterior detail.*

*Figure 3-20. Interior detail.*

## Wall-wash Toplighting



**Recommendation**

Use wall-wash toplighting for interior walls to balance daylight from window walls, brighten interior rooms and make them seem more spacious.

**Description**

Linear skylights or roof monitors located above an interior wall brighten a space by providing a "wash" of daylight across the wall surface. Skylight and roof monitor wells obscure the occupants' direct view of the bright glazing, thus minimizing uncomfortable glare. Diffusing glazing, baffles and reflective, matte light well and interior wall surfaces help diffuse the daylight.

**Applicability**

Toplighting is appropriate in single-story buildings or the top floor of multistory buildings. Many types of spaces may benefit from wall-wash toplighting, including private offices, meeting rooms, open plan offices, retail stores, classrooms, circulation areas and multipurpose spaces.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

Wall-wash toplighting reflects glare-free daylight into the space, making it appear larger and brighter. This is approach, when combined with another wall-wash or a sidelighting strategy that increases daylight on the opposite side of the room, is an excellent way to create balanced daylight across an entire space.

This strategy can save energy if the first row or two of electric lights adjacent to the wall wash are controlled in response to daylight conditions. During daylight hours, savings for controlled fixtures can range from 40% to 80%.

If the wall-wash toplighting scheme uses operable rooftop fenestration, it can be used to provide natural ventilation, which may increase occupant productivity. See the Natural Ventilation Guidelines for more information.

**Integrated Design Implications**

**Design phase:** Wall-wash toplighting must be planned for in the schematic design phase. The glazing for wall-wash toplighting may be either horizontal or vertical. Vertical glazing may face north, east, south or west. Compared to roof monitors, skylights can offer an advantage of lower construction costs.

**Interior layout of space:** When designing a space, take into account that this daylighting scheme will draw attention to the wall that is being "washed" with daylight. It may be possible to eliminate task lighting for work areas that are located closer to the wall-wash toplighting. But to avoid glare, do not position work areas directly under the wall-wash toplighting.

**Balance with other daylighting strategies:** Balance wall-wash toplighting with a daylighting scheme on the opposite wall to supply uniform lighting across the whole space.

**Integration with electric lighting:** An electric lighting wall-wash luminaire can wash the wall with light at night or during very cloudy conditions. The electric light should be photocontrolled to respond to daylight conditions.

See the General Principles for Daylighting Design Guideline for an overview of integrating daylighting with electric lighting.

**Integration with structural system:** Coordinate the location and size of skylights and roof monitors with the structural system and roof diaphragm to maintain the building's strength and integrity.

**Integration with HVAC:** Coordinate the location of skylights, roof monitors and their light wells with the location of rooftop HVAC equipment and interior ductwork. Toplighting that is properly oriented, glazed, shaded and integrated with electric lighting controls, should decrease a building's heating and cooling loads, which in turn can reduce the size and first costs of the HVAC system as well as yearly energy costs.

**Integration with natural ventilation:** Operable rooftop fenestration can be used to naturally ventilate the space. See the Natural Ventilation Guidelines for information.

**Design Details**

**Skylights:** Skylights perform better in a predominantly overcast sky condition and non-north/south orientations.

A pyramid or arch-shaped diffusing skylight is more effective at collecting daylight during the very low sun angles of early morning or late afternoon. Horizontal glazing is more effective when the sun is high in the sky and associated with higher solar gains.

**Roof monitors:** A roof monitor with glazing oriented north or south will be more expensive, but may perform better than a skylight in areas with predominantly sunny conditions. North- or south-facing monitors exhibit less variation of daylight levels than east- or west-facing monitors. They are also easier to design for good energy performance. To reduce solar heat gain with south-facing vertical glazing, use an overhang or a spectrally selective low-e coating with an SHGC of less than .45, along with baffles or diffusing glazing to eliminate direct sun. East- or west-facing roof monitors may show more variation in daylight levels and quality. If an east or west orientation is required, consider a skylight instead of a roof monitor.

**Diffusion:** To provide gentle, attractive light and to avoid bright spots of direct sun, the daylight needs to be diffused before it washes the wall. Use diffusing glazing, baffles or a deep light well. A diffusing material like prismatic acrylic will increase a skylight's light transmission while reducing bright spots. Baffles used with clear glazing should be adjustable or should be designed so that all anticipated sun angles are cut off.

**Visible transmittance**: Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Light wells:** A light well brings daylight through the roof and the ceiling plane. Light well walls should be light in color — with a reflectance of greater than 80% — to reflect more light down into the space. Avoid dark well walls. Avoid dark well walls. Flat, bright white paint performs best. Diffusely reflecting light wells should be less than 8 ft deep. For deeper wells, mirrored reflecting wells can be used.

**Surface colors:** The top of the wall below the skylight or roof monitor should be white or off-white with a reflectance of greater than 70% to better reflect daylight into the space.

**Insulation:** Ideally, the roof should be appropriately insulated. But if the insulation is located at the ceiling, then it is also necessary to insulate the light well walls to prevent heat gain into the space.

**Task and accent lighting:** Wall-wash toplighting can be used to light corridors and other circulation spaces, and can provide task and accent lighting on a wall.

**Safety and security:** Toplighting designs can present safety and security concerns, especially on flat roofs. Make sure that any operable fenestration is designed to prevent physical entry. A safety/security grating can be placed in the light well under the toplight glazing (make sure this grating does not create an undesirable shadow on the wall). Louvers and baffles can also provide security.

**Leakage:** There are leakage risks with all roof penetrations. Use well-tested curb design details and flashing kits provided by the manufacturer. Make sure that operable fenestration is designed to prevent rain penetration.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings. For designs that include sloped surfaces, make sure that the simulation program can handle them. The SkyCalc program, available at www.energydesignresources.com, can be used to quickly optimize the size of the daylighting aperture ratio for most simple skylight schemes.

**Costs**

Costs for wall-wash toplighting are moderate to high, depending on design. Commercial, single-glazed skylights are usually the least expensive approach.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

In general, wall-wash toplighting is a less cost-effective daylighting strategy than patterned or central toplighting. Wall-wash toplighting may be most appropriate when it is necessary to balance daylight from view windows on the opposite side of space or to provide special emphasis on a wall.

**Operation and Maintenance Issues**

To provide maximum daylight to the space, glazing needs to be cleaned on a regular schedule. In climates with low rainfall, horizontal glazing will require more frequent cleaning.

Educate occupants so that they understand how the wall-wash toplighting delivers daylight to the space, and discourage them from hanging dark-colored items such as artwork on the washed wall.

Operable louvers and blackout shades should be durable, accessible to the occupants and easy to repair. The building maintenance staff should check operable fenestration daily to ensure that it is closed when appropriate.

**Commissioning**

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

**Utility Programs**

Energy-efficient toplighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

**Case Study**[9]

At the Oakridge High School in El Dorado Hills, California, diffusing skylights provide wall-wash toplighting in classrooms. The 4 ft by 4 ft double-glazed prismatic domes line both sides of an interior wall shared between classrooms, and bring diffuse, glare-free daylight into the spaces. Four-foot deep rectangular light wells are painted white, as are the walls, to better reflect daylight into the classrooms. The teaching wall is located perpendicular to the skylit wall to avoid glare problems.

Teachers can manually operate louvers in the light wells to adjust light levels and darken the room during video presentations. View windows and clerestories on the opposite side of the classroom from the wall-wash toplighting help to balance the daylight. South-facing windows are shaded with roof overhangs and shaded walkways to reduce direct sun penetration in the summer.

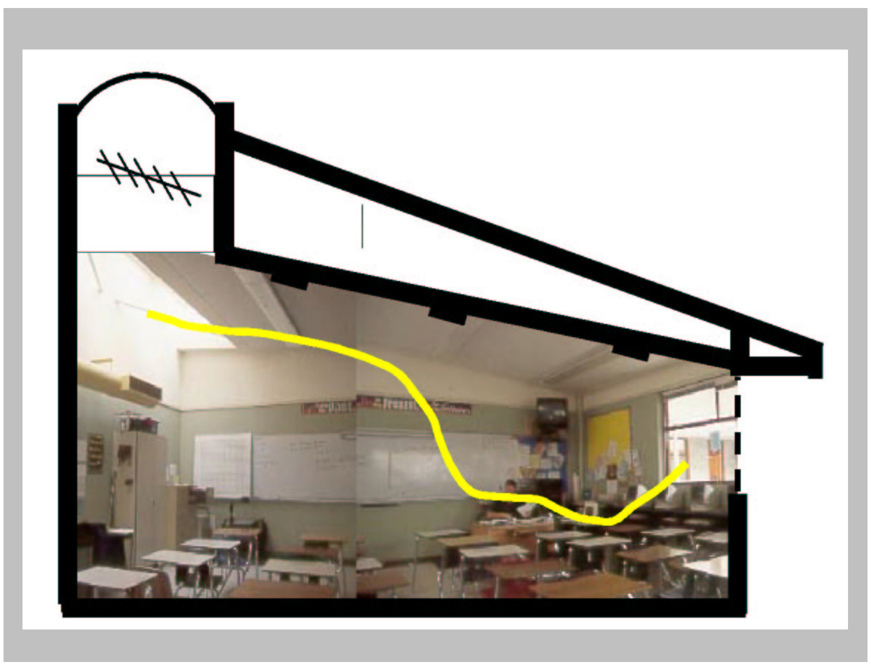


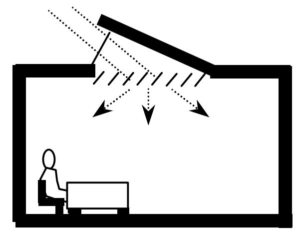
*Figure 3-21. Oakridge High School, El Dorado Hills, CA. Wall-wash toplighting from diffusing skylights on the left is balanced with daylight from view windows and clerestories on the right. Photo: Lisa Heschong.*

Electric lights are circuited parallel to the view windows and toplit walls, and were originally designed with automatic daylight dimming controls. However, over the years many of these controls

[9] Source: Eley Associates. *Collaborative for High Performance Schools Best Practices Manual, Vol. I — Planning,* 2001. Web site: www.chps.net.

have been disabled and are now working in only about 20% of the classrooms. Many teachers use the wall switch to turn off the electric lights when there is sufficient daylight.

## Central Toplighting



**Recommendation**

Use central toplighting in single-story buildings or the top floor of multistory buildings to provide even, balanced daylight across the entire space.

**Description**

With central toplighting, a central roof monitor, a skylight or a group of skylights delivers daylight evenly across a space. Diffusing glazing materials or baffles that are fixed or operable diffuse the daylight. Daylight levels are highest directly under the toplighting aperture and gradually reduce toward the space's perimeter.

*Figure 3-22. Central sawtooth roof monitor provides even illumination across desktops in this classroom. Photo: Barbara Erwine.*

**Applicability**

Central toplighting is appropriate for single-story buildings or top floor spaces, including offices, warehouses, assembly and light industrial spaces, retail stores, and classrooms.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

When used with appropriate diffusion techniques, central toplighting creates uniform, balanced daylight across the space.

This approach saves electric lighting energy if the electric lights are controlled in response to daylight levels. Electric lighting energy savings may range from 40% to 80% during daylight hours.

Operable skylights or operable roof monitors can be used as part of a natural ventilation strategy. See the Natural Ventilation Guidelines for details.

**Integrated Design Implications**

**Design phase:** Toplighting schemes apply to single-story buildings or the top floor of multistory buildings. Toplighting should be considered during the programmatic, schematic and design development phases of a building project. Central toplighting may employ either horizontal glazing or vertical glazing that faces north, east, south or west.

**Balance with other daylighting strategies:** Central toplighting may be combined with view windows. Since the toplighting can provide most of the ambient daylight, smaller view windows can be judiciously spaced in perimeter walls, which frees up wall space for other needs.

**Integration with electric lighting:** With central toplighting, the daylight levels may be lower near the perimeter walls. Electric lighting wall-wash luminaires can provide supplemental light. If the light well is visible, pendant uplight luminaires can help prevent the light well from appearing to be a dark hole in the ceiling at night. Use photocontrols on the electric lights to respond to daylight conditions.

**Integration with structural system:** Coordinate the location and size of skylights and roof monitors with the structural system and roof diaphragm to maintain the building's strength and integrity.

**Integration with HVAC:** Coordinate the location of skylights, roof monitors and their light wells with the location of rooftop HVAC equipment and interior ductwork. Toplighting that is properly oriented, glazed, shaded and integrated with electric lighting controls, should decrease a building's heating and cooling loads, which in turn can reduce the size and first costs of the HVAC system as well as yearly energy costs.

**Integration with natural ventilation:** Operable rooftop fenestration can be used to naturally ventilate the space. See the Natural Ventilation Guidelines for information.

**Design Details**

**Orientation:** Skylights perform better than roof monitors in a predominantly overcast sky condition or non-north/south orientations. A roof monitor with glazing oriented north or south will be more expensive, but may perform better than a skylight in areas with predominantly sunny conditions.

**Glazing area:** Refer to the Energy-Efficient Windows Guidelines for information about appropriately sizing the glazing areas.

**Roof monitors:** North- or south-facing sawtooth roof monitors exhibit less variation of daylight levels than east- or west-facing monitors. They are also easier to design for good energy performance. To reduce solar heat gain with south-facing monitors, use an overhang or a spectrally selective low-e coating with an SHGC of less than .45. Don't use east- or west-facing sawtooth monitors because they will produce large variations in light level and quantity from morning to afternoon, and will have poor thermal performance.

**Diffusion:** To provide gentle, attractive light and to avoid bright spots of direct sun, use diffusing glazing or baffles. Use adjustable baffles or make sure that baffles are designed to cut off all anticipated sun angles. Avoid placing diffusing glazing within the occupant's normal field of view, as it will cause excessive glare.

**Visible transmittance:** Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Light wells:** A light well brings daylight through the roof and the ceiling plane. Light well walls should be light in color — with a reflectance of greater than 80% — to reflect more light down into the space. Avoid dark well walls. Flat, bright white paint performs best. Diffusely reflecting light wells should be less than 8 ft deep. For deeper wells, mirrored reflecting wells can be used.

To reduce glare and spread daylight more effectively, splay the light well walls. A 45- to 60-degree angle is recommended.

**Reflectors:** Reflectors located below the light well can help wash the ceiling or walls with daylight, making the room appear brighter and more spacious. Options include mirrored or matte reflective surfaces that can be flat or curved. Reflectors may also be made from partially translucent materials like fabric, plastic or perforated metal. Reflector devices require additional floor-to-ceiling height. Their daylight distribution performance should be evaluated with a daylight analysis tool such as a physical scale model or simulation program.

**Insulation:** Ideally, the roof should be appropriately insulated. But if the insulation is located at the ceiling, then it is also necessary to insulate the light well walls to prevent heat gain into the space.

**Safety and security:** Toplighting designs can present safety and security concerns, especially on flat roofs. Make sure that any operable fenestration is designed to prevent physical entry. A safety/security grating can be placed in the light well under the toplight glazing (make sure this grating does not create an undesirable shadow on the wall). Louvers and baffles can also provide security.

**Leakage:** There are leakage risks with all roof penetrations. Use well-tested curb design details and flashing kits provided by the manufacturer. Make sure that operable fenestration is designed to prevent rain penetration.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings. For designs that include sloped surfaces, make sure that the simulation program can handle them. The SkyCalc program, available at www.energydesignresources.com, can be used to quickly optimize the size of the daylighting aperture ratio for most simple skylight schemes.

**Costs**

Costs for central toplighting are medium to high, depending on design. Unit skylights will be the least expensive. Site-built monitors with vertical or sloped glazing will cost more.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Operation and Maintenance**

To provide maximum daylight to the space, glazing needs to be cleaned on a regular schedule. In climates with low rainfall, horizontal glazing will require more frequent cleaning.

Operable louvers and blackout shades should be durable, accessible to the occupants and easy to repair. The building maintenance staff should check operable fenestration daily to ensure that it is closed when appropriate.

**Commissioning**

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

**Utility Programs**

Energy-efficient toplighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

**Case Study**

An operable central skylight in the Honolulu Hale provides natural ventilation and fills the building's interior with daylight.

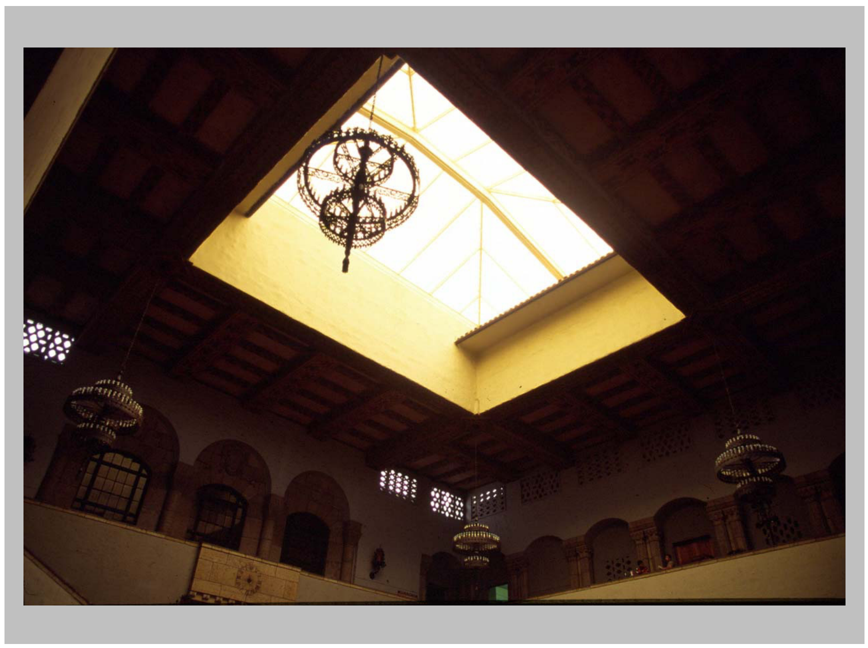
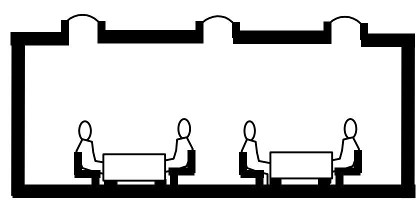


*Figure 3-23. Central skylight, Honolulu Hale. Photo: Erik Kolderup, Eley Associates.*

## Patterned Toplighting



**Recommendation**

Use patterned toplighting in large spaces that need uniform, low-glare illumination.

**Description**

Patterned toplighting uses a grid of skylights or rows of sawtooth or square roof monitors to provide glare-free daylight across a large space. The spacing of the pattern depends on the ceiling height.

