# Chapter 4: The Building Architectural Design

- Schematic Design
- Designing Using Computer Simulations
- Design of High Performance
   Features and Systems
- **...** Designing for Daylighting
- Passive and Active Solar Systems
- **#** Accommodating Recycling Activities

# Chapter 4

# The Building Architectural Design

# **Schematic Design**

Achieving a sustainable building requires a commitment from developing the initial F&OR documents through construction detailing and commissioning. Initial decisions, such as the building's location, general massing, and configuration profoundly affect the building's environmental impact and energy performance. Welldefined sustainable goals will guide the entire spectrum of decision-making throughout the design and construction process (see Chapter 2).

In a sustainable building, the architecture itself is expected to provide comfort for the occupants. Architectural programming establishes the needs and requirements for all of the functions in the building and their relationship to one another. Wise programming maximizes energy savings by placing spaces in the most advantageous position for daylighting, thermal control, and solar integration. It may also uncover opportunities for multiple functions to share space, thus reducing the gross square footage of the building.

Architectural programming involves an analysis of the required spaces to meet the functional and operational needs of the facility. With an eye toward sustainability



The long east/west axis, undulating Trombe wall providing passive solar heating and daylighting, and the horizontal architectural elements shading the Trombe wall in summer are sustainable building design features of the National Renewable Energy Laboratory Visitor's Center in Golden, Colorado.

and energy-efficiency targets, the individual spaces should be clearly described in terms of their:

- Primary functions
- Occupancy and time of use
- Daylight potential and electric light requirements
- Indoor environmental quality standards
- Equipment and plug loads
- Acoustic quality

Safety and security

Similar functions, thermal zoning (see Chapter 5), need for daylight or connection to outdoors, need for privacy or security, or other relevant criteria can then be used to cluster spaces.

After completing the F&OR document, careful conceptual design should strive for a building that:

Has properly sized daylight apertures to avoid glare and maintain proper contrast ratios for visual comfort.

- Utilizes passive solar gain when the building is in heating mode.
- Minimizes solar gain when the building is in cooling mode through orientation, shading, and glazing selection.
- Facilitates natural ventilation where appropriate.
- Has good solar access if use of solar thermal or photovoltaic (PV) systems is anticipated.

We shape our buildings, and afterwards our buildings shape us.

– Winston S. Churchill, 1943





## Siting the Building for Solar Accessibility

Careful site selection and building placement are essential for optimal daylight and solar utilization.

- Does the building site receive unobstructed solar radiation between the hours of 9 a.m. to 5 p.m.?
- Are there major sky obstructions such as geologic features, trees, or adjacent buildings?
- Does the site allow for an elongated east-west configuration? If not, then manipulate the building shape to increase the potential for daylighting and solar load control.



Solar access is extremely important where use of solar thermal or PV systems is anticipated or for passive solar heating in small buildings with minimal internal gains. This chart shows solar access angles for buildings in Los Alamos.



#### Plan early

In the conceptual design phase, site planning and building configuration and massing must involve all members of the design team. For example, the decision to daylight the building will influence the architectural design, the interior design, the HVAC design, and the electric lighting design. Use shading device tools and computer simulations to assess how building massing and orientation resulting from particular design decisions will affect overall building performance.



Los Alamos National Laboratory Sustainable Design Guide

#### **Building Massing and Orientation**

There is a trade-off between a compact form that minimizes conductive heat transfer through the envelope and a form that facilitates daylighting, solar gain, and natural ventilation. The most compact building would be in the shape of a cube and would have the least losses and gains through the building skin. However, except in very small buildings, much of the floor area in a square building is far from the perimeter daylighting.

Another energy-related massing and orientation consideration is the seasonal wind pattern. Breezes can enhance natural ventilation, but they can also increase heating loads in cold weather.

A building that optimizes daylighting and natural ventilation would be shaped so that more of the floor area is close to the perimeter. While a narrow shape may appear to compromise the thermal performance of the building, the electrical load and cooling load savings achieved by a well-designed daylighting system will more than compensate for the increased skin losses.

Effective daylighting depends on apertures of appropriate size and orientation, with interior or exterior shading devices to control unwanted direct sunlight. Computer simulations done during early design stages can measure the degree of this trade-off between skin exposure and daylighting benefits.



The skin-to-volume ratio is the exposed surface area compared to the building volume.

## **Designing Using Computer Simulations**

The thermal performance of any building entails complex interactions between the exterior environment and the internal loads that must be mediated by the building envelope and mechanical systems. The difficulty is that these various external and internal load conditions and associated utility loads are constantly changing from hour to hour and season to season. Also, the number of potential interacting design alternatives and possible trade-offs is extremely large. Computer simulations are the only practical way to predict the dynamic energy and energy cost performance for a large number of design solutions.

Accurate energy code-compliant base-case computer models give the design team typical energy and energy cost profiles for a building of similar type, size, and location to the one they are about to design. The design team uses this information to develop a design concept to minimize these energy loads and energy costs from the very outset. At this stage, the design team can manipulate the building massing, zoning, siting, orientation, internal organization, and appearance of the facades without adding significantly to the cost of design.