**Applicability**

Patterned toplighting is appropriate for providing even daylight levels to large areas such as grocery stores, big-box retail stores, gymnasiums, cafeterias, warehouses, and light industrial and assembly spaces. Since this is a toplighting scheme, it applies to single-story buildings or the top floor of multistory buildings.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

Patterned toplighting creates balanced, glare-free daylight across large spaces. If electric lighting systems are controlled in response to daylight levels, energy savings may range from 40% to 80% during daylight hours.

Daylight levels can be varied by using operable louvers. Natural ventilation can be provided if the skylights or roof monitors are operable (see the Natural Ventilation Guidelines for information).

**Integrated Design Implications**

**Design phase:** Patterned toplighting should be planned for during the programmatic, schematic and design development phases.

**Interior layout:** In spaces with tall shelves, such as grocery stores, big-box retail stores and warehouses, the toplighting design needs to be coordinated with the shelving layout.

**Balance with other daylighting strategies:** Balance the amount of glazing in a patterned toplighting scheme with the need for view windows and other apertures in the space. Since the toplighting provides most of the ambient daylight, smaller view windows can be judiciously spaced in perimeter walls, which frees up wall space for other needs.

**Integration with electric lighting:** To maximize the energy benefits of daylighting, circuit and control the electric lighting so that the lights can be turned off in areas where there is adequate daylight and kept on where daylight is insufficient.

See the General Principles for Daylighting Design Guideline for an overview of integrating daylighting with electric lighting.

**Integration with structural system:** Coordinate the location and size of skylights and roof monitors with the structural system and roof diaphragm to maintain the building's strength and integrity.

**Integration with HVAC:** Coordinate the location of skylights, roof monitors and their light wells with the location of rooftop HVAC equipment and interior ductwork. Toplighting that is properly oriented, glazed, shaded and integrated with electric lighting controls, should decrease a building's heating and cooling loads, which in turn can reduce the size and first costs of the HVAC system as well as yearly energy costs.

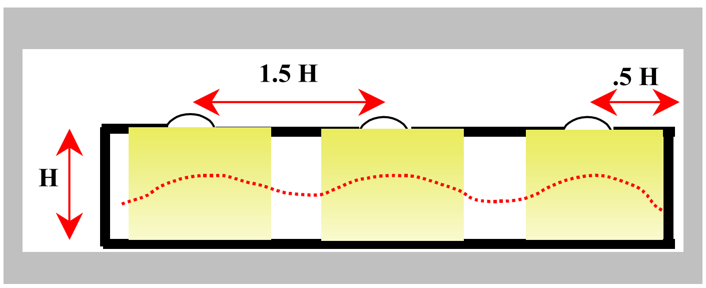
**Integration with natural ventilation:** If the rooftop fenestration is operable, it can be used to naturally ventilate the space. See the Natural Ventilation Guidelines for information.

**Design Details**

**Orientation:** The glazing for patterned toplighting may be either horizontal or vertical. Skylights perform better than roof monitors in a predominantly overcast sky condition or non-north/south orientations. A monitor with glazing oriented north or south will be more expensive, but may perform better than a skylight in areas with predominantly sunny conditions.

**Skylights:** As a rule of thumb, skylights used in a patterned toplighting scheme should be spaced roughly 1.5 times the floor-to-ceiling height (H in Figure 3-24). Their glazing should be about 3% to 12% of the floor area to be lighted. (The SkyCalc program, available at www.energydesignresources.com, can be used to optimize the design.)

*Figure 3-24. Skylight grid spacing.*




**Roof monitors:** North- or south-facing sawtooth roof monitors exhibit less variation of daylight levels than east- or west-facing monitors. They are also easier to design for good energy performance. To reduce solar heat gain with south-facing roof monitors, use an overhang or a spectrally selective low-e coating with an SHGC of less than .45. Don't use east- or west-facing sawtooth monitors because they will produce large variations in light level and quantity from morning to afternoon, and will have poor thermal performance.

**Diffusion:** To provide gentle, attractive light and to avoid bright spots of direct sun, use diffusing glazing or baffles. Use adjustable baffles or make sure that baffles are designed to cut off all anticipated sun angles. Avoid placing diffusing glazing within the occupant's normal field of view, as it will cause excessive glare.

**Visible transmittance:** Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Light wells:** A light well brings daylight through the roof and the ceiling plane. Light well walls should be light in color — with a reflectance of greater than 80% — to reflect more light down into the space. Avoid dark well walls. Flat, bright white paint performs best. Diffusely reflecting light wells should be less than 8 ft deep. For deeper wells, mirrored reflecting wells can be used.

To reduce glare and spread daylight more effectively, splay the light well walls. A 45- to 60-degree angle is recommended.

**Insulation:** Ideally, the roof should be appropriately insulated. But if the insulation is located at the ceiling, then it is also necessary to insulate the light well walls to prevent heat gain into the space.

**Safety and security:** Toplighting designs can present safety and security concerns, especially on flat roofs. Make sure that any operable fenestration is designed to prevent physical entry. A safety/security grating can be placed in the light well under the toplight glazing (make sure this grating does not create an undesirable shadow on the wall). Louvers and baffles can also provide security.

**Leakage:** There are leakage risks with all roof penetrations. Use well-tested curb design details and flashing kits provided by the manufacturer. Make sure that operable fenestration is designed to prevent rain penetration.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings. For designs that include sloped surfaces, make sure that the simulation program can handle them. The SkyCalc program, available at www.energydesignresources.com, can be used to quickly optimize the size of the toplighting designs.

**Costs**

Costs for patterned toplighting range from low to high, depending on design. Costs to consider include the expense of the skylight or roof monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.

A grid of skylights without light wells will be the least expensive — roughly $1,000 each installed. Roof monitors with reflecting devices will be much more expensive. Packaged skylights with integrated light wells and electric lighting cost closer to $3,000 each including installation.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

Patterned toplighting is the most cost-effective form of daylighting, provided that it is feasible for a given space. Compared to other daylighting strategies, it requires less aperture area to achieve the needed illumination.

**Operation and Maintenance**

To provide maximum daylight to the space, glazing needs to be cleaned on a regular schedule. In climates with low rainfall, horizontal glazing will require more frequent cleaning.

Operable louvers and blackout shades should be durable, accessible to the occupants and easy to repair. The building maintenance staff should check operable fenestration daily to ensure that it is closed when appropriate.

**Commissioning**

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

It's critical to test and adjust automatic lighting controls to ensure that expected energy savings are achieved with daylighting systems. For a daylighting system with automatic controls to work properly, several commissioning steps are important:

- Clearly specify the intended control operation;
- Carefully specify the control equipment to ensure that the installed equipment has the necessary capabilities;
- Provide the contractor with a detailed testing protocol; and
- Require that the contractor certify proper operation.

**Utility Programs**

Energy-efficient toplighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

**Case Study**

At the Foodland store in Ewa on Oahu (Figure 3-25), the patterned toplighting design uses a specialized skylight with an integral light well and a diffuser at the bottom. The electric lighting is automatically controlled in response to daylight levels.

*Figure 3-25. Foodland, Ewa, Oahu. Skylights and integrated light wells with diffusers (inset) at the ceiling. Photos: Erik Kolderup, Eley Associates.*

The Better Brands warehouse on Oahu employs a similar skylight system with integrated light wells, which also includes electric lighting. These units contain six 4-ft T-5 fluorescent lamps mounted behind the diffuser at the bottom of the light well. These lamps can be controlled in several steps to supplement daylight or provide nighttime illumination.

*Figure 3-26. Better Brands warehouse, Oahu. Skylights with integrated light wells, fluorescent lighting, and diffusers (inset). Photos: Erik Kolderup, Eley Associates.*

## Linear Toplighting

**Recommendation**

Use linear toplighting to direct movement or establish visual orientation in a long, linear space such as a hallway. Use linear toplighting on two sides of a space to define separate tasks or activities, to define edges in a larger space, or to downlight the space from two directions.

**Description**

Linear toplighting provides a line of high intensity daylight directly under it. As you move away from this line of daylight, its intensity drops. Used bilaterally (from two sides), it can frame a larger space.

**Applicability**

Since this is a toplighting scheme, it applies to single-story buildings or the top floor of multistory buildings. Use linear toplighting in corridors or linear walkways within a larger space. Linear toplighting can also be used bilaterally to frame larger areas like gymnasiums, shopping malls, convention centers and multipurpose areas. Linear toplighting may also be used in covered outdoor walkways to reduce shadows, especially in covered walkways next to spaces with sidelighting.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, at the beginning of this chapter.

**Benefits**

Linear toplighting creates bright corridors that provide important visual orientation for circulation during daylight hours. In a bilateral design, it can provide daylighting that graduates in intensity from a bright perimeter to a more moderate light level between the two linear toplights.

If electric lighting systems are controlled in response to daylight levels, energy savings may range from 40% to 80% during daylight hours.

Daylight levels can be varied by using operable louvers. Natural ventilation can be provided if the skylights or roof monitors are operable (see the Natural Ventilation Guidelines for information).

**Integrated Design Implications**

**Design phase:** Linear toplighting should be planned for during the programmatic, schematic and design development phases.

**Interior layout:** When applicable, coordinate linear toplighting with major circulation areas in the building. Consider increasing light levels at major intersections and at the ends of hallways.

**Balance with other daylighting strategies:** The amount of glazing in a linear toplighting scheme should be balanced with the need for view windows and other apertures in the space.

**Integration with electric lighting:** Electric lighting should be aligned with the toplighting without blocking it and causing annoying shadows. To maximize the energy benefits of daylighting, circuit and control the electric lighting so that the lights can be turned off in areas where there is adequate daylight and kept on where daylight is insufficient.

See the General Principles for Daylighting Design Guideline for an overview of integrating daylighting with electric lighting.

**Integration with structural system:** Coordinate the location and size of skylights and roof monitors with the structural system and roof diaphragm to maintain the building's strength and integrity.

**Integration with HVAC:** Coordinate the location of the linear toplights and their light wells with the location of rooftop HVAC equipment and interior ductwork. Interruptions in the toplighting design's linear run may be required to accommodate HVAC and duct requirements. Arrange these interruptions in a regular manner to avoid creating random patterns of light and dark.

**Integration with natural ventilation:** Operable rooftop fenestration can be used to naturally ventilate the space. See the Natural Ventilation Guidelines for information.

**Design Details**

**Orientation:** The glazing for patterned toplighting may be either horizontal or vertical. Skylights perform better than roof monitors in a predominantly overcast sky condition or non-north/south orientations. A monitor with glazing oriented north or south will be more expensive, but may perform better than a skylight in areas with predominantly sunny conditions.

**Diffusion:** In circulation areas, diffuse daylight can be used to provide balanced light in the space, while areas of direct sun can brighten intersections and circulation spines. To diffuse daylight, use translucent glazing or baffles. For smaller areas of direct sun, use transparent glazing.

**Visible transmittance:** Refer to the Energy-Efficient Windows Guidelines for details about the appropriate visible transmittance of glazing in Hawaii.

**Glazing area:** Refer to the Energy-Efficient Windows Guidelines for information about appropriately sizing the glazing areas.

**Shared daylighting:** Diffuse corridor daylight can be shared with adjacent spaces by glazing the upper portion of the adjoining wall. Avoid this if acoustic separation is an issue. In multistory buildings, daylight from the top floor corridor can be shared with the lower floor by periodically cutting light wells to the lower level.

**Light wells:** For diffusing skylights with deeper, narrow light wells, a splayed light well spreads the daylight more effectively and reduces glare. A 45- to 60-degree angle is recommended.

**Insulation:** Ideally, the roof should be appropriately insulated. But if the insulation is located at the ceiling, then it is also necessary to insulate the light well walls to prevent heat gain into the space.

**Safety and security:** Toplighting designs can present safety and security concerns, especially on flat roofs. Make sure that any operable fenestration is designed to prevent physical entry. A safety/security grating can be placed in the light well under the toplight glazing (make sure this grating does not create an undesirable shadow on the wall). Louvers and baffles can also provide security.

**Leakage:** There are leakage risks with all roof penetrations. Use well-tested curb design details and flashing kits provided by the manufacturer. Make sure that operable fenestration is designed to prevent rain penetration.

**Design and Analysis Tools**

See the General Principles for Daylighting Design Guideline for information about design tools that can be used to evaluate daylight distribution and calculate energy savings. For designs that include sloped surfaces, make sure that the simulation program can handle them. The SkyCalc program, available at www.energydesignresources.com, can be used to quickly optimize the size of the toplighting designs.

**Costs**

Costs for linear toplighting range from moderate to high, depending on design. A linear row of skylights will be the least expensive; roof monitors with reflecting devices will be more expensive. Costs include the expense of the skylight or monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

In most cases, linear toplighting is typically less cost effective than patterned toplighting. Patterned toplighting is generally more effective at providing even daylighting coverage, while linear toplighting is often chosen more for architectural and aesthetic reasons than specifically for providing daylight.

**Operation and Maintenance**

Clean glazing on a regular schedule. Horizontal glazing and clear glazing need more frequent cleaning in climates with low rainfall.

**Commissioning**

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

**Utility Programs**

Energy-efficient toplighting that exceeds the Hawaii Model Energy Code requirements may be eligible for customized incentives. Contact your utility company representative as early as possible in the design process.

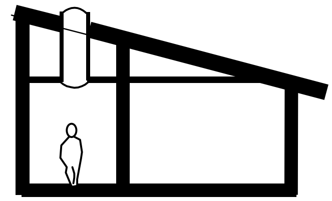
**Case Study**

In the Cameron Park Library (California), 8 ft x 4 ft x 4 ft ridge skylights help to establish visual orientation and guide circulation in the space. White ceilings and walls help to spread the daylight in the space. This photograph was taken before the electric light fixtures had been installed, but the skylights provided enough daylight that the library was able to open for business.

*Figure 3-27. Linear skylights in Cameron Park Library, Cameron Park, CA. Photo: SunOptics.*

## Tubular Skylights

**Recommendation**



Use tubular skylights to bring daylight into spaces with deep roof cavities and for low-cost retrofits to existing spaces.

**Description**

Tubular skylights are small, domed skylights with clear glazing. They are connected to the space's ceiling with mirrored reflective ducts. An interior diffuser at the ceiling plane distributes daylight in the space. Some tubular skylights have electric lighting in the duct or a diffuser that is controlled in response to daylight levels.

**Applicability**

Tubular skylights are especially good for small spaces including restrooms, kitchens, interior corridors, enclosed work areas and other interior spaces that are intermittently occupied. They are also recommended for retrofits in existing spaces that would benefit from additional daylight.

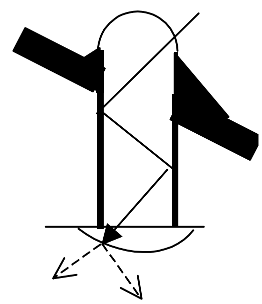


*Figure 3-28. Tubular skylight's mirrored duct reflects daylight into small spaces.*

Because they depend on multiple reflections to deliver daylight to the space, tubular skylights perform significantly better in clear sky conditions than in overcast climates. The longer the duct, the less daylight is delivered; so their use is limited to spaces with roof cavities of 8 ft or less.

**Codes and Standards**

See Codes and Standards section in General Principles for Daylighting Design, above.

**Benefits**

If arranged in a grid, tubular skylights can provide balanced daylight across a space, although daylight levels will fluctuate as conditions change from direct sun and to overcast skies.

They are a good low-cost retrofit option for existing spaces.

Tubular skylights can save electric lighting energy if the electric lights are controlled in response to the daylight levels. Savings may range from 20% to 60% during daylight hours.

**Integrated Design Implications**

**Design phase:** Since this is a toplighting scheme, it applies to single-story buildings or the top floor of multistory buildings. It should be planned for during schematic design, but can also be retrofitted in existing buildings.

**Balance with other daylighting strategies:** The amount of glazing in a linear toplighting scheme should be balanced with the need for view windows and other apertures in the space.

*Figure 3-29. Tubular skylight in reception area. Photo: Solatube International, Inc.*

**Integration with electric lighting:** Consider a system that incorporates a fluorescent — not an incandescent — light in the duct or ceiling plane diffuser to minimize ceiling luminaires. These units should have photocontrols so that they can be dimmed or switched in response to available daylight. Make sure the electric lamp does not block transmission of daylight.

**Integration with HVAC:** Coordinate the location of tubular skylights with the location of rooftop HVAC equipment and interior ducts. Although the tubular skylight's reflective duct can jog somewhat to avoid barriers in the ceiling plenum, each change in direction decreases the efficiency of daylight delivery.

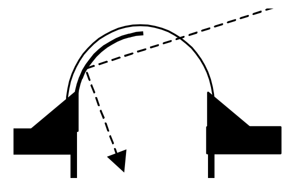
**Integration with structural system:** The small diameter of tubular skylights reduces their impact on the structural system compared to larger framed skylights.

**Design Details**

**Sizing:** An 8 in. tubular skylight can supply daylight to an area of about 100 ft². A 13 in. tubular skylight can serve daylight to an area of about 150 ft².

**Reflective ducts:** Use a product with a highly reflective cylindrical duct. (Don't use a corrugated duct; the corrugations trap light.) Minimize the length and minimize the bends in the reflective duct.

*Figure 3-30. Tubular skylight with reflective half-dome.*



**Half dome vs. full dome:** In regions where clear skies predominate, use a tubular skylight with a south-facing, reflective half-dome under the skylight bubble to increase the reflection of low-angle winter sun into the skylight (see Figure 3-30). In predominantly overcast regions, use a full clear dome.

**Diffusers:** Some tubular skylights have a flat bottom diffuser that fits into a standard 2 ft x 2 ft or 2 ft x 4 ft dropped ceiling grid. These diffusers may have electric lighting in them or they may be alternated in a grid with recessed fluorescent luminaires.

**Safety and security:** Unless these skylights are larger than 16 in. square, they shouldn’t pose a safety or security liability.

**Leakage:** There are leakage risks with all roof penetrations. Use well-tested curb design details and flashing kits provided by the manufacturer.

**Design and Analysis Tools**

It is difficult to simulate the performance of tubular skylights with physical scale models or computer programs. Some manufacturers provide estimating tools for evaluating performance. Note, however, that some manufacturers of tubular skylights have made exaggerated claims about the daylight delivery and R-value of their products.

*Figure 3-31. Cross section of tubular skylight. Photo: Solatube International, Inc.*

U-factor and solar heat gain coefficient data is typically not available for tubular skylights. Once this information is readily available, hourly building energy evaluation programs like DOE-2.1E and Energy 10 could be used to evaluate energy impacts.

**Costs**

Costs for tubular skylights are low relative to standard unit skylights because they don’t require construction of a separate light well and because the small opening may not require structural reinforcement.

For information about the costs of daylighting controls, see the Electric Lighting and Controls Guidelines.

**Cost Effectiveness**

For small spaces with attics, tubular skylights may be the most cost-effective daylighting option.

**Operation and Maintenance**

Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

**Utility Programs**

To take advantage of any existing opportunities for daylighting design incentives, contact your utility company representative as early as possible in the design process.

# 4. ELECTRIC LIGHTING AND CONTROLS GUIDELINES



## Overview

Lighting accounts for between 15% and 45% of the total electricity used in commercial buildings in Hawaii. Dramatic energy savings can be achieved through the use of energy-efficient luminaires and light sources, intelligently designed controls, and integrated daylighting design.

Efficient electric lighting systems also reduce internal heat gain, which can save air-conditioning energy, increase the potential for natural ventilation, and improve thermal comfort. And good electric lighting design improves visual performance and visual comfort by providing appropriate illumination and contrast while controlling reflectance and glare.

This chapter provides general guidelines for energy-efficient lighting systems and more detailed guidelines for three types of lighting systems: pendant-mounted lighting, recessed lighting and surface-mounted lighting. The Lighting Controls Guideline discusses various types of lighting control systems, including switches and dimmers, occupancy sensors and daylighting controls.

The final section of this chapter describes a number of energy-efficient lighting designs for typical commercial building spaces, including private and open-plan offices, grocery stores, big-box retail stores, small retail stores, classrooms, corridors, hotel guestrooms and warehouses.

## General Lighting Guidelines

**Recommendation**

Design lighting systems carefully, using efficient equipment and effective controls, to achieve a high level of energy savings while meeting the occupants' needs for visual comfort, security and productivity. Pay particular attention to integrating the building's electric lighting systems with available daylight.

The cost of electricity to operate lighting is easily the largest expense related to lighting system ownership. In the long-term, therefore, the lowest-cost lighting system will be one that is effective and energy efficient.

**Description**

Electric lighting systems consist of various components, including:

- Luminaires (for example, recessed, suspended indirect or direct/indirect, and surface-mounted);
- Light sources (for example, incandescent, halogen, linear fluorescent, compact fluorescent, high-intensity discharge lamps, and LEDs);
- Ballasts; and
- Lighting controls.

These components are discussed in detail later in this guideline.

When designing electric lighting systems, designers need to consider numerous critical issues, including vertical and horizontal illumination, glare control, lighting uniformity, color rendering, and integration with daylight. These issues are discussed later in this section.

**Applicability**

Energy-efficient electric lighting systems should be a feature of all new and renovated commercial buildings.

**Codes and Standards**

Hawaii developed a Model Energy Code (MEC) to ensure that efficient, energy-saving lighting technologies are used in renovations and new construction. This code, based on ASHRAE 90.1–1989 and the more stringent Federal version of the standard, has been adopted, with various modifications, by all counties except Maui. For the latest details about the code, see www.hawaii.gov/dbedt/ert/model_ec.html or contact the local building department.

The MEC includes a lighting compliance computer program called Hilight that can be downloaded at www.hawaii.gov/dbedt/ert/mec/app-b.html.

**Disposal requirements.** Hawaii has accepted U.S. EPA universal waste regulations for lighting materials that contain more than trivial amounts of mercury. This means that fluorescent and HID lamps not meeting EPA TCLP (Toxicity Characteristic Leaching Procedure) requirements need to be treated as typical hazardous waste in many cases. See the Operations and Maintenance section below for more information about disposing of lamps that contain mercury.

**Benefits**

Some of the many potential benefits of effectively designed, installed and controlled electric lighting systems include: dramatic energy savings, improved visual comfort and satisfaction for occupants, improved productivity, reduced operating and maintenance costs, reduced environmental impacts, and greater flexibility for building owners and tenants.

**Integrated Design Implications**

**Integration with daylighting.** To achieve energy savings in daylit spaces, electric lighting must be integrated with daylighting. At a minimum, circuit the luminaires to match the dispersion of daylight into the space. Circuit the luminaires closest to windows or skylights separately from other electric lighting in the space. This saves energy by allowing luminaires in daylit zones to be switched off during most daylight hours.

For a lighting system that maximizes energy savings and flexibility, consider using dimming ballasts with manual or automatic dimmers for additional flexibility. See the Lighting Controls Guideline for details.

**Resource Efficiency**

Although lighting's environmental impacts primarily relate to energy performance and indoor environmental quality, resource efficiency is also an environmental consideration.

Metal components of luminaires can sometimes be recycled, and the metal components of some luminaires may include recycled content. Intact luminaires can sometimes be salvaged during building deconstruction, and then refurbished and reused. However, paint and other optical materials deteriorate, and new lighting technologies perform much better than old ones, so reuse isn't always the most effective strategy.

**Design Details**

***Quality of Light***

Providing appropriate visibility is one of the most important goals of good quality lighting. Lighting quality also has a significant impact on many other human needs, including visual comfort, health and safety, social communication, mood, and the ability to perform tasks.

**IESNA illuminance recommendations.** In the past, the Illuminating Engineering Society of North America (IESNA) provided illuminance recommendations for specific spaces. But the new lighting design procedure in the ninth edition of the *IESNA Lighting Handbook* has been enhanced to address lighting *quality* as well as lighting *quantity*. This new procedure emphasizes the relative importance of numerous design issues for specific applications. These design issues include color appearance, daylighting integration and control, luminances of room surfaces, reflected glare, and many other issues. Chapter 10 of the *IESNA Lighting Handbook* discusses these issues in detail and provides a Lighting Design Guide that illustrates the relative importance of these lighting quality issues for specific space types.

Table 4-1 provides information about the relative importance of some lighting quality issues for some sample commercial building spaces. The IESNA Lighting Design Guide lists these space types plus hundreds more.

*Table 4-1. Importance of a few lighting quality issues for sample building spaces.*

| | Private Office | Meeting Room | Class-room (General) | Hotel Guest Room (General) | Food Court | Super-market Shelving | Industrial Simple Assem-bly |
|---|---|---|---|---|---|---|---|
| Appearance of space and luminaires | ⦿ | ● | ○ | ● | ● | ⦿ | ○ |
| Color appearance | ⦿ | ⦿ | ○ | ⦿ | ● | ● | ○ |
| Daylight integration and control | ● | ○ | ⦿ | | ● | | ⦿ |
| Control of direct glare | ● | ● | ⦿ | | ⦿ | ● | ○ |
| Light distribution on task plane (uniformity) | ⦿ | ⦿ | ⦿ | | ○ | ● | ○ |
| Luminance of room surfaces | ● | ⦿ | ⦿ | ● | ○ | ○ | ● |
| Control of shadows | ⦿ | ○ | ○ | | ⦿ | ● | ● |

● Very Important ⦿ Important ○ Somewhat Important *Blank* Not important

Source: *IESNA Lighting Handbook, 9th edition,* chapter 10.

While illuminance is not the sole design criteria, IESNA's lighting design procedure does provide recommended illuminance levels for seven categories, which are organized into three groups of visual tasks. These are shown in Table 4-2.

*Table 4-2. IESNA recommended illuminance levels*

| Category | Description | Recommended Illuminance (fc) |
|---|---|---|
| Orientation and simple visual tasks | Public spaces | 3 |
| | Simple orientation for short visits | 5 |
| | Work spaces where simple visual tasks are performed | 10 |
| Common visual tasks | Performance of visual tasks of high contrast and large size | 30 |
| | Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size | 50 |
| | Performance of visual tasks of low contrast and small size | 100 |
| Special visual tasks | Performance of critical visual tasks with very small or very low contrast elements | 300–1000 |

Source: *IESNA Lighting Handbook, 9th edition,* chapter 10, p. 13.

**Vertical illumination.** Lighting should be designed to achieve adequate vertical illumination. Our perception of what comprises lighting quality is strongly influenced by vertical illumination. For example, proper wall illumination is critical for uniformly lit spaces such as offices and classrooms. Similarly, in very low ambient conditions, such as outside at night, vertical illumination that promotes facial recognition is important for creating a sense of security.

**Glare control.** To avoid causing discomfort or disabling glare, carefully control all sources of light, including daylight. Direct glare can occur when a bright light source is in the occupant's field of vision. Reflected glare occurs when bright light reflects on surfaces such as glossy paper or a computer screen. Both types of glare can impair visual performance by reducing task visibility and causing visual fatigue. Common glare problems include overhead glare from direct distribution luminaires, reflections of luminaires on computer screens, and direct glare from uncontrolled windows or skylights.

**Lighting uniformity.** Few lighting systems provide completely uniform illumination. Although the IESNA provides target illuminance levels, it's important for designers to understand that these targets are not minimum levels; rather, the illuminance levels can vary within a certain range. A design that combines task and ambient illumination will help avoid over- or under-illumination.

Avoid shadows or sharp patterns of light and dark in spaces that are used for tasks requiring concentration (such as office spaces, libraries and classrooms). In such spaces, the luminance contrast ratios between the visual task and its immediate surroundings should not exceed 3:1, and the contrast between the brightest surfaces in the visual field and the visual task should not exceed 5:1. However, some shadows and light patterns may be suited for areas such as lobbies or lunchrooms to create a cheerful atmosphere. Higher ratios contribute to fatigue, because the eye will constantly adapt to differing light levels.

Avoid shadow patterns in spaces that are used primarily for "heads-up" visual tasks. For example, luminaires that use parabolic louvers may require supplemental wall-wash lighting to eliminate upper wall shadows. Use very bright visible sources, such as T-5 and T-5HO lamps, only in high spaces like gyms, or in cove lighting or in indirect luminaires.

Maximize lighting uniformity by providing light for vertical surfaces as well as the ceiling whenever possible. Use light-colored diffuse surface materials to help optimize lighting uniformity.

**Color rendering.** Light sources that render color well enhance the visual environment. Light sources should have a minimum color-rendering index (CRI) of 75 for most interior spaces. For areas where accurate color rendering is more critical (retail spaces, art rooms, exhibition spaces), select a source with a CRI of at least 80. The latest, more efficient "second-generation" or "premium" T-8 lamps, T-5 lamps and most compact fluorescent lamps have CRI in the range of 82–86.

## Light Sources

Light source selection critically affects the space's appearance, as well as visual performance and comfort. This section outlines the different types of sources available.

### *Incandescent Lamps (Including Halogen)*

Incandescent lamps represent the oldest of electric lighting technologies. Advantages of incandescent technology include point source control, high color rendering, instant starting, and easy and inexpensive dimming. Disadvantages include low efficacy, short lamp life, high energy and maintenance costs, and a narrow range of color choices (mostly in warm, yellow tones).

To save lighting costs, avoid incandescent sources in most spaces except in very limited and special accent lighting circumstances. Examples include dimming applications where color rendering, beam control or dramatic effect is critical, such as in teleconference rooms or theaters or for highlighting artwork. In most of these cases, halogen sources—which offer longer life, better point source control, and crisper color performance—are superior to standard incandescent lamps.

***Fluorescent Lamps***

Fluorescent lamps can and should be used to light most types of spaces. They offer long life, high efficacy, good color performance, and low operating and maintenance costs. There are no inherent disadvantages to fluorescent technology; however, dimming fluorescent lamps requires special electronic ballasts that cost more. Past problems with fluorescent lamps, such as flicker, buzzing and greenish color, no longer exist with electronic ballasts and modern phosphor choices.

*Figure 4-1. New small diameter T-5 fluorescent lamps shown next to an older, conventional T-12 fluorescent lamp.*[1]

Several different types of fluorescent lamps are worth noting. These are described in Table 4-3.

[1] Except where otherwise noted, photographs and other images in this chapter are provided courtesy of the High Performance Schools *Best Practices Manual,* available at www.chps.net.

*Table 4-3. Summary of fluorescent lamp technology.*

| Type of Lamp | Advantages & Disadvantages | Applications |
|---|---|---|
| T-12 | Relatively antiquated technology. Supplanted by newer technologies. | Some low temperature applications, such as food storage or display areas. |
| T-8 | Advantages include higher efficacy, more design options, better color rendering than T-12s. Newly available "premium" T-8 lamps offer higher color rendition, higher maintained lumens, and a 20% increase in lamp life over standard T-8s; very cost effective. | Most general lighting applications, including classrooms, offices, libraries, outdoor and industrial spaces. |
| T-5 | Similar performance to T-8 lamps, but more compact lamp envelope (5/8-in. vs. 1-in. diameter). T-5 luminaires should be well shielded to minimize glare. Electronic ballasts are necessary to achieve expected lamp life and performance. | Smaller profile luminaires. Especially effective in indirect luminaires, cove lighting systems, and wall washers. |
| T-5 High Output (T-5HO) | One T-5HO lamp produces nearly the equivalent light as two standard T-8 lamps, but somewhat less efficiently.<br>May allow designer to increase the spacing between direct/indirect luminaire rows, compared to a typical T-8 design, which allows use of fewer lamps and/or fewer luminaires, reducing lighting costs.<br>Currently more expensive than T-8 designs. | Like standard T-5 lamps, but may allow even smaller luminaires or better optical control and projection. |

**Fluorescent ballasts.** Electronic high frequency ballasts are now standard equipment for most fluorescent sources. In addition to their efficiency advantages, electronic ballasts reduce flicker and noise, and are available in a variety of ballast factor ratings, allowing the designer to "tune" light levels based on the ballast specification.

Here are some recommendations for fluorescent ballasts:

- Consider using reduced light output (RLO) electronic ballasts in building spaces where lower light levels will suffice. RLO ballasts have ballast factors of approximately 75% of rated light output (compared to about 88% for normal electronic ballasts and 93% for old magnetic ballasts). Applicable spaces might include corridors, restrooms, storage areas and similar spaces. The reduction in light output corresponds to lower input wattage, thus reducing lighting demand and energy use.

*Figure 4-2.*
*Electronic ballast.*


- Electronic ballasts for most fluorescent lamps employ one of two methods to start the lamps: rapid-start and instant-start. For maximum energy performance, use instant-start ballasts (for T-8 lamps only) in areas where the lights are unlikely to be switched frequently.
- In areas with more frequent switching, rapid-start ballasts maximize lamp life. "Programmed rapid-start" ballasts are the best type of rapid-start design, and are optimized for use with occupancy sensors or other frequent switching applications. They allow T-5 lamps to achieve rated lamp life, so they are the only type of T-5 ballast recommended.
- Dimming ballasts for fluorescent lamps require an additional investment, but increase lighting system performance by optimizing space appearance, occupant satisfaction, system flexibility and energy efficiency. Dimming fluorescent ballasts should be considered in all cases requiring maximum energy performance and light level control. They are particularly effective in medium to large daylit spaces, computer classrooms, audiovisual (AV) rooms, conference rooms and similar spaces.

**Compact fluorescent lamps.** Compact fluorescent lamps (CFLs) can be used in most applications that traditionally employed incandescent sources. CFLs offer excellent color rendering and quick starting. A large palette of different lamp configurations enhances design flexibility. Principal advantages of CFLs over incandescent sources include higher efficacy, color selection and longer lamp life. Dimming CFL ballasts are available for many CFL types, but they may be expensive.

*Figure 4-3. Compact fluorescent lamps. Photo: NREL.*

Use CFL lamps extensively in task and accent lighting applications, including wall washing, supplementary task lighting, and portable task lighting in computer environments. They are also valuable for medium- to low-level general illumination in spaces such as lobbies, corridors, restrooms, storage rooms and closets. They are quite suitable for outdoor corridors, step lighting, and lighting over doorways. High-wattage long CFLs can be used for general space illumination in recessed lay-in troffers (see the Luminaires section below), in wall-wash luminaires, and in more decorative luminaires for office lobbies, libraries and other spaces requiring a more "high-end" look.

### *High-Intensity Discharge Lamps (HID)*

HID lamps provide high efficacy in a wide variety of lamp wattages and configurations. In addition, they offer relatively long lamp life. There are basic types of high-efficacy HID lamps: metal halide (MH) and high-pressure sodium (HPS). The principal disadvantages to HID sources are that they start slowly, take time to warm up to full brilliance and suffer from significant lamp lumen depreciation. This makes them difficult to use in many automatic lighting control scenarios. In some applications, such as warehouses and vehicle maintenance areas, two-level dimming systems may be cost effective when evaluated from a

*Figure 4-4. High intensity discharge lamps.*

lifecycle cost perspective, but be prepared for reduced color performance and lamp life. Continuous dimming of HID lamps is expensive and generally not recommended.

Some of the traditional drawbacks to Metal Halide HID lamps are reduced with newer pulse-start technology and lamps with ceramic (or formed quartz) arc tubes. The pulse-start lamps reach full brightness more quickly, have longer life and are somewhat more efficient. The lamps with ceramic arc tubes may have better color stability.

***Light-Emitting Diodes (LEDs)***

LEDs are semiconductor devices that generate a monochromatic light. Commercially viable white LED sources are available today, using a phosphor-coated LED or by combining three primary-colored LEDs. The efficiency of the white light source is much higher than the tiny incandescent lamps that produce the same amount of light, but no better than a good tungsten halogen lamp. The principal advantages of LEDs over other lamps are their extremely long life and efficiency in producing colored light. As a result, they are cost effective in exit signs, traffic signals and other signaling devices.

LEDs are highly recommended for use in exit signs. The green and red LEDs used for exit signs offer high efficacy and very low maintenance costs when compared with either incandescent or fluorescent exit signs, and are available in most of the popular exit sign configurations. A two-sided LED exit sign can usually be illuminated with less than 5 watts, and may not require maintenance for 10 or more years.

Decorative lighting applications can make good use of LEDs, thanks to their vibrant color, low voltage, low maintenance and outstanding controllability. Some landscape or outdoor pathway lighting, with very low lighting levels, can also benefit. The very cool color of white LEDs can suggest moonlight, often desirable in outdoor hospitality applications.

***Energy-Efficient Choices***

Lamps convert electricity (watts) to light energy (lumens), and most modern lamps require a ballast to start the lamp and regulate power flow into the lamp. The efficacy of the conversion is measured in lumens of light output divided by watts of electric power input (L/W). The input watts include both the lamp and the ballast. In general, it is best to use the system with the highest possible efficacy that is suited for the project.

Most electric lamps emit less light as they age; this is called *lumen depreciation.* The lumen depreciation of certain lamp types has improved significantly. New metal halide lamps, for example, use pulse start to improve lumen depreciation, and the best fluorescent lamps depreciate only slightly. Lamp ratings for mean lumens are at 40% of rated lamp life, and reflect the typical light output over life.

Table 4-4 gives the mean lumens per watt (MLPW) for a variety of lamp/ballast systems and may be used to select light sources. Be careful to follow it closely to get the best value. For instance, "premium" T-8 lamps are the best overall choice for most applications, and you can use 835 (neutral color), 830 (warm color) or 841 lamps (cool color) and get the same efficacy. But if you substitute 735 color (which costs less initially), the MLPW drops significantly.