## Simplified peak load calculations versus hourly load simulations

Steady-state heat loss and gain calculations have commonly been used to determine heating and cooling peak loads and equipment sizes, but they give only a brief snapshot of the thermal performance under design load conditions in the summer and winter. They do not indicate the overall energy performance of the building, nor do they adequately treat day-lighting, solar loads, and thermal capacitance effects. Only through dynamic hour-by-hour (or shorter time-step) computer simulations over a typical climate year will the complete picture of energy, energy cost, peak load, and comfort performance be revealed. Computer modeling early in the design process can pinpoint areas of particular concern and highlight areas of potentially significant energy savings. Updates of the model as the design progresses ensure that energy-efficiency goals are being met.



Daylighting strategy analysis for a typical LANL office/laboratory building.



Building energy simulation tools help designers understand the complex interactions between design solutions.

As the design progresses, the design team compares the simulations of the proposed design alternatives to each other and to the base-case building simulation to understand the energy use, energy cost, and peak load implications of alternatives.

Building thermal simulation software tools that provide hour-by-hour analysis have been in use for more than 30 years. These software tools rely on an annual weather file for the site that provides the external hourly climate data. While several weather data formats are available, the Typical Meteorological Year (TMY2) format is commonly used. Appendix B describes typical weather conditions for Los Alamos.

To simulate a building using these tools, describe building parameters, such as assembly construction, volumes, and number of floors, along with their respective orientations. Account for the hourly variations in internal load conditions, such as occupant, lighting, and equipment loads, using hourly schedules. Also, enter HVAC equipment and operation schedules and lighting schedules. The simulation analyzes the conditions at the beginning hour and then the results are passed along to the next hour and so on throughout the simulation period. This process allows for the inclusion of thermal capacitance (mass) effects and solar impacts over time. The output of the simulation typically includes annual energy and cost data as well as hourly performance reports of the various building components.

#### Start early to simulate building energy performance

A detailed load analysis through computer simulation can identify energysaving opportunities early in the design process. Unfortunately, most detailed computer simulations, if they are used at all, are applied late in the process as a way to verify performance. At this point in the process, it is too late to change the major form, orientation, or fenestration of the building. With a baseline energy model created at the outset of the project, the energy performance can be monitored throughout the design process. Changes in the design should be entered into the model to assess the energy impact.





Operable clerestory windows automatically open when natural ventilation is appropriate for cooling the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio.

The computer energy simulation provides a method to test the integration of various design solutions to verify that they are meeting design goals. Decisions about building form, materials, and systems can be tested and adjusted to improve performance. Appendix F gives an example of how simulations were used to make design decisions throughout the design process for a laboratory/office building.

# When should the design team use computer simulations?

Begin initiating computer simulations early in the design process for maximum effectiveness.

- Pre-design Simulation helps identify and prioritize potential envelope-based energyefficiency strategies.
- Schematic design phase Add the building massing, fenestration, and envelope constructions to the model to determine if energy targets are still being met.
- Design development Test the performance of the full building together with the HVAC systems.
- Construction Evaluate how design changes proposed during construction will affect the building performance before implementing the change.
- Commissioning Run a simulation of the asbuilt construction to provide a baseline building performance that can be used for actual performance comparisons.
- Post-Occupancy Periodically update the simulation after the building is occupied to reflect variations in operations, use patterns, and unique climate conditions. These conditions may dramatically affect the actual performance of the building.

#### ocess"

The steps design teams take when following the energy design process are:

- Create a geometrically simple computer model of a code-compliant base-case building. This can be done in pre-design as soon as preliminary architectural requirements for the building have been defined in the F&OR document. A rule set for creating the base case is generally given in the performance path chapter of the applicable energy code. The code is usually 10CFR434 for federal buildings.
- Perform dynamic hourly annual simulations of the base-case building to determine annual energy loads, annual energy costs, peak loads, demand charges, hourly profiles for typical days representative of the climatic seasons, and occupant comfort. In addition to total energy loads, the software can identify the composition of the loads by end use (heating, cooling, ventilation, lighting, plug) and by source (window solar heat gains, envelope conduction, waste heat from lights and plug loads, etc.).
- Use the end-load disaggregation of building energy costs to understand energy issues associated with major functional spaces in the base-case building. This understanding can help generate potential architectural solutions to the energy loads. After optimizing the envelope design, use mechanical concepts and strategies to continue minimizing the energy costs without compromising the building's functional and comfort requirements.
- Simulate the design alternatives and trade-offs to measure their impact on energy performance and comfort compared to the base-case building and to each other.
- Conduct cost/benefit analyses of the various alternatives and trade-offs to understand what gives the most "bang for the buck."
- Reiterate through this process from pre-design through construction, commissioning, and occupancy.