In terms of efficiency, MLPW is a good indicator of average performance. But when choosing lamps to provide a specific illumination, it’s important to consider the "design lumens." Design lumens are rated at 75% of lamp life, the usual economic point for group relamping. Since owners will replace lamps at this point, design lumens are the practical minimum output that an owner will encounter and therefore the best lamp lumen rating to establish minimum light levels. Consult manufacturers’ literature to determine design lumens.

*Table 4-4. Lamp application guidelines.*

| MLPW | Lamp Type | CRI | Ballast | Good Applications | Limitations |
|---|---|---|---|---|---|
| **92** | T-5 standard 4-ft lamps (F28T5/835) | 86 | Electronic and electronic dimming | Specialty lighting such as valances, undercabinet, coves, wall washing. | Not for troffers or other direct viewing. |
| **90** | T-8 premium 4-ft lamps (F32T8/835) | 86 | Electronic and electronic dimming | General lighting. The lowest cost system available, especially with low ballast-factor ballasts. | Larger than T-5 lamps. |
| **87** | T-8 premium 8-ft lamps (F96T8/835) | 86 | Electronic | General commercial and institutional lighting, especially for retrofits. | 4-foot lamp system may cost less. |
| **81** | T-5HO high output 4-ft lamps (F54T5/835) | 86 | Electronic and electronic dimming | Indirect office ltg; high ceiling industrial ltg; specialty applications: coves, wall washing. | Very bright lamps should not be visible unless mounted very high. |
| **79** | T-8 premium “U”-bent lamps (F32T8/U/835) | 86 | Electronic and electronic dimming | Recessed 2 ft x 2 ft commercial lighting. | More expensive than straight lamps. |
| **78** | T-5 twin tube (“biax”) 40–50W (FT40T5/835) | 82 | Electronic and electronic dimming | Track-mounted wallwashing and display lighting. | More expensive than straight lamps. Can be too bright in open luminaires. |
| **78** | Metal halide lamps, pulse start, 450-watt class | 65 | Magnetic CWA (constant wattage auto-trans-former) | General high-bay lighting for gyms, stores, and other applications to about 30 ft; parking lots. | Long warm up and restrike times; poor lumen maintenance. |

Continued --->

| MLPW | Lamp Type | CRI | Ballast | Good Applications | Limitations |
|---|---|---|---|---|---|
| **75** | T-8 premium 2-ft lamps (F17T8/835) | 86 | Electronic and electronic dimming | General commercial lighting; 2-ft luminaires. | Cost more than 4-ft lamps; not as efficient. |
| **67** | Metal halide lamps, pulse start, M137 (175W class) | 65 | Magnetic CWA | Parking lots, outdoors, roadway lighting. | Long warm up and restrike times prevent rapid switching. |
| **63** | Metal halide lamps, pulse start, ED-17 M140 (100W class) high CRI | 85 | Electronic or magnetic HX (high reactance) or CWA | Recessed and track-mounted display lighting. | May not be suitable for general illumination due to lamp cost; long warm up and restrike times prevent rapid switching. |
| **62** | Compact fluorescent 18–42W triple | 82 | Electronic and electronic dimming | Downlights, sconces, wall washers, pendants and other compact lamp locations; can also be used outdoors in most climates. | More costly than some other fluorescent lamps. |
| **20** | Halogen infrared reflecting lamps in PAR-30, PAR-38, MR16 and T-3 shapes | 100 | None required | Localized accent ltg and where full range dimming is required such as fine restaurants, hotels, high-end retail. | Halogen lamps should be used only in limited amounts. Halogen IR lamps can be cost effective compared to standard halogen lamps. |

Notes: MLPW = mean lumens per watt

### Luminaires

Luminaires — or light fixtures — generally consist of lamps, lamp holders or sockets, ballasts or transformers (where applicable), reflectors to direct light into the task area, and/or shielding or diffusing media to reduce glare and distribute the light uniformly. There is an enormous variety of luminaire configurations. This section briefly outlines some of the more important types for commercial building lighting design.

**Recessed luminaires.** Recessed luminaires represent a large segment of the overall luminaire market. There are two basic variations: lay-in troffers and downlights. Lay-in troffers replace some tiles in a dropped ceiling, and are primarily used as a direct general light source. Downlights are relatively compact luminaires used for wall washing, accent lighting, and supplemental general or task illumination, as well as for lower levels of ambient illumination.

**Suspended luminaires.** Suspended indirect or direct/indirect luminaires are the preferred luminaires for lighting classrooms, offices, administrative areas, library reading areas, computer work areas and other spaces with taller ceilings. Typically these luminaires employ T-8, T-5 or T-5HO lamps, and often mount in continuous row configurations. See the Pendant-Mounted Lighting Guideline later in this chapter. Low ceilings may preclude this design.

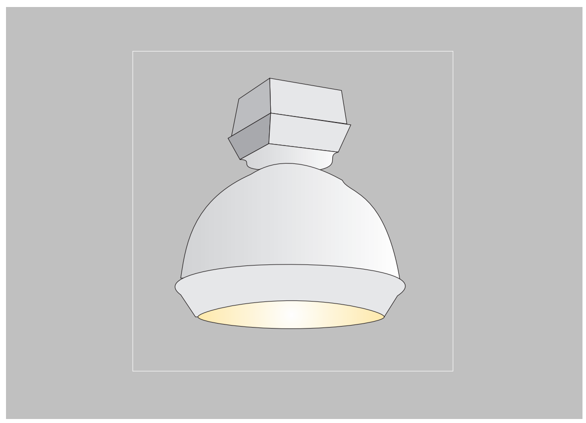


*Figure 4-5. Low-bay HID luminaire.*

**Suspended high-ceiling luminaires.** Both fluorescent and HID suspended luminaires are useful for illuminating building spaces with high ceilings. HID luminaires can be classified as either high bay (>25 ft mounting height) or low bay. Multi-lamp fluorescent luminaires employ up to eight lamps to approximate the light output of an HID luminaire, while allowing for additional control flexibility. Linear hooded industrial fluorescent luminaires can be extremely effective at lighting high ceiling spaces.

**Surface-mounted luminaires.** Surface-mounted fluorescent, compact fluorescent and HID luminaires are valuable for wall and ceiling mounting situations, particularly when ceiling access is a problem.

**Specialty luminaires.** Several specialty luminaires are available for specific lighting applications. These include wall-washing luminaires to accent or brighten walls and features; task lighting luminaires to supplement general illumination; damp or wet location luminaires for exterior areas open to the elements; and high-abuse luminaires designed to withstand vandalism in institutional environments.

**Exit signs.** Numerous exit sign configurations are available. LED exit signs offer the best value for minimizing energy use and maintenance. However, compact fluorescent exit signs may be preferable when an additional downlight component is desired.

**Design and Analysis Tools**

Several high quality analysis tools exist to help professionals design lighting systems. The simplest of these programs provide rudimentary zonal cavity calculations to predict average horizontal footcandles, while the most sophisticated tools can handle advanced calculations and produce realistic renderings.

Many of the major luminaire manufacturers offer standard computational software that can predict the performance of their (or other manufacturers') luminaires in typical lighting designs. Usually these programs can calculate horizontal and vertical illuminance for a number of points within the space. Some can produce renderings as well. Most can export output to AutoCAD.

Companies that specialize in lighting software offer the most sophisticated lighting software packages. These products are typically more robust than the manufacturer-provided packages, and can handle more complex problems, such as surface luminances, daylight effects, irregularly shaped rooms, and high resolution rendering.

Lighting software products include: AGI (Lighting Analysts); LitePro (Columbia Lighting); Genesys (Lightolier); Lightscape (Autodesk); Visual (Lithonia); and LumenMicro (Lighting Technologies).

**Operations and Maintenance**

Appropriate maintenance is critical to the performance, lighting quality, and energy efficiency of lighting systems. Establishing proper maintenance procedures is as much a responsibility of the lighting designer as it is of the person who changes spent lamps. A good lighting maintenance plan should be included with the building specifications.

### *Luminaire Cleaning and Troubleshooting*

Thoroughly clean luminaires at regular intervals. Regular maintenance ensures that the lighting system will continue to perform as designed, thereby maximizing lighting quality and space appearance. When cleaning luminaires, maintenance personnel should also check for and replace any broken or malfunctioning equipment, such as lenses, louvers and ballasts.

### *Group Relamping*

Lighting systems perform best when they are maintained at regular intervals. Group relamping is a maintenance strategy aimed at maximizing lighting system performance and economy by changing out all lamps at regular intervals, just before the start of the highest failure period. While some spot relamping is usually required to maintain appearance and illumination due to occasional early lamp failures, spot relamping by itself is normally labor intensive and therefore expensive. In the long run, group relamping reduces the cost of lighting system components through simple economies of scale. Furthermore, relamping luminaires at regular intervals maintains light levels and lighting quality according to design intent. For best economy, group relamping should usually be combined with luminaire cleaning and troubleshooting.

### *Specifications*

Lighting designers have a number of specification tools available to promote proper maintenance and reduce maintenance costs. For example:

- Specify premium T-8 lamps whenever possible to extend lamp life by 20%.
- Limit the number of different lamp types specified. This will simplify maintenance and allow for reduced backup inventory.
- Include specification language that requires the builder to supply the owner with manuals for occupancy sensors and other automatic control hardware.
- Include a maintenance manual (see below) in the lighting specification.

### *Maintenance Manual*

Include a detailed maintenance package with the building specifications. At a minimum the package should contain the following:

- As-built plans showing the installed lighting systems
- Luminaire schedule that includes detailed lamp and ballast information
- Luminaire cut sheets
- Lamp inventory list, including recommended stocking quantities

- Manufacturer data for all lighting controls, including operating documentation and tuning procedures
- Procedures and schedule for maintaining lighting controls
- Luminaire cleaning and troubleshooting procedures
- Group relamping procedure and schedule
- Lamp recycling plan and contacts

***Lamp Disposal and Recycling***

Mercury is a toxic element and there are significant concerns about mercury being emitted into the atmosphere or released into groundwater when fluorescent lamps are improperly discarded. On average, fluorescent lamps manufactured in 2001 contain 8.3 milligrams of mercury per 4-ft lamp. This is a considerable reduction from about 40 milligrams a decade ago but still a potential health hazard.

The U.S. Environmental Protection Agency has declared that used lamps containing mercury are hazardous materials, requiring special handling in many cases. This applies to linear and compact fluorescent lamps, and in many cases may also apply to high-intensity discharge (HID) lamps. Exceptions to the EPA standards are lamps that have been tested through the Toxic Characteristic Leaching Procedure (TCLP) to show that they do not exceed specific contamination limits when discarded in a landfill.

Small users that dispose of less than 100 kilograms total of hazardous waste per month are exempt from EPA disposal regulations; their spent lamps may be disposed of in landfills, although it is much more ecologically responsible to recycle them. Current costs for recycling fluorescent lamps average about $0.06 per linear foot (when shipped to the recycling facility). When preparing a maintenance plan for a lighting system, it is advisable to include lamp recycling.

For demolition and renovation projects, lamps should be recycled where local recycling options are available. Contact the Hawaii Department of Health, Solid and Hazardous Waste Branch, tel. 808-586-4226, for details.

We recommend using lamps that pass the EPA TCLP test to minimize the use of mercury. Also, we recommend recycling all lighting products that contain mercury in order to minimize the mercury that enters our environment. Some old lighting ballasts may contain toxic PCBs; these need proper disposal.

Note that lamp disposal requirements are subject to change, and it is always a good idea to check on current regulations.

**Commissioning**

For information about commissioning lighting systems, see the Lighting Controls Guideline.

**Utility Programs**

Incentives may be available for specific lighting equipment or systems. Contact your local utility as early as possible in the design process to take advantage of existing incentive programs.

**Resources**

*Advanced Lighting Guidelines,* 2001, New Buildings Institute. Web site: www.newbuildings.org.

*High Performance Schools Best Practices Manual,* 2002, Coalition for High Performance Schools (CHPS). Web site: www.chps.net.

*Daylighting Design: Smart and Simple,* 1997, by R.A. Rundquist, T. McDougal, Palo Alto, CA: Electric Power Research Institute (EPRI). EPRI report #TR109720. Web site: www.epri.com.

*IESNA Lighting Handbook,* 9th edition, Illuminating Engineering Society of North America. Web site: www.iesna.org.

*Lighting Controls: Patterns for Design,* 1996, by R.A. Rundquist, T. McDougal, J. Benya. Palo Alto, CA: Electric Power Research Institute (EPRI). EPRI report #TR107230. Web site: www.epri.com.

## Pendant-Mounted Lighting

**Recommendation**

In rooms having a ceiling at least 9.5-ft high, consider suspended fluorescent lighting having either:

- A semi-indirect or indirect distribution and at least 85% luminaire efficiency, using T-8 premium or T-5 lamps and electronic ballasts and a connected lighting power of 0.8 to 1.3 W/ft²; or
- Direct/indirect distribution and at least 75% luminaire efficiency, using T-8 premium or T-5 lamps and electronic ballasts and a connected lighting power of 0.8 to 1.1 W/ft².

**Description**

There are several types of suspended fluorescent luminaires, which are classified according to the amount of uplight and downlight they provide.

- Direct/indirect luminaires can provide relatively even illumination on ceiling, walls and floors by adding a little direct light to the indirect component.

- Indirect luminaires illuminate a space by reflecting light from the ceiling.

With a direct/indirect luminaire, a light-colored ceiling is preferred to take advantage of the uplight. The suspension length for direct/indirect lighting is less critical than for indirect lighting.

In an indirect luminaire, the amount of uplight is at least 90% of the total light output. The downlight is generally intended to create a sense of luminance, but most of the illumination in the room is caused by reflected light from the ceiling. Indirect lighting requires a high reflectance ceiling and a minimum suspension length of 12 in., with 18 in. or more strongly preferred.

In both cases, affordable luminaires may have steel bodies and steel or plastic louvers. More sophisticated luminaires employ extruded aluminum housings, but this generally costs significantly more. Likewise, T-5 and T-5HO lighting systems will cost more than T-8, and these very bright lamps may create glare when used in any direct lighting component.

**Applicability**

Pendant-mounted lighting is appropriate for offices, classrooms, libraries, multi-purpose spaces, lobbies, and administration spaces that have a high enough ceiling.

**Codes and Standards**

See the Codes and Standards section of the General Lighting Guidelines above.

**Benefits**

Direct/indirect lighting systems often offer a combination of efficiency and visual comfort, and make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 W/ft² (with a very reflective ceiling) will generate between 40 and 50 footcandles, maintained average, with excellent uniformity. Indirect lighting systems are generally less efficient, requiring 1.1–1.2 W/ft² to achieve 40 to 50 footcandles.

**Integrated Design Implications**

Suspended lighting systems can work well with almost all ceilings that are at least 9.5 ft high. However, avoid dark ceilings such as stained wood or highly colored paint, or areas with many ducts or louvers that can absorb large amounts of light. For direct/indirect luminaires, ceilings should be light colored. For indirect luminaires, ceilings must be high-reflectance white or off-white, as should be upper walls. If the room has an extremely high ceiling, such as with a sawtooth clerestory, use a direct/indirect luminaire with a greater percentage of downlight (50% or more).

**Design Details**

Pendant-mounted lighting provides good general lighting throughout a room. Some types of direct/indirect lighting are optimized for computer screen work, although they tend to be expensive. It may be necessary to provide separate wall-wash lighting for display areas or separate chalkboard illumination in classrooms, especially if the suspended lighting system is manually dimmed. For T-8 lamps, be certain to use premium types with 835 or 841 color, rated 24,000 hours. For non-dimming applications, luminaire light and power can be tuned through choice of ballast factor.

**Design and Analysis Tools**

Although minimally acceptable results will be obtained using the zonal cavity (lumen ) method, a modern point-by-point computer program will provide much more information and confidence. See the General Lighting Guidelines above for more about design and analysis tools.

**Costs**

Suspended lighting systems costs are shown in Table 4-5.

*Table 4-5. Pendant-mounted lighting system costs.*

| Lighting System Type | Cost per Lineal Foot, Installed* |
|---|---|
| Steel indirect luminaires, 90%+ uplight, T-8 lamps, non-dimming | $42 |
| Steel direct/indirect luminaires, plastic louvers, 65% uplight, T-8 lamps, non-dimming | $48 |
| Steel direct/indirect luminaires, steel louvers, 50% uplight, T-8 lamps, non-dimming | $54 |
| Extruded aluminum luminaires, parabolic louvers, 75% uplight, T-8 lamps, non-dimming | $60 |
| Add for dimming ballasts using standard 0–10 volt type | $14–18 |

*Approximate cost to owner, including labor, materials (luminaires, lamps and suspension hardware) and costs of construction. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 mainland prices, marked up by 20% to account for additional shipping costs to Hawaii. Costs vary depending on market conditions.

**Cost Effectiveness**

Suspended lighting systems are highly cost effective in most applications. Non-dimming, indirect steel luminaires are the lowest cost, but optimum solutions are generally steel luminaires with steel or plastic louvers with 35% to 50% downlight.

**Operations and Maintenance**

These lighting systems rarely need extra maintenance. As with all fluorescent systems, lamps should be group-replaced at approximately 18,000 to 21,000 hours of operation (based on a 24,000-hour life rating). Luminaires should be cleaned annually. Open-louvered luminaires, especially using plastic louvers, require less cleaning and are more tolerant of poor maintenance and abuse.

**Commissioning**

None, other than preconditioning lamps in dimming applications. Controls, such as dimming or occupancy sensors, need to be commissioned. See the commissioning section of the Lighting Controls Guideline.

**Utility Programs**

Incentives may be available for specific lighting equipment or systems. Contact your local utility as early as possible in the design process to take advantage of existing incentive programs.

**Case Study**

The office at Pearlridge Elementary School uses pendant-mounted fixtures to complement the high ceiling and create a bright and open feeling. The direct/indirect luminaires provide good task light while also illuminating the ceiling. The result is very even illumination that improves visual performance compared to a direct lighting design with the same lighting level. Installed lighting power is less than 1.0 watt per square foot.

*Figure 4-6. Direct/indirect luminaires at Pearlridge Elementary School office. Photo: Erik Kolderup, Eley Associates.*

## Recessed Lighting

**Recommendation**

Use recessed lighting in low-ceiling spaces where pendant-mounted lighting is inappropriate or when the budget is limited. Use fluorescent lens troffers with at least 78% luminaire efficiency, T-8 premium lamps and electronic ballasts, and a connected lighting power of 0.9 to 1.1 W/ft².

**Description**

Luminaires recessed into the ceiling provide ambient lighting. While recessed luminaires may include incandescent, compact fluorescent and metal-halide lamps, the most common type of recessed lighting in commercial buildings is the fluorescent troffer.

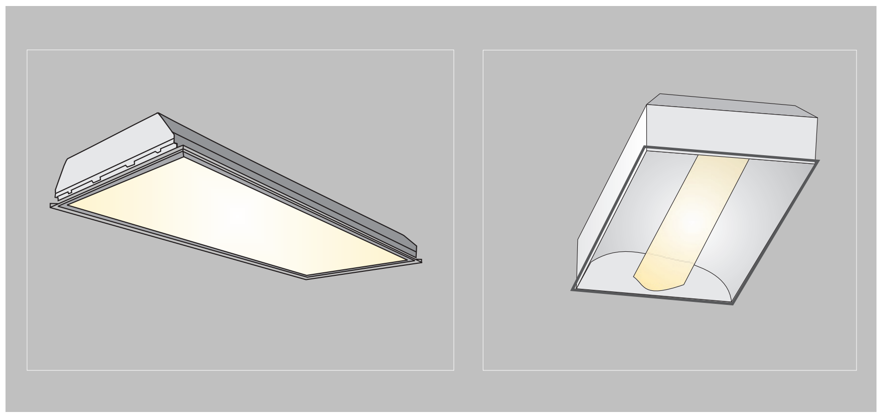


*Figure 4-7. Lensed recessed troffer (left) and industrial recessed troffer (right).*

Fluorescent troffers are designed to "lay-in" in place of an acoustical tile in suspended T-bar ceiling systems. The most common and cost-effective size is 2 ft x 4 ft. Less common sizes include 2 ft x 2 ft and 1 ft x 4 ft. The luminaire typically contains two T-8 lamps (some contain three, four or six lamps, but the two-lamp version is more efficient and allows better uniformity, especially with low ceilings). The interior reflector should be either high-reflectance white paint or specular (highly polished) silver coating or aluminum. Silver, special aluminum and the best white paint all reflect approximately 95% of incident light on internal optical surfaces, increasing room illumination without using more energy.

The lens may be an industry standard "Pattern 12" prismatic acrylic lens, with a minimum lens thickness of .125 in. to provide durability and to prevent glare-inducing lens sag. For specific applications, other lenses, good louvers or both may provide better luminance control. The luminaires can be configured in rows, although in spaces such as classrooms many architects prefer a "donut" configuration.

There are a number of variations among troffers. These include:

- *Quality or price class.* A "specification grade" troffer is generally deeper, heavier gauge metal, includes better hardware and costs more. A basic troffer may work just as well, but it is flimsier and may use a lower performance reflector and other materials.
- *Door type.* Recessed troffers without doors may be difficult to maintain, adding labor costs. A flat steel door with butt joints costs the least; a regressed aluminum door with mitered corners costs quite a bit more. The regress may provide some glare relief.
- *Static,* meaning that the luminaire is basic and enclosed; *heat extraction*, meaning the luminaire is designed to draw air through the luminaire and heat into the ceiling plenum above; and *air handling*, in which the luminaire can be connected to special HVAC supply or return devices. The cost of HVAC attachments is high, and they do not eliminate the need for conventional HVAC diffusers and grilles. Careful heat extraction design can optimize lamp and ballast temperature and therefore luminaire output. But since electronic ballasts and efficient lamps generate much less heat than old magnetic ballasts and T-12 lamps, there may no longer be a need for heat extraction.

Lens troffers do not illuminate the ceiling and upper walls well, and may not provide appropriate lighting quality for some tasks. They are also essentially the same luminaire style as used in many institutional buildings, contributing to an ordinary, cheap-looking appearance. Premium lenses can improve both appearance and performance, but better luminaire selection can result in even more improvement for a similar cost.

**Applicability**

Recessed lighting is appropriate for offices, classrooms, libraries, multi-purpose spaces, administration spaces, and some retail, storage and industrial applications.

**Codes and Standards**

See the Codes and Standards section in the General Lighting Guidelines above.

**Benefits**

Recessed troffer lighting systems generally offer excellent efficiency, but usually with some loss of visual comfort. They make excellent use of the low-cost, widely available T-8 lamps. Systems operating at about 1.0 W/ft² will generate between 50 to 60 footcandles maintained average, with very good uniformity.

**Integrated Design Implications**

This type of lighting is primarily used in flat acoustic tile ceilings, and then only when ceiling height and/or budget precludes other options.

**Design Details**

Recessed fluorescent troffers provide general downlighting throughout a room. However, lens troffers may cause problems for computer workspaces due to reflections on computer screens. Employ premium T-8 lamps with 835 or 841 color, rated 24,000 hours.

For non-dimming applications, luminaire light and power can be varied through careful choice of ballast factor.

**Design and Analysis Tools**

A modern lighting point-by-point calculation program should be used. However, minimally acceptable results may be obtained using the zonal cavity calculation method. For more about design and analysis tools, see the General Lighting Guidelines.

**Costs**

Recessed lighting systems will cost about $140 per luminaire[2] for basic, white reflector luminaires with #12 lens, two premium T-8 lamps, and electronic ballast. A dimming ballast will add about $45–$55 to each luminaire.

**Cost Effectiveness**

Lens troffer lighting systems are extremely low cost, but their inexpensive appearance can be a drawback.

**Operations and Maintenance**

These lighting systems rarely need extra maintenance. As with all fluorescent systems, lamps should be replaced at approximately 18,000 to 21,000 hours of operation (based on 24,000-hour lamp rating). Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and occasional lens replacement (acrylic lenses last far longer than styrene).

**Commissioning**

None, other than preconditioning lamps in dimming applications. Lighting controls used with recessed luminaires need commissioning; see the commissioning section of the Lighting Controls Guideline.

**Utility Programs**

Incentives may be available for specific lighting equipment or systems. Contact your local utility as early as possible in the design process to take advantage of existing incentive programs.

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[2] Approximate cost to owner, including labor, materials (luminaires, lamps, and suspension hardware) and costs of construction. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 mainland prices, marked up by 20% to account for shipping costs to Hawaii. Costs vary depending on market conditions.

## Surface-Mounted Lighting

**Recommendation**

Use surface-mounted lighting in rooms that do not have recessed or suspended lighting systems. There are several possible circumstances:

- Ceiling height is 8.5 ft or less, preventing use of suspended luminaires.
- Ceiling cavity is impenetrable because of, for example, the presence of asbestos or roof insulation.
- The space design employs a hard ceiling surface, such as concrete, that is impenetrable or has only a moderate reflectance.

When using surface-mounted lighting, there are two good choices:

1. Use short stem-mounted semi-direct fluorescent luminaires having at least 65% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 1.1 to 1.2 W/ft².

2. Use surface-mounted fluorescent lens troffers having at least 78% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 0.9 to 1.1 W/ft².

**Description**

Surface-mounted semi-direct luminaires provide general downlighting in a space, as well as some uplighting of the ceiling surface. They are versions of direct/indirect luminaires designed for short stem mounting. In general, this means a luminaire that is mounted very close to the ceiling, no more than 6 in. or so from the ceiling to the lowest part of the luminaire. A small percentage of uplight illuminates the adjacent ceiling with a minimum amount of light to prevent a hot spot.

*Figure 4-8. Surface-mounted troffer.*

These T-8 lamp luminaires require some form of downlight shielding. Louvers and lenses are the two most likely choices.

In general, the layout of surface-mounted semi-direct luminaires will be similar to the layout for suspended lighting systems. This will result in higher light levels with a slight sacrifice in lighting quality.

Surface-mounted direct luminaires are similar to recessed troffers, but they have finished box enclosures. The most common and cost-effective size is 2 ft x 4 ft; less common sizes include 2 ft x 2 ft and 1 ft x 4 ft. As with recessed troffers, inside the box there are two T-8 lamps.

The interior reflector should be either high-reflectance white paint or specular (highly polished) silver coating or aluminum. High-reflectance materials may increase the cost considerably but they also increase luminaire efficiency. Silver, special aluminum and the best white paint all reflect approximately 95% of incident light on internal optical surfaces, increasing room illumination without using more energy.

The lens may be an industry standard "Pattern 12" prismatic acrylic lens, with a minimum lens thickness of .125 in. to provide durability and to prevent glare-inducing lens sag. For specific applications other lenses, good louvers or both may provide better luminance control. Other variations applicable to troffers — such product grade and door type — also apply.

**Applicability**

Surface-mounted luminaires are typically used where it isn't practical to recess a luminaire into a surface. An example of this is a cast concrete corridor, with a simple recessed electric box. The surface-mounted luminaire is connected to the box and bolted to the box or concrete surface.

**Codes and Standards**

See the Codes and Standards section of the General Lighting Guidelines.

Suspended luminaires need to be restrained in case of an earthquake. For short-stem luminaires, the luminaire usually cannot swing, but support independent of the ceiling system is still needed.

**Benefits**

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 W/ft² will generate between 50 to 60 footcandles maintained average, with very good uniformity.

**Integrated Design Implications**

Use surface-mounted lighting systems only in very specific applications. Pursue the pendant-mounted and recessed lighting strategies first; use surface-mounted luminaires only when ceiling issues preclude other options.

**Design Details**

Surface-mounted lighting systems provide general lighting throughout a room. However, lensed luminaires are not recommended for computer workspaces. Be certain to use premium T-8 lamps with 835 or 841 color, rated 24,000 hours.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor.

Refer to the Pendant-Mounted Lighting Guideline and the Recessed Lighting Guideline for information about using semi-direct and surface-mounted direct luminaires — the design details described there also apply to surface-mounted luminaires.

**Design and Analysis Tools**

A modern lighting point-by-point calculation program should be used. However, minimally acceptable results will be obtained using the zonal cavity (lumen) calculation method.

For more about design and analysis tools, see the General Lighting Guidelines.

**Costs**

Surface-mounted lighting systems will cost about $240 per luminaire[3] for basic, lensed, white reflector direct luminaires with .125 in. lens, two premium T-8 lamps and an electronic ballast. Aluminum surface luminaires will probably cost a bit more, perhaps $280 each. A dimming ballast will add about $45–$55 to each luminaire.

**Cost Effectiveness**

Surface-mounted lighting systems are relatively expensive compared to recessed troffers but may still offer a good value.

**Operations and Maintenance**

These lighting systems rarely need extra maintenance. As with all fluorescent systems, lamps should be replaced at approximately 18,000 to 21,000 hours of operation (based on 24,000-hour lamp rating). Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and occasional lens replacement (acrylic lenses last far longer than styrene).

**Commissioning**

No commissioning is needed, other than preconditioning lamps for dimming applications. See the Lighting Controls Guideline for information about commissioning lighting controls.

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[3] Approximate cost to owner, including labor, materials (luminaires, lamps, and suspension hardware), and costs of construction. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 mainland prices, marked up by 20% to account for shipping costs to Hawaii. Costs vary depending on market conditions.

**Utility Programs**

Incentives may be available for specific lighting equipment or systems. Contact your local utility as early as possible in the design process to take advantage of existing incentive programs.

## Lighting Controls

**Recommendation**

Use lighting controls to reduce lighting energy use, ensure good lighting quality and offer occupants better control of their lighted environment.

**Description**

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques range from simple to extremely sophisticated. Lighting control strategies are most successful when the people who use them easily understand how to operate them. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent.

Finally, regularly scheduled maintenance of control equipment will improve the system's long-term success. Poorly designed, commissioned or maintained automatic lighting controls can actually increase lighting energy use, and will cause user dissatisfaction.

Control devices include switches and dimmers, occupancy sensors, time controls, photoelectric controls, and energy management systems. Different control devices will be appropriate depending on the specific application.

**Switches.** Manual switches are the simplest form of user-accessible lighting control. Manual switches are especially valuable in daylit spaces because they allow people to turn off electric lights when daylight is adequate. Manual switches should also be installed in spaces with occupancy sensors (they may be an integral part of the control). This increases the energy savings of occupancy sensor controls by allowing people to turn off the lights when they are not needed.

**Manual dimmers.** Next to standard wall switches, manual dimmers are the simplest of lighting control devices. Manual dimmers serve two important functions. First, dimming the lights reduces lighting demand and energy use. With incandescent and halogen sources, there is the additional benefit of extended lamp life (dimming a halogen lamp too low, however, may cause lamp blackening). Second, and more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort. Consider manual dimmers (combined with dimming ballasts, where applicable) for many building spaces, including classrooms, computer workrooms and office spaces.

*Figure 4-9. Dual-technology occupancy sensor.*

**Occupancy sensors.** Occupancy sensors automatically shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Some sensors employ both passive infrared and either ultrasonic or microphonic detection.

Mounting configurations include simple wallbox sensors appropriate for small spaces such as private offices, and ceiling- or wall-mounted sensors that provide detection of areas up to 2,000 ft$^2$.

Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied. Good applications include classrooms, private offices, conference rooms, restrooms and storage areas. Use occupancy sensors in combination with manual overrides whenever possible to maximize energy savings, space flexibility, and occupant satisfaction. Careful control specification can preclude annoying events, such as the lights turning off prematurely in a restroom.

*Figure 4-10. Digital time switch.*

**Time controls.** Time controls save energy by reducing lighting time of use through preprogrammed scheduling. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones. Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable. Candidate building spaces include classrooms, offices, auditoriums and exteriors.

Be sure to keep a summary of the programming instructions with the time controls so that the maintenance staff doesn't need to search for the instructions when recovering from some failure.

**Photoelectric controls.** Photoelectric controls employ a photosensor and logic controller to control lights in daylit spaces. The logic controller processes a signal from the photosensor and sends a dimming or switching signal to the lighting circuit based on the monitored light level. Open-loop systems "see" only daylight, while closed-loop systems monitor both daylight and the light emitted by the luminaires they control. Successful use of photoelectrically controlled lighting systems requires careful design, installation and commissioning, as well as a commitment to the long-term maintenance of the system. Without these elements, energy savings are rarely sustainable.

In areas with ample daylight, such as outdoors, a simple photoelectric switch can ensure that lighting is off during daylight hours. Even though the switch is simple, it may occasionally fail or need other maintenance. Without periodic performance verification and maintenance, even a simple control problem can cause significant increases in lighting costs.

**Energy management systems (EMS).** Typically when lighting is controlled through an EMS it is via a time clock. However, many building operators take advantage of the built-in EMS functions to monitor lighting usage on a space-by-space basis. EMS control of lighting systems may also allow building operators to shed non-essential lighting loads during peak demand periods, or even dim some of them to reduce electric load.

**Applicability**

Lighting controls are recommended for a wide variety of commercial building types, including offices, warehouses, retail stores, schools, and assembly and light manufacturing facilities.

**Codes and Standards**

Building energy codes adopted in Oahu, Hawaii, and Kauai include minimum requirements for lighting controls. The type and number of controls required depends on the type and size of the space being lighted. In some cases multi-level switching or occupancy sensors may be required. Details are available in the Hawaii Model Energy Code Application Manual available on the Internet at http://www.hawaii.gov/dbedt/ert/model_ec.html. Software called Hilight is also available to assist with documenting lighting controls compliance and may be downloaded at http://www.hawaii.gov/dbedt/ert/mec/app-b.html.

**Benefits**

Lighting controls can reduce energy consumption by 50% in existing buildings and at least by 35% in new construction. As a rule of thumb, every watt saved in lighting saves an additional 1/10 to 1/4 watt in avoided HVAC energy.

In addition to saving energy, lighting controls can improve occupant satisfaction and comfort by giving people the ability to change the light levels around them in response to changing tasks, moods or other conditions. Also, today's workers move around often, changing tasks, workspaces and even jobs more frequently than they once did. A flexibly controlled lighting system can accommodate these changes with minimal disruption and expense.

**Design Details**

**Design for flexibility.** Design lighting controls to accommodate the varying nature of spaces (such as office conference rooms, auditoriums, and spaces used for multiple tasks like AV presentations, performances and meetings).

- Bi-level or multiple-level switching enables the selection of different light levels to respond to changing requirements.
- Separate circuiting of luminaires in daylit zones enhances space flexibility and energy savings.
- Control flexibility improves lighting energy performance by encouraging only the use of lights that are needed for the activity at hand.

**Design for occupant satisfaction.** Design lighting controls so that they are accessible and easy to understand, and so that occupants can override automatic controls where appropriate.

- In spaces such as private offices, give occupants the ability to override automatic dimming or occupancy sensor controls, so that they can switch the lights off manually when they need to.
- In multipurpose spaces, consider designing several different lighting control schemes to account for different activities. It may make sense to specify a preset dimming or switching system allowing one-button scene changing.
- Make lighting control systems easy to understand and operate. Non-intuitive control interfaces are likely to be ignored or disabled.
- With automatic controls, make sure that occupancy sensors and daylighting controls are not set so that lights shut off at inappropriate times or cycle on and off too frequently, or occupants may complain and even disable the controls.

- Be proactive about asking users if they like the controls that affect them. Respond to issues or complaints promptly.

**Design and Analysis Tools**

There are few useful design tools in this evolving field. Controls manufacturers and their representatives can usually provide the best information.

**Costs**

Manual controls cost less than automatic controls. Automatic controls typically have higher installation and maintenance costs, but can save a significant amount of energy in large buildings by ensuring that the optimum amount of illumination is provided in public spaces where manual controls may not be used effectively.

The choice of dimming versus switching can have major first-cost implications, especially in retrofit situations. Special dimming ballasts are required for fluorescent and HID lamps, but the cost of fluorescent dimming (or controllable) ballasts is about twice that of equivalent non-dimming ballasts. HID dimming ballasts can be much more expensive. Multi-level ballasts, either fluorescent or HID, are less expensive than equivalent dimming ballasts, but may not give users the feeling of total control.

**Cost Effectiveness**

Controls are an evolving area of building technology. At present, cost effectiveness is good, but initial costs for some types seem relatively high. Still, lighting upgrades in existing buildings are usually more cost effective than HVAC improvements. In new buildings, lighting controls can reduce the effective lighting power density so that a smaller HVAC unit can be installed, saving on first costs.

- *Manual controls* are cost effective in small spaces such as private offices.
- *Automatic controls* are more cost effective than manual controls in shared spaces such as lobbies and break rooms where an individual occupant wouldn't usually feel responsible for turning off or dimming the lights. *Switching* hardware is relatively simple and generally very cost effective.
- The cost effectiveness of *occupancy sensors* varies depending on the overall energy management skills and interests of the occupants. People who are personally careful about turning lights off when they're not needed will generally outperform occupancy sensors, but for less well-managed spaces, occupancy sensors are worthwhile.
- *Daylight sensors* and dimming ballasts are worthwhile if the daylighting is designed correctly.