## **Design of High-Performance Features and Systems**

The warm summers of Los Alamos coupled with the intense high-altitude sunshine make solar control of all fenestration one of the important design considerations. Uncontrolled solar gain results in high cooling loads, excessive illumination, and glare. The first strategy in passive cooling is solar heat gain avoidance, which can be achieved primarily through shading and glazing selection. Use solar angle charts for the Los Alamos latitude (36° N) to design shading devices that block unwanted solar gain at specific dates and times (see Appendix G). Glazing selection is also an important consideration in window design as it determines the visual, thermal, and optical performance of the window.

Gretz

#### Defining passive solar design

A passive solar building is designed to maximize the use of natural systems to maintain thermal comfort for the occupants. A passive solar building successfully integrates the site, the local climate and microclimate, the Sun, and local materials in order to minimize dependence on external energy sources. The term "passive" implies a conceptually simple approach that uses few, if any, moving parts or input energy, requires little maintenance or user control, and

results in no harmful pollution or waste byproducts. Because of the inclusive nature of passive solar design, considerations for passive solar design permeate the entire design process and become critical architectural elements.



#### Solar Shading

The most effective solar shading devices are exterior to the building envelope. Shades and blinds located inside the building may be effective at controlling glare, but are not effective in reducing the solar gain entering the space. Consider light-colored surfaces on shading devices such as overhangs, louvers, or light shelves. These light surfaces can help bounce diffuse sunlight into the building. Diffuse daylight is ideal for providing lighting without glare.

Consider a deep exterior wall section that can be used to self-shade the window surfaces with overhangs



Shading angles for a south elevation. Diagrams like this are used to determine the optimal size and location of shading devices. Depending on the building type and interior space, the goal may be to prevent solar gain in summer while allowing it in the winter, or to prevent direct solar gain year round.

Chapter 4 | The Building Architectural Design



Overhangs and vertical fins on the lower windows and the overhangs on the clerestory windows provide shade to maximize daylighting and minimize summer solar gains to the Thermal Test Facility, National Renewable Energy Laboratory, Golden, Colorado. and vertical fins. Move the plane of the glass toward the interior plane of the wall to get free shading from the wall thickness.

Solar shading is most easily and effectively handled on south and north elevations. One method of describing the horizontal overhang is the ratio of the horizontal projection (x) to the height of the window (y) below the horizontal projection (see Appendix B). Horizontal overhangs can adequately shade south-facing windows. North-facing windows receive predominately diffuse solar radiation and indirect daylight, and therefore do not need overhangs. East- and west-facing windows are the most difficult to shade. Early morning and late afternoon sun rays are approaching perpendicular to these windows, causing excessive heat gain and visual glare. Minimize use of east- and west-facing windows. When these windows cannot be avoided, carefully size and place them for daylighting and view purposes only. Use a combination of horizontal louvers and vertical fins to shade these windows as much as possible.



Horizontal and vertical shading ratios. This figure lists the appropriate x/y ratios for completely shading a south-facing window for various months at two different time ranges. Use the lower portion of this figure to determine the appropriate azimuth angle for shading an east- or west-facing window at various dates and times.

JULIMAY



Shading angle example. This figure demonstrates how to apply the horizontal and vertical shading ratio in sizing the horizontal overhang that will shade a south-facing window from 9 a.m. to 3 p.m., March 21 through September 21.

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## Shading Strategies

Glare control is another function of shading. Limit or protect the views of extremely bright exterior surfaces, such as parked cars and large paving or sand areas. The reflected glare from these surfaces can be visually uncomfortable.

Interior shading devices have limited solar control potential and they often depend on user control to function properly. More likely an occupant will set the shading device once and leave it in position for the remainder of the day. This is often the case on east- and westfacing windows where louvers or shades are drawn to



To maintain an exterior view while shading the window, consider fine mesh roll screens that reduce illumination and glare while allowing contact with the view. Another option is to use screens or louvers that operate upward from the window sill. This provides shade near the bottom of the window where it is often first needed while allowing an effective clerestory for daylighting.



South facade, horizontal architectural elements to shade the atrium windows of the Process and Environmental Technology Laboratory, Sandia National Laboratories, Albuquerque, New Mexico. Exterior shading devices and light shelves can often be designed as prominent aesthetic architectural features.



Mounting the shade below the top of this west-facing office window allows the occupant to close the blinds to control glare on the work surface while still permitting daylight to enter the space. This strategy also works well when controlling glare from extremely bright exterior surfaces, such as from a nearby parking lot. Light-colored shades are preferred over the dark shades shown in this photo.



## **Glazing Selection**

Select insulated low-e glazing units to reduce thermal loads and provide better comfort in perimeter zones. Low-emissivity (low-e) coatings and argon between the panes can dramatically increase thermal performance. Low-e coatings also can be specified to shade a higher fraction of the heat-carrying infrared radiation, while permitting more visible light to pass through. In general, spaces dominated by cooling loads should have glass with a low solar heat gain coefficient (SHGC), possibly with a reflective outer surface