**Operations and Maintenance**

A properly commissioned lighting control system needs only periodic maintenance to ensure optimum performance. Refer to the manufacturer's recommended recalibration and cleaning cycle for sensors.

Make sure the maintenance staff understands the control system operation, as well as commissioning, maintenance and design goals. It will be up to the maintenance staff to ensure that the system is working for the building occupants. Poorly trained staff can create more problems and resultant costs than no controls at all.

**Commissioning**

All automatic lighting control systems must be tuned after installation to ensure optimal performance and energy efficiency. Malfunctioning automatic control systems waste energy and will disturb occupants. Systems that work properly will be left to do their job; systems that have false tripping and other unwanted behavior will end up disconnected or bypassed.

Commissioning of occupancy sensor systems and daylighting controls is critical to their success. Here are some good rules of thumb:

- *Dimmed fluorescent lamps:* Fluorescent lamps must be seasoned for 100 hours at full light output prior to being dimmed. Dimming the lamps before completing this "burn in" period can significantly reduce lamp life.
- *Occupancy sensors:* Occupancy sensors must be adjusted to make certain that they only sense motion in the controlled space. Motion in adjoining spaces can cause false triggering or cause the lights to remain on needlessly, thereby wasting energy. Similarly, sensors must not turn lights off when spaces are occupied.

  An additional adjustment on sensors controls the time-delay period between last detection and lights off. This time-out setting is important: a setting too short may cause false cycling; a setting too long fails to save energy as well as it could. A preliminary time-out setting of 15 minutes is suggested as a compromise, but the control manufacturer can recommend good preliminary settings for each application.
- *Photosensors:* Mount photosensors designed for use in open-loop daylighting control systems so that they cannot detect the lights they control. This may require some tweaking, masking or relocating of the unit after installation. Consult the manufacturer's recommendations for proper procedures for commissioning photosensor devices.

Daylight sensor settings should be made and checked several times. If illuminance criteria are specified, use a good light meter with a silicon photodetector to verify design adjustment settings. Cheap meters can give poor results. If necessary, borrow a better meter from your local electric utility.

- *Dimming controllers:* Dimming controllers for lighting systems should be tuned so that illuminance at the high dimming range will not exceed design parameters. This is a relatively easy procedure on most dimming boards, requiring a simple adjustment.
- *Relay controllers:* If a stepped lighting control system is used for daylighting, adjust the deadband between the on and off switching thresholds so that the system does not cycle on cloudy days. Continuous on-off cycling is annoying to occupants and reduces lamp life.

**Utility Programs**

Incentives may be available for specific lighting equipment or systems. Contact your local utility as early as possible in the design process to take advantage of existing incentive programs.

## Lighting Design Applications

This section describes a number of energy-efficient lighting designs for some typical commercial building spaces: private and open-plan offices, grocery stores, big-box retail stores, small retail stores, classrooms, corridors, hotel guestrooms and warehouses. Except in the case of corridors, hotel guestrooms and warehouses, these design recommendations are derived from the *Advanced Lighting Guidelines* (ALG), 2001 edition, which contains an entire "Applications" chapter with detailed information and diagrams of recommended advanced lighting designs. The ALG can be downloaded for free from the New Buildings Institute (www.newbuildings.org/lighting.htm) or can be purchased as a CD from IESNA (www.iesna.org).

**Private Offices**

***Design Options***

The *Advanced Lighting Guidelines* offers several task-ambient lighting design recommendations for small offices of about 104 ft². In each of these designs, the ambient light level is between 15 and 30 footcandles, average, and meets the IESNA's *Design Guide* criteria. Task lighting is provided on the desk only. Two of the eight private office examples from the *ALG* are described here.

- **Direct.** One suggested design uses two overhead high-performance recessed luminaires that generate more than 40 footcandles in the center of the room. Each luminaire includes one F32T8 lamp and a high-light-output ballast (ballast factor > 1.1, 76W). An undercabinet task light with one 25W F25T8 lamp produces more than 70 footcandles on the desk surface. Power density is 0.97 W/ft².
- **Indirect.** A second option uses one uplight luminaire containing two F32T8 lamps (48–80W, depending on ballast factor and the resulting illuminance level for the room) and one undercabinet luminaire with one F25T8 lamp. With this design, it's particularly important to have a light-colored ceiling to reflect light down into the space. Power density is 0.81 to 1.1 W/ft².

***Controls***

In small offices and workrooms, provide both manual and occupancy sensor controls (sometimes the occupancy sensor integrates manual override into the control). In rooms with windows, consider providing either controls that automatically dim the lights in response to daylighting or manual dimmers so that occupants can adjust the illumination to their preference.

**Open Offices**

***Design Options***

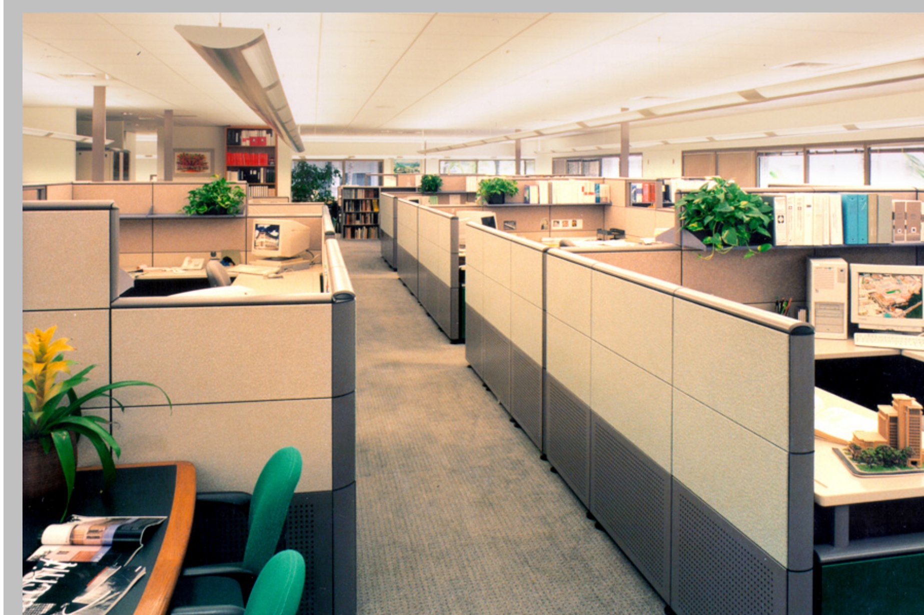
The *ALG* shows a number of advanced lighting designs for open offices, including the two described below. As with the private office examples above, task lighting is only provided on the desk. The ambient light level is between 15 and 30 footcandles, average, and the design follows the IESNA's *Design Guide* criteria.

- **Lay-in troffers.** One suggested design uses two-lamp recessed troffers (F32T8) that are spaced 8 ft x 12 ft. For this wide spacing to be effective, a luminaire must be positioned over each workstation, and each workstation must have a task light. Wall washers with FT40 lamps (or linear T-5 lamps) provide balanced illumination in the circulation areas. The connected power of this design is 0.89 W/ft².
- **Uplighting.** In the second *ALG* example, rows of indirect suspended luminaires are spaced every 10 ft. Each luminaire contains one T-8 lamp with a high ballast factor ballast. In the circulation areas, a continuous wall slot uses a standard T-5 or T-8 lamp. This design's connected power density is 1.05 to 1.10 W/ft². Another option would be to use one T-5 lamp in the uplights, which would reduce the connected power to 0.88 W/ft², but additional task lights may then be needed.

A slightly different approach is illustrated by a lighting retrofit at the Honolulu office of Architects Hawaii. This design, which uses two-lamp luminaires and a slightly higher lighting power, may be more appropriate in retrofit applications where the occupants are accustomed to a certain light level. The office renovation involved changing work areas to an open-plan layout. Existing 2 ft x 4 ft T-8 fluorescent lay-in luminaires were replaced with suspended direct/indirect T-8 fluorescent luminaires with two lamps per luminaire and electronic ballasts.

The luminaires were suspended about 18 inches below the ceiling, both for optimal spread of light on the ceiling and to clear the fire-sprinkler heads. The lighting retrofit reduced lighting energy usage to 1.30 W/ft$^2$ from 2.57 W/ft$^2$. The evenly spread light has virtually eliminated glare reflected in the computer monitors and employees' complaints about eye strain have disappeared. In addition, many of the company's clients have commented on the attractiveness of the lighting design.

*Figure 4-11. Suspended lighting at office of Architects Hawaii, Honolulu. Photo: Architects Hawaii.*



### *Controls*

In open offices, one or more local override switches are typically connected to a relay that is also controlled by a time-of-day program.

Consider providing individual dimmers for the luminaires above each workstation. Many workers, particularly those who spend a lot of time using computers, prefer to be able to control the light levels in their workspaces. Dimmers with handheld controllers can reduce costs and the need for wiring.

Provide a separate switching zone for daylit areas near windows. Using automatic daylight dimming on the luminaires nearest to the windows can save a significant amount of energy.

Plug-strip occupancy sensors can be used at each workstation to control task lights, computer monitors, printers and other equipment. Occupancy sensors can save from 10% to 30% of the energy used by these devices.

**Grocery Store**

### *Design Options*

Grocery stores are a good application for skylights: daylit grocery stores can use considerably less electricity than comparable stores without daylighting. Whether or not the store is daylit, consider using T-5 task lighting integrated with shelving to reduce lighting power to 1.2 to 1.4 W/ft². The *ALG* design described below has a connected light power of about 1.4 to 1.5 W/ft², not including refrigerated case lighting.

- **General lighting.** The *ALG* provides an example of an energy-efficient grocery store lighting design that uses striplights or recessed troffers running perpendicular to the aisles with T-8 lamps and electronic ballasts. A continuous fluorescent valance or uplight illuminates the store's perimeter. (A T-5 lamp used in uplights here would permit a very small cove valance.)
- **Specialty departments.** For pendant luminaires in small specialty departments such as a bakery or flower display, consider using a 26W or 32W triple-tube CFL lamp with a shield. A 70W or 100W metal halide lamp (ceramic arc tube may be best) can illuminate larger areas.
- **Produce area.** To provide dramatic lighting in the produce area, the *ALG* design uses track lighting with metal halide lamps. Other options include suspended fluorescent direct luminaires or larger industrial luminaires with metal halide or large compact fluorescent lamps.

### *Controls*

Consider using multilevel switching for alternating lamps or ballasts so that lower light levels can be used at night, during stocking hours, or in the case of an energy crisis. If a single lighting zone serves an area, partial dimming can ruin uniformity and create unappealing dark areas.

**Big-Box Retail**

### *Design Options*

Big-box retail stores typically have 20- to 30-ft ceiling heights and display racks that are 12- to 14-ft tall. As described in the *ALG,* the metal halide industrial downlights generally used in big-box retail stores don't provide ideal lighting for the narrow aisles lined by tall racks of merchandise. The *ALG* suggests an advanced lighting design for a daylit big-box retail store that uses metal halide downlights in the open areas and fluorescent luminaires between the shelving racks.

- **Daylighting.** Big-box retail is an excellent application for skylights. In the *ALG* example*,* a skylit big-box store uses 100W metal halide industrial-style downlights and 100W metal halide track floodlights for general lighting. Continuous rows of single-lamp F59T8 luminaires are positioned above the aisles. Low display fixtures are illuminated with continuous rows of two-lamp F32T8s. Store windows are lit with dual 40W T-5 twin-tube floodlights, while 42W compact fluorescent pendants are used in "boutique" areas. The lighting power density is 1.5 W/ft².
- **High-bay T-5 high output.** Another option for big-box retail is to use high-bay T-5 high-output luminaires with reflectors that direct light downward. This option is very energy efficient, since high-output T-5s have mean lumens per watt (MLPW) of more than 80, compared to only 60–65 MLPW for small metal halide or compact fluorescents. With a nominal output of about 5,000 lumens, six T-5 HO lamps are approximately equivalent to a 400-watt MH since the mean light output is about 30,000 lumens for either option.

### *Controls*

If the store is daylit, automatic daylight dimming controls on the fluorescent lighting could reduce the average power of the design described above by 20% to 30%, according to the *ALG.* For further savings, consider using bilevel controls on the metal halide or fluorescent luminaires before and after regular business hours, when employees stocking merchandise or doing other work may find lower light levels adequate.

**Small Retail**

### *Design Options*

There are many energy-efficient options for lighting small retail stores such as specialty stores, coffee retailers or delis. It's possible to achieve 2.0 W/ft² or less in small retail stores by limiting the use of incandescents to a few halogen IR lamps for accent lighting.

- **Coffee, deli or other specialty stores.** One design shown in the *ALG* uses four large decorative pendants with compact fluorescent lamps for ambient lighting. Compact fluorescent pendants hang over the counters. In the windows, track lights have 37-watt MR-16 IR lamps. The work areas behind the counters and the menu boards are lit with F40T5 twin tubes with 0.85 BF ballasts. The connected power is 1.9 to 2.0 W/ft².
- **T-5 high output.** Another option shown in the *ALG* uses attractive suspended fluorescent luminaires containing a single T-5 high-output lamp. Thirty-two watt compact fluorescent pendants hang over the counters.
- **Small general retail or grocery.** The *ALG* shows another energy-efficient design using 2 ft x 2 ft recessed luminaires with three F17T8 lamps (or two FB32 lamps on a low ballast factor ballast). The perimeter spaces are lit with wall washers that have F40T5 twin tubes and 0.85 BF ballasts. T-5 HO wall washers may also work well, with longer lamp life.

### *Controls*

Dimming controls can be used for adaptive compensation to save energy after dark (at night, eyes are adapted to lower outside lighting levels, so lower interior lighting levels seem more comfortable). The use of dimming during the day may be limited, since many small retail spaces only have access to daylight at the front window.

**Classroom**

### *Design Options*

The *ALG* provides two lighting design examples for a typical 960-ft² classroom.

- **Direct/indirect or semi-indirect suspended luminaires.** Pendant-mounted lights are an excellent choice for classrooms because they provide balanced, glare-free illumination. The *ALG* shows an energy-efficient design with three rows of two-lamp T-8 direct/indirect or semi-indirect luminaires with normal ballast-factor ballasts. This design generates at least 50 footcandles, with a connected power of 1.16 W/ft². Independently switched chalkboard lighting with four F32T8 or F28T5 lamps could also be included; this would increase the lighting power by about 0.13 W/ft².

- **Lens troffers.** Another common classroom lighting design is the "donut" configuration, with four rows of lens troffers outlining the classroom's perimeter (the ring of the "donut") and a short row of luminaires in the center (the "donut hole"). The design shown in the *ALG* uses inexpensive two-lamp T-8 troffers and low ballast-factor ballasts to provide good vertical illumination on all four walls.

### Controls

In classrooms, use occupancy sensors as the basic on/off lighting control. (Note: especially in lower grade classrooms, some teachers do a better job of turning off unnecessary lighting than occupancy sensors do; the higher the grade, the more need for automatic lighting controls.) Also provide manual override switches so that the teacher can turn the lights off as needed. Controls can save from 5% to 15% of lighting energy used by classrooms, according to the *ALG*. In classrooms with good daylighting design, automatic controls can save as much as 20% to 60%.

## Corridor

### Design Options

In corridors with tall ceilings, typical lighting includes recessed 2 ft x 2 ft troffers, recessed CFL downlights or indirect linear fluorescent (pendant or cove lighting). CFL wall sconces may also work well, and they are common in hospitality applications. While the horizontal illumination requirement for corridors is modest, vertical illumination to identify other people in the corridors is important.

Surface-mounted fluorescent luminaires may be required for some applications, but glare might be a problem without careful design. If necessary, look for louvered luminaires or prismatic luminaires with generous uplight. A larger number of luminaires with fewer or smaller lamps per luminaire will increase lighting uniformity.

### *Controls*

Some occupancy sensors are specially designed for corridors. The less frequently a corridor is used, the more it needs an occupancy sensor. Some stairways can also benefit from occupancy sensors. For stairways, however, some of the lighting must remain on at all times, so a few luminaires should not have occupancy sensor control. Avoid preheat lamps when using occupancy sensors; their blinking upon startup may be disconcerting or in some cases unsafe.

**Hotel Guestroom**

### *Design Options*

The actual design depends greatly on the room style and decoration, but fluorescent lamps and CFLs will save considerable energy. In particular, T-8 fluorescent lamps with color rendering index (CRI) above 80 in the lavatory and bath areas can provide excellent color rendering and energy efficiency. Careful luminaire and lamp selection can make this combination compatible with almost any interior decoration theme.

Recessed downlights in areas such as an entry foyer can save energy using CFLs (use programmed rapid-start ballasts to preserve lamp life). Portable luminaires should use CFLs for a combination of long lamp life and energy efficiency. Pin-based CFLs will decrease theft problems; locks for some screw-based CFLs are also available. To preserve guest satisfaction, do not use lamps with a CRI less than 80.

Some hotels have started using a new type of table lamp that has separate dimming CFLs, one for indirect uplight and another for direct downlight. Hotels save energy by using CFLs with efficient electronic ballasts, and can also save energy if users dim from full light output.

***Controls***

The Honolulu, Hawaii and Kauai energy codes require that all hardwired lights and switched receptacles be controlled from a switch at the entry door. Other controls, such as timers in bathrooms, can potentially save a lot of energy. Dimmers or 3-way switches in portable luminaires may save also some energy.

**Warehouse**

***Design Options***

Warehouses typically use either fluorescent or HID lamps in industrial high-bay or low-bay luminaires. While simple and generally inexpensive, industrial luminaires use key design features to optimize light distribution for task visibility, low maintenance and low energy costs. Many warehouses use aisle storage racks; these present difficulties for some HID luminaire designs, but manufacturers offer a number of them specifically intended for aisle applications. Since some warehouse areas may be infrequently occupied, controls can save significant amounts energy (see below).

Many warehouses use high-bay luminaires. Lamp selection should consider both lamp characteristics and the method of changing lamps. For example, unless the maintenance crew already has a lift that can be used for changing high-bay lamps, buying or renting a lift will add to relamping costs. A long string of fluorescent luminaires along each aisle may provide good uniformity, but if a rented lift must be raised, lowered, and then moved to relamp each luminaire in the string, the relamping project could take a while.

Some high-bay HID luminaires allow relamping access by a person on the ground using a pole; other poles types are available to change lamps in open fluorescent luminaires. Some lamps, such as T-8 fluorescent, high-pressure sodium and 400-watt metal halide offer very long lamp life, decreasing overall maintenance costs. While fluorescent lamp life may be affected by frequent starting, the overall lamp life may be longer for lamps that operate on occupancy sensors because they are on for fewer hours. HID lamps, on the other hand, are still on whenever they are controlled by an occupancy sensor, so all hours count toward lamp life.

Some warehouses utilize daylight from windows or skylights to supplement electric light. If these are combined with photocontrols to dim or switch off lamps when daylight is sufficient, the controls may save ample energy. The key to saving energy with daylighting is a well-designed daylighting system, properly integrated with the luminaires and controls.

***Controls***

Two-level controls (hi-lo or step) often work well with HID lamps and especially well with fluorescent lamps. These controls usually rely on a motion detector to determine that an aisle needs the higher light level. Most HID lamps will work properly with a hi-lo ballast package, but a few may cause problems; check with the ballast manufacturer for details.

Fluorescent lamps start quickly when switched on. Some industrial fluorescent lighting applications may need only 20% or less of the lamps on for safety, while the remaining lamps can turn on quickly when the occupancy sensor switches them on. With fluorescent lamps, consider the frequency that full lighting will be used; that will determine the best electronic ballast start mode. If the lamps will start many times daily, programmed rapid-start ballasts can eliminate early lamp failure. While these ballasts cost more and use slightly more energy than instant-start ballasts, the overall cost may be lower if lamps last significantly longer. T-5 lamps always use programmed rapid-start ballasts.

# 5. ENERGY-EFFICIENT WINDOWS



## Energy-Efficient Windows Overview

**Description**

A window is vertical glazing located in a building to provide views, natural ventilation, daylight, or some combination of these three. Energy-efficient window design takes into account the window area, glass type, building orientation, and shading devices to maximize daylighting while minimizing solar heat gain.

**Benefits**

Windows serve many important functions. They can provide views, fresh air and cooling breezes, and daylight. Views of the outdoors give people a sense of connection to nature and the surrounding community, and also provide a sense of passing time and changing weather conditions. Natural ventilation and daylight can help provide more comfortable conditions for occupants, and may result in significant energy savings for the building owner or tenant.

Access to views, daylight and natural ventilation have been associated with increased employee productivity. Views through windows, for example, may improve eye health by encouraging people to occasionally shift their eyes’ focus from close-up tasks to more distant sights.

Windows also provide people on the outside with views of the activities inside a building, which is quite important for many types of commercial buildings such as stores and restaurants.

**General Design Considerations**

While there are many powerful arguments for including windows in commercial buildings, windows also admit direct solar gain into a space. This heat gain can be a source of passive heating in colder climates, but it is not desirable in cooling-dominated climates, such as Hawaii.

In addition to affecting HVAC energy use, a window’s surface temperature can make occupants in the building’s peripheral zones feel uncomfortably hot or cold. In Hawaii, glazing types that tend to have high surface temperatures when exposed to direct sun are not desirable. Also, if windows are not properly located or shaded, direct sun penetration may cause uncomfortable glare for the occupants.

But by optimizing aperture size, glazing type and solar shading, it's possible to take advantage of the benefits of windows without significantly increasing the cooling load or causing thermal or visual discomfort.

Solar control — whether achieved with shading devices, window orientation or glass selection — reduces heat gain by cutting off direct solar penetration into the building. In existing buildings that are retrofitted with solar control devices such as interior or exterior shading, this results in significant savings in peak load energy and lower energy bills. In new construction, good solar shading design may also mean that the size of the air conditioning equipment can be reduced. In some cases, the savings in equipment costs will offset the cost of the shading devices.

***Window Terminology***

Windows have four principle performance characteristics: solar heat gain coefficient (SHGC), visible light transmittance (VLT), U-factor and efficacy. Other important window terminology includes window-wall ratio (WWR) and projection factor (PF).

- **Solar heat gain coefficient (SHGC)** is the ratio of solar heat gain entering a space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which then enters the space through reradiation, conduction or convection.

  A window that allows no solar gain would have an SHGC of zero, while perfectly transmissive glazing would have an SHGC of 1.0 (these extremes are both theoretical and are not possible in the real world). **In Hawaii, glazing materials should be selected with the lowest possible SHGC.** However, some glazing materials with a low SHGC (like dark gray and bronze tints) may also have a low visible light transmittance (VLT). The challenge is to identify spectrally selective low-emissivity (low-e) products and blue or green tints that combine the lowest SHGC with the highest VLT.

- **Visible light transmittance (VLT)** is the ratio of visible light transmitted through the glazing to the total amount of light that strikes the glass. Single-pane clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05. In general, VLT should be as high as possible to allow more daylight inside, as long as it does not create glare or other visibility problems.

- **U-factor** measures the heat flow through a window assembly due to the temperature difference between the inside and outside (U-factor = 1/R-value). The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. However, U-factor is more critical in areas that have very hot summers or cold winters. **In Hawaii, where the weather is not extremely hot or extremely cold, low SHGC is more important than low U-factor.**
- **Efficacy** is the ratio of VLT to SHGC. The higher the efficacy, the better the fenestration product is at allowing daylight in and reducing solar gain.

  Glazing materials with a high efficacy are known as **"spectrally selective"** because they selectively transmit radiation in the visible portion of the spectrum while blocking solar radiation in the ultraviolet and infrared spectra. Spectrally selective products typically have a VLT to SHGC ratio greater than 1.3.
- **Window-wall ratio (WWR**) is the ratio of window area to the exterior wall area.
- **Projection factor (PF**) is the ratio of an overhang's horizontal projection to the vertical distance from the windowsill to the bottom of the overhang. The overhang projection is measured as the perpendicular distance from the window surface to the overhang's outside edge.

### *NFRC Rating*

The National Fenestration Rating Council (NFRC) has established a rating system to evaluate the whole window performance of manufactured windows, including the frame, spacer and glazing. The whole-window SHGC, VLT and U-factor are shown on a label attached to all rated windows. Site-built windows and skylights will not have these ratings. For more information, visit the NFRC's Web site, www.nfrc.org.

### *Solar Control Glazing*

As mentioned above, in Hawaii the most important glazing characteristic for windows is low solar heat gain coefficient. A low SHGC can be provided through several different technologies:

- **Heat-absorbing tints.** These tints are available in a range of colors. Some tints, typically blue or green, offer better visible light transmittance while providing equal or better solar control than gray or bronze tints. Consider using these blue or green tints in daylighting designs. All heat-absorbing tints get hot in direct sunlight, which is an important concern in buildings where occupants work close to windows.
- **Heat-reflecting coatings (including low-e).** Several types of coatings are available. Some appear mirrorlike, while others are designed to reflect as much heat as possible while also appearing as clear as possible. The latter type of coating is called "spectrally selective" and is a better choice for simultaneously providing daylight and solar control.

  Some — but not all — of these heat-reflecting coatings will have low-emissivity (low-e) properties. Low-e coatings reduce the radiant heat transfer between two surfaces, for example from one pane to the other in a double-pane glazing. Low-e coatings improve a window's insulation value (lower U-factor), but in Hawaii, SHGC is a much more important concern. Therefore, when specifying a heat-reflecting window, it's not adequate to specify a low-e window; **it's critical to specify the desired SHGC and VLT.**

  Be aware that not all low-e windows have a low SHGC. There are several types of low-e coatings: some reduce solar gain while others allow solar gain. Low-e coatings that allow solar gain are not desirable in Hawaii.

  Often these heat-reflecting coatings are applied to one of the surfaces facing the air gap in a double-pane window. This is necessary to protect the coating from scratches that might occur if it were exposed. While it wouldn't normally be cost effective to add a second pane of glass in Hawaii, double-pane windows are necessary if you want the performance benefits of higher performance coatings.
- **Laminates.** Either heat-absorbing or heat-reflecting plastic film can be sandwiched between two sheets of glass to create a single pane. To provide further solar control, heat-absorbing glass can be used. Laminated glazing provides stronger resistance to lateral forces and is recommended in hurricane-prone areas.
- **Retrofit films.** Plastic films similar to those used to create laminated glass can be applied to the surface of the glass. This should be considered only as a retrofit measure because the exposed film is not as durable as glass.

***Glazing types and their properties***

Table 5-1 compares the performance and relative costs of a range of representative glazing types, from basic single-pane clear glass to high-performance double-pane glass. Table 5-2 describes some of the advantages and disadvantages of these glazing types. All glass types in these two tables are intended as examples; they don’t refer to a particular manufacturer’s product.

*Table 5-1. Glazing types and their properties. Shows typical performance values. These values may vary slightly among manufacturers.*

| **Glass Type[a]** | **SHGC** | **VLT** | **U-factor** | **Efficacy** | **Relative Cost[b] ($/ft²)** |
|---|---|---|---|---|---|
| **Single Clear** | 0.82 | 0.88 | 1.09 | 1.08 | --- |
| **Single Tinted** (gray tint) | 0.59 | 0.43 | 1.09 | 0.73 | 0.68 |
| **Single High-Performance Tinted** (green or blue tint) | 0.50 | 0.66 | 1.09 | 1.32 | 1.86 |
| **Single Reflective** (medium reflectance) | 0.55 | 0.39 | 1.09 | 0.71 | 1.69 |
| **Single Reflective** (high reflectance) | 0.25 | 0.13 | 0.91 | 0.52 | 3.18 |
| **High-Performance Laminated Clear** | 0.45 | 0.71 | 1.06 | 1.58 | 9.17 |
| **High-Performance Laminated Clear Low-e** | 0.38 | 0.63 | 0.71 | 1.66 | 10.67 |
| **Double Clear** | 0.70 | 0.78 | 0.48 | 1.12 | 5.10 |
| **Double Tinted** | 0.47 | 0.38 | 0.48 | 0.81 | 5.78 |
| **Double High-Performance Tinted** | 0.38 | 0.58 | 0.48 | 1.55 | 6.96 |
| **Standard Double Clear Low-e[c]** (lowest SHGC) | 0.36 | 0.47 | 0.31 | 1.32 | 8.28 |
| **Standard Double High-Performance Tinted Low-e[c]** (lowest SHGC) | 0.22 | 0.35 | 0.31 | 1.63 | 10.14 |
| **Premium Double Clear Low-e[c]** (highest efficacy) | 0.38 | 0.70 | 0.31 | 1.87 | 8.28 |
| **Premium Double High-Performance Tinted Low-e[c]** (highest efficacy) | 0.27 | 0.53 | 0.31 | 2.00 | 10.14 |

Notes:

**(a)** All values are COG, based on 1/4-in. thick glass. Double-pane alternatives have 1/2-in. air gap.
**(b)** Relative cost column shows approximate incremental increase in cost compared to single-pane clear glass.
**(c)** Some manufacturers offer many different types of low-e coatings, with a range of SHGC and VLT values. The four low-e glazings listed here represent two generic categories: "standard" refers to a low-e coating with very low solar heat transmission, while "premium" refers to a low-e coating with relatively low heat transmission but much higher light transmission (better efficacy).

*Table 5-2. Advantages and disadvantages of representative glazing types.*

| Glass Type | Description | Advantages | Disadvantages |
|---|---|---|---|
| **Single Clear** | Single layer of glass. Recommended only for well-shaded windows. | Lack of tinting allows good color rendition. | Allows a lot of direct solar radiation into the space. Poor thermal performance (high SHGC). |
| **Single Tinted** | Single layer of tinted glass (blue, green, gray, bronze, etc.). Green and blue are preferable to gray and bronze. Not recommended for unshaded windows. | Relatively inexpensive. Can improve visual comfort by reducing glare. Green and blue tints have relatively high efficacy. | Gray and bronze tints have relatively low efficacy, so they reduce visible light more than they reduce overall heat gain. Tinted glazing is less desirable if it's important that views are not altered by tinting. Tinted glazing gets hot when the sun strikes it so may be uncomfortable for people next to it. |
| **Single High-Performance Tinted** | Some manufacturers offer higher performance blue or green tinted glazing. These are similar to standard single-pane tinted but the tint transmits more visible light and less visible heat. These high-performance tints usually range from light green to light blue. | Relatively high efficacy. Lower cooling load impact and relatively affordable price. More expensive than standard single tinted but much less expensive than double-pane low-e glass. | Views are not rendered in true color, although the tinting is lighter than with standard single-pane tinted. SHGC still somewhat higher than the best performing glazings. |
| **Single Reflective** (medium reflect-ance) | Special coating reflects much direct solar energy. | Relatively low SHGC. | Mirrorlike appearance causes excessive glare outside. Low efficacy. Low VLT makes it a poor choice for view windows or daylighting. |
| **Single Reflective** (high reflect-ance) | Similar to single reflective–medium but reflects a higher percent of incident solar radiation. | Lower SHGC than single reflective–medium. | Mirrorlike appearance causes excessive glare outside. Very low efficacy and VLT. The light-to-heat-gain ratio makes it one of the worst choices for daylighting. |

Continued -->

| Glass Type | Description | Advantages | Disadvantages |
|---|---|---|---|
| **High-Performance Laminated Clear** | Special heat-reflecting plastic film sandwiched between two sheets of clear glass to create a single pane. | High efficacy. Good daylighting performance. Can provide similar performance to high-performance tinted glass without the green or blue color cast. Provides the typical penetration resistance of standard laminated glass, with better energy performance. | Relatively expensive. Laminated glass may require more careful handling during installation to prevent cracking. |
| **High performance Laminated Clear Low-e** | Similar to high-performance laminated clear glazing but one of the panes of glass has a spectrally selective low-e coating. | Even higher efficacy and lower SHGC than the non-low-e laminated alternative (above). Very good daylighting performance. | Relatively expensive. Laminated glass may require more careful handling during installation to prevent cracking. |
| **Double Clear** | Two sheets of clear glass separated by a gap filled with air or gas (such as argon). Depth of gap typically varies from 1/8 in. to 1/2 in. | Has lower U-factor and somewhat lower SHGC than single-pane clear. | In Hawaii, the performance improvements over single-pane clear glazing are not worth the cost of adding an extra pane of glass. Lower U-factor is not a major benefit in Hawaii. |
| **Double Tinted** | Similar to double clear glazing, with one pane (typically the exterior) tinted. Generally not recommended in Hawaii. | Lower SHGC than double clear glazing. | Worse efficacy than double clear glazing. |
| **Double High-Performance Tinted** | High-performance tint on outer layer of glass. Generally not recommended in Hawaii. | High efficacy. Typically cheaper than double low-e glazing. | In Hawaii, the extra expense of adding a second pane isn't worth the improvement in performance. |

continued -->

| Glass Type | Description | Advantages | Disadvantages |
|---|---|---|---|
| **Standard Double Clear Low-e[(a)]** (lowest SHGC) | Double-pane glazing with a low-e coating typically on the inner surface of the outer pane. Premium low-e (see below) is typically a better choice because of its enhanced daylighting performance. But for larger glass areas, standard low-e would be a better choice than the highest efficacy low-e coating because higher VLT wouldn't be as important. | Low SHGC and high VLT. | Similar SHGC but lower efficacy than premium low-e glazing. Expensive. Sacrifices some efficacy. |
| **Standard Double High Perform-ance Tinted Low-e[(a)]** (lowest SHGC) | Outer pane has high-performance tint and low-e coating on inner surface; separated from inner clear glass pane with 1/2-in. air gap. Different thicknesses of glass and air gap are available. | Very low SHGC. Relatively good efficacy. | May not be very cost effective. |
| **Premium Double Clear Low-e[(a)]** (highest efficacy) | Same type of glass as standard double clear low-e (lowest SHGC), but with better thermal and daylighting performance. | Excellent efficacy. In general, best daylighting performance. | For large glass areas, the standard double-clear low-e might be a better choice because it has lower SHGC and high enough VLT. |
| **Premium Double High Perform-ance Tinted Low-e[(a)]** (highest efficacy) | Same type of glass as standard double high-performance tinted low-e, but with better thermal and daylighting performance. | Excellent efficacy. In general, best daylighting performance. | For large glass areas, the standard double high-performance tinted low-e might be a better choice because it has lower SHGC and high enough VLT. |

Notes:

**(a)** Some manufacturers offer many different types of low-e coatings, with a range of SHGC and VLT values. The four low-e glazings listed here represent two generic categories: "standard" refers to a low-e coating with very low solar heat transmission; while "premium" refers to a low-e coating with relatively low heat transmission but much higher light transmission (better efficacy).

## General Principles of Window Design

**Recommendation**

To achieve high-performance window design, choose a combination of building orientation, shading, window area and glass type that maximizes daylighting while minimizing heat gain.

- **Orientation.** Proper orientation is the most important strategy. Whenever possible, limit the amount of window area on the east and west facades. Sunlight is easier to control on the north and south sides of a building.
- **Exterior Shading.** A designer's first choice should be to minimize the amount of direct solar radiation that reaches the windows. If direct sunlight can be kept off the windows, then inexpensive clear or lightly tinted glass can be used.

  Overhangs are typically the best choice for keeping sunlight off the windows, and are especially effective on the north and south facades. The combination of overhangs and vertical fins can nearly eliminate direct solar gain for most of the year. See the Exterior Overhangs and Side Fins Guideline for details.

  Operable exterior shades are another option. They are particularly useful where it's difficult to provide complete shading with overhangs or fins. The operable shades could be automatically controlled in response to the sun's position or manually adjusted to shade the window at different times of the year.
- **Interior shading.** Interior shades such as blinds and drapes provide some reduction in heat gain, but are not nearly as effective as exterior shades. Consider using interior shades on east- and west-facing windows where it's difficult to provide exterior shading throughout the day. See the Design Details section later in this General Principles section for more information about interior shading.
- **Combination of size and glazing type.** There's no single best combination of window size and glazing type. The optimum design will allow enough light transmission to provide good daylighting and adequate views while admitting no more solar heat than necessary. The energy, peak cooling load and lifecycle cost graphs in this chapter can be used to evaluate designs employing various window sizes and glass types.

- **Glazing performance.** If it is not possible to completely shade the windows from direct sunlight, then solar-control glazing should be specified. In Hawaii, select glazing materials with a low solar heat gain coefficient and a high visible light transmittance. Consider "spectrally selective" low-emissivity (low-e) products and blue or green tints that combine low SHGC with high VLT. Remember that in Hawaii, high SHGC is much more important than low U-factor.

**Description**

Well-designed, energy-efficient windows can reduce the overall building cooling loads. They can also deliver enough dependable daylight to reduce electric lighting loads, if manual or automatic controls are used to turn off the electric lights when not needed.

**Applicability**

Windows are essential in most commercial buildings (except in spaces requiring visual privacy) to provide relaxing views and information about exterior natural conditions, to allow people outside of a space to view and connect with activities inside, and to allow in daylight. They should be planned for in the schematic design phase.

**Codes and Standards**

The Hawaii Model Energy Code does not require that view windows or skylights be installed.

The code limits the maximum Relative Solar Heat Gain factor (RSHG) for various window-wall ratios for windows. There are different limits for north-facing and non-north facing windows. The RSHG factor is a function of the shading coefficient of the glazing (shading coefficient is similar to SHGC; see the code for a definition) and the exterior shade screens and/or louvers, interior shading devices, overhangs and fins. Individual windows may exceed the maximum RSHG limit as long as the area-weighted average RSHGs for both north and the combined east, west and south orientations are less than or equal to the maximum limit. Most buildings require window shading or tinted glass in order to comply with the code.

**Benefits**

Energy-efficient window design reduces solar heat gain while offering high visible light transmittance to allow more daylight inside. Benefits include:

- Smaller and less expensive air conditioning equipment required
- Lower cooling energy cost
- Lower lighting energy cost

- Potentially better dehumidification performance from the air conditioning system because there is less variability in the space's cooling loads, and because the AC system can be smaller and run at a more constant capacity (See the Dehumidification Guidelines for details).

**Costs**

Clear single-pane glass is generally the least expensive type of glazing. Solar control options such as tints and low-e coatings typically add some cost. Approximate incremental costs are listed in Table 5-1 above.

**Cost Effectiveness**

The lifecycle cost of window design options is described in the Integrated Design Implications section below.

**Integrated Design Implications**

***Energy Impact of Windows***

Windows have a significant impact on energy consumption in a building's perimeter spaces. The most direct impact is on cooling and fan energy for air conditioning.

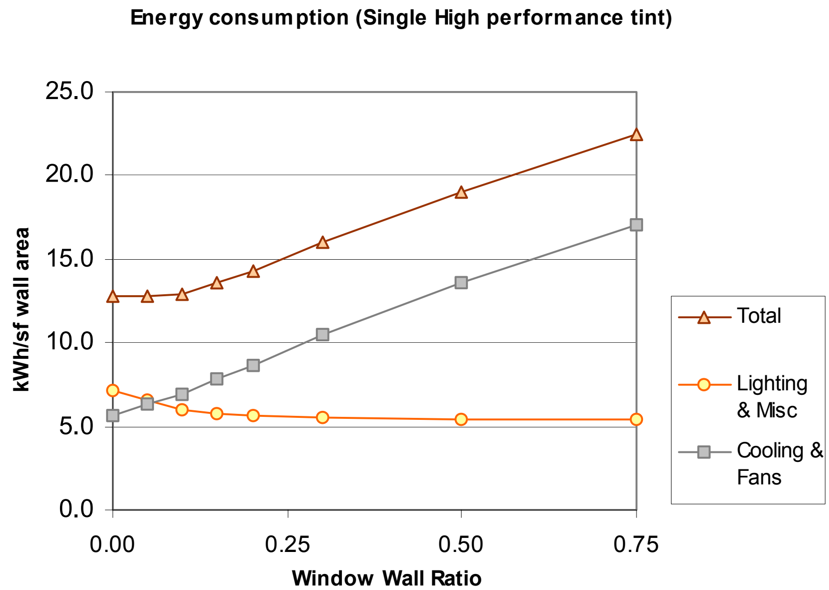
If the windows are properly designed and the lighting system is well controlled, windows can eliminate or reduce the need for lighting energy during the day by providing daylight.

The energy consumption, peak cooling load and lifecycle cost graphs in this chapter can be used to evaluate window options. They are based on a typical office building with manual or automatic daylighting controls in the perimeter spaces, operating five days a week for normal business hours (8 AM to 5 PM).

**Impact of WWR on energy consumption.** Figure 5-1 shows the effect of window-wall ratio on energy use for a south-facing window with high-performance tinted glazing (without any shades). In this example, as WWR increases from 0% to 75%, air conditioning energy rises steadily while lighting energy drops initially and then levels off. Total energy consumption drops slightly at first while the lighting savings dominate; then total energy use rises as lighting savings level off and air conditioning energy continues to rise.

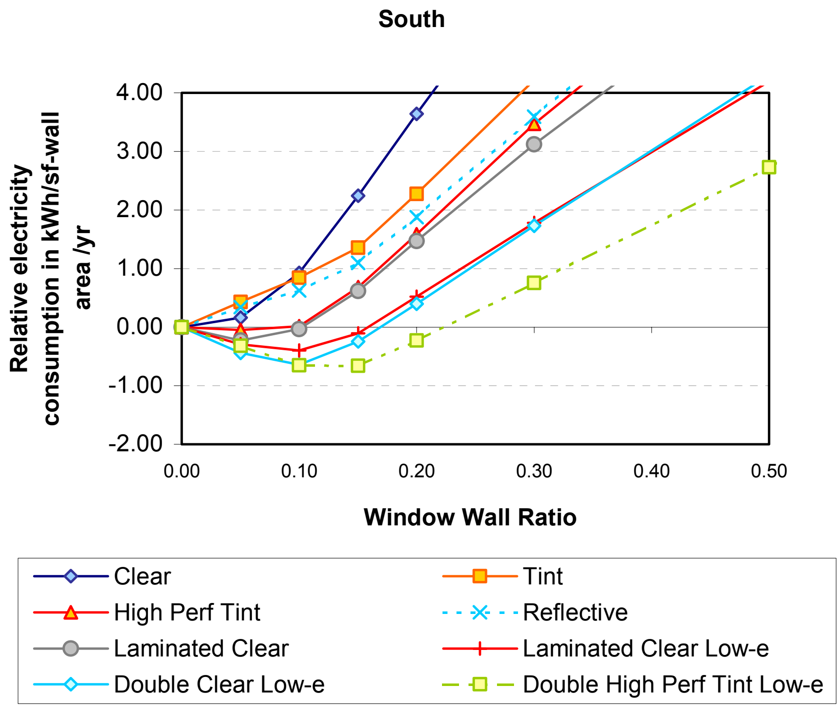
In this particular example, total energy use doesn't rise until WWR reaches about 15%. These results will vary depending on orientation and glass type; the graphs later in this section and in the Windows Performance Data section provide more information for evaluating eight different orientations and a range of glass types.

*Figure 5-1. Impact of WWR on energy consumption for a south-facing window with high-performance tinted glazing.*




**Impact of glazing type on energy consumption.** Figure 5-2 provides another perspective on the energy impact of windows: it compares the energy consumption of several types of glass for a south-facing window without interior or exterior shading devices. For a WWR of less than 10%, the lowest energy consumption occurs with double-pane clear glazing with a low-e coating. For larger window areas, the double-pane high-performance tinted low-e glazing is most efficient.

*Figure 5-2. Impact of WWR on total electricity consumption for various glazing types (south-facing window). Electricity consumption is relative to having no windows at all (i.e., negative value means that electricity consumption is lower with window than without).*



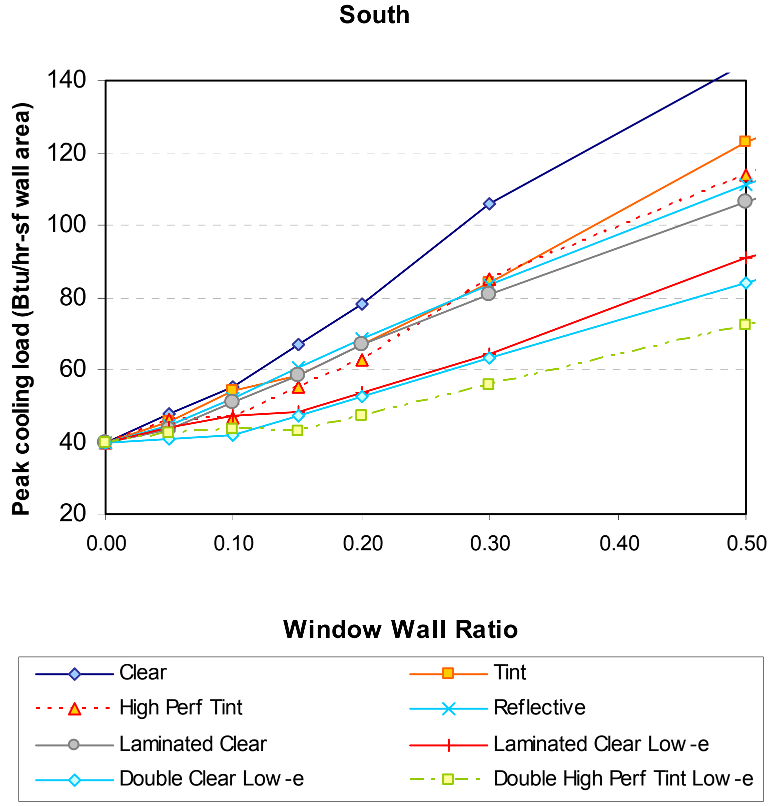

### *Impact of Windows on AC Sizing*

Solar heat gain can account for the majority of the cooling load in perimeter spaces with windows. By using windows with solar control, it may be possible to reduce the size of the air conditioning equipment; this equipment savings, in turn, can help offset some of the additional cost of the windows.

Figure 5-3 shows how the peak cooling load in the perimeter zone increases as the window area increases. It also shows the relative impact of various glass types on peak cooling load. In general, glazing types with the lowest SHGC will have the least impact on peaking cooling load. But with small window areas, a higher VLT will be important because it allows electric lighting to be turned off, eliminating the lighting load.

Figure 5-3 shows that for a south-facing window with no interior or exterior shading devices, double-pane low-e clear glass has the lowest impact on peak load, up to a 12% WWR. Above that point, double-pane glazing with a high-performance tint and low-e coating has the least impact on peak load.

*Figure 5-3. Impact of WWR on peak cooling load for various glazing types (south-facing window).*




### *Impact of Windows on Lifecycle Cost*

Window design affects both a building's construction cost and its operating cost, which makes it challenging to select the most cost-effective combination of glass type and window area.

Figure 5-4 shows the lifecycle cost (initial purchase and installation cost plus operating costs over the building's lifetime) of a single-pane, high-performance tinted window that faces south and has no interior or exterior shades. The results are presented as cost per square foot of wall area. Energy and cooling system costs apply to the corresponding indoor perimeter space. The four components of this lifecycle cost calculation are:

- **Wall & window cost.** With zero window area, the cost is assumed to be \$10/ft² of wall (actual cost will vary depending on construction type). As the window area increases, glazing displaces a fraction of the wall and the cost increases proportionately because windows are assumed to cost \$15/ft² for baseline clear glass. When glass accounts for 50% of wall area, the wall and window cost is \$12.50 per square foot.

- **HVAC system cost.** Figure 5-4 assumes that the cooling system costs $1,200 per ton of cooling capacity. The system cost increases as window area increases.
- **Other energy.** In Figure 5-4, "other energy" refers to lighting and plug loads (but not cooling or fan energy). This cost component drops as the window area increases. The lifecycle energy cost is based assumptions of $0.12/ kWh for electricity, inflation of 3%, a discount rate of 10% and a lifetime of 25 years.
- **HVAC energy.** As shown in Figure 5-4, cooling energy increases with window area. Economic assumptions are the same as for "other energy."

*Figure 5-4. Impact of WWR on lifecycle cost (south-facing window, single-pane, high-performance tinted glass).*

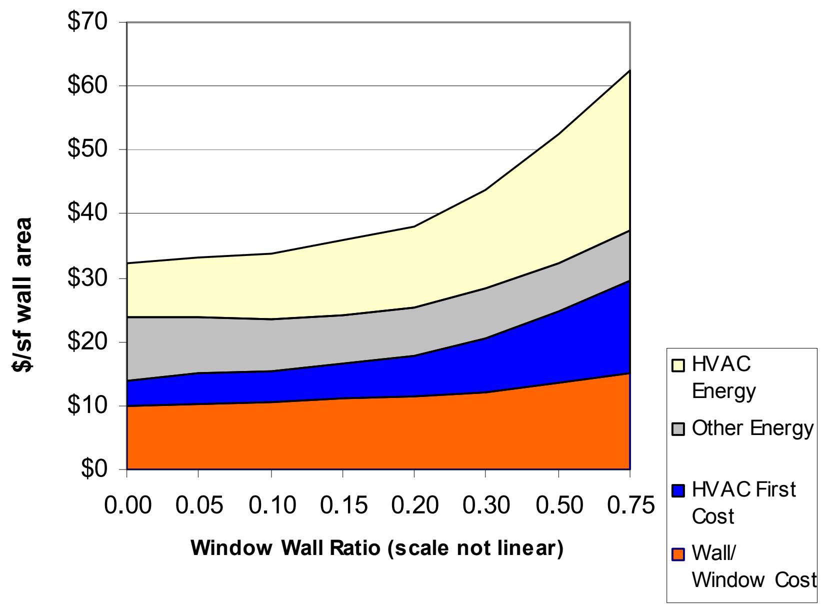


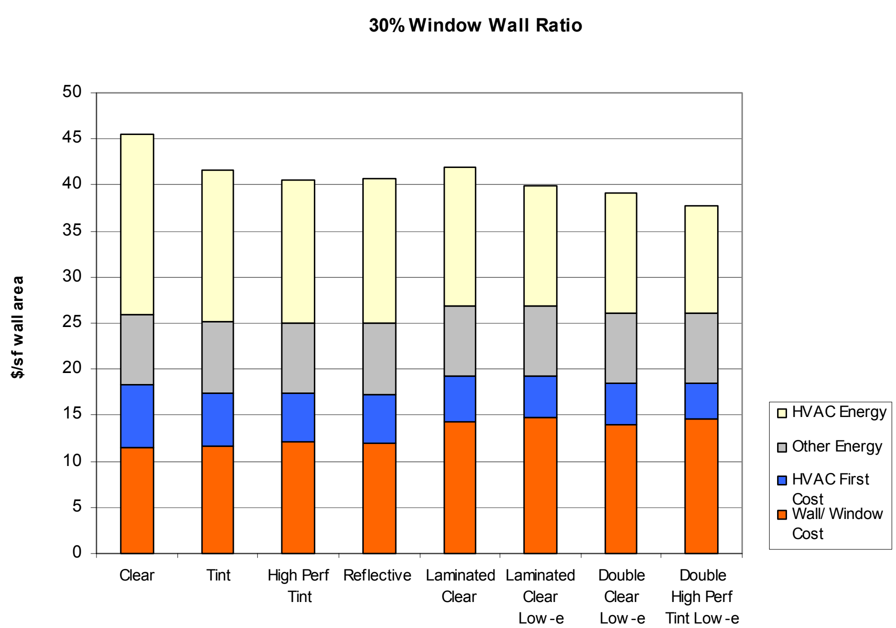

Figure 5-4 shows the lifecycle cost for one case: single-pane, high-performance tint in a south-facing window. The "other energy" decreases gradually until the WWR reaches about 0.20, while the other components of lifecycle cost increase slightly. The net result is a gradual increase in the lifecycle cost up to about 0.20 WWR.

As the WWR increases beyond this point, lighting energy levels off but cooling energy, cooling system cost, and wall and window cost all continue to increase, resulting in a substantial increase in the lifecycle cost. When the WWR reaches 0.50, the lifecycle cost is just over $50/ft² of wall area.

In this example, it appears that the most cost-effective design will have no windows at all. That will sometimes be the result when only construction and operating costs are considered. There are, of course, other factors that influence window design beyond the direct economic impacts, as discussed at the beginning of this chapter. Aesthetics, views, and the productivity and health benefits associated with daylighting are also important. The ideal design should meet aesthetic, social, comfort and other goals while also optimizing the lifecycle cost of the building.

Lifecycle costs can be used to help select the optimal glass type. Figure 5-5 plots the total lifecycle cost for several glazing options at a WWR of 0.30. In this case, for a south-facing window, double-pane, high-performance tinted, low-e glass offers the lowest lifecycle cost. But the best choice for glazing will vary with window orientation and WWR (see the Windows Performance Data section for graphs showing the lifecycle costs for other window-wall ratios and orientations).

*Figure 5-5. Impact of glazing type on lifecycle cost (south-facing window, 0.30 WWR).*




### *Integration with Natural Ventilation*

Operable windows can potentially reduce the number of hours the cooling equipment operates if natural ventilation is used to cool the building when the outdoor environment is favorable. See the Natural Ventilation chapter for details.

### *Visual Comfort*

Many aspects of window design will affect the occupants' visual comfort, including the glazing type, window location, position of the sill height relative to floor height, and the distribution of windows. Uniform illumination and lack of glare also contribute to good visual comfort. The Daylighting chapter provides guidelines for designing windows and skylights to reduce glare and achieve good visual comfort.

### *Resource Efficiency Issues*

In addition to affecting energy use, the fenestration system — combined glazing and framing — has other environmental impacts, including resource use, indoor air quality, and pollution created during manufacturing or disposal. However, data comparing the cradle-to-grave lifecycle impacts of various fenestration systems is difficult to come by. When considering framing and sash options, the best environmental performance strategy is to select durable frame and sash options that enhance energy performance and meet programming and daylighting needs.

Table 5-3 describes some of the environmental benefits and considerations of various framing options.

*Table 5-3. Strategies for selecting resource-efficient window frames and sashes.*

| Frame and Sash | Strategies | Environmental Considerations |
|---|---|---|
| Wood | Select windows produced with wood certified by Forest Stewardship Council. | Certified wood prevents degradation to forest and wildlife habitat. Wood can be high maintenance. Good energy performance. |
| Finishing coat | Specify factory-applied finish. | More durable than field-applied. Controlled finishing environment reduces pollution. |
| Wood and Plastic Composite | Durable options combine wood fiber, post-consumer waste plastic, recycled PVC scrap, virgin PVC, or recycled wood scrap. | Uses waste, stretching the wood supply. Very durable. Low maintenance. But PVC manufacturing may create pollution. Good energy performance. |
| Vinyl/PVC | Vinyl frames include foamed PVC insulating core. | Low maintenance. Needs no paint. PVC manufacturing may create pollution. High coefficient of thermal expansion can lead to premature failure of seal. Excellent energy performance. |
| Fiberglass | Pultruded fiberglass frame members have a hollow profile usually insulated with fiberglass or polyurethane foam. | Durable. Difficult to recycle. Emissions may contribute to indoor air quality problems and manufacture may create pollution. Moderately good energy performance. |
| Metal | Specify durable, factory-applied finishes: anodized, polyvinlidene fluoride, or siliconized polyester. | Durable. Reduces potential pollution on site. Energy-intensive production. Not the best energy performance. |

Source: *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications.* For specific product recommendations, see *GreenSpec* (www.buildinggreen.com) or OIKOS's *REDI Guide* (www.oikos.com).

**Design Details**

### *Energy Impact of Exterior Shading*

This section provides an overview of important details to consider when designing windows with exterior shading devices. For an in-depth discussion of exterior shading, see the Exterior Overhangs and Side Fins Guideline later in this chapter.

Exterior shading devices such as horizontal overhangs and vertical side fins can significantly reduce overall energy consumption and peak cooling load. For reducing solar heat gain, **overhangs are most effective on the south side of a building. On the north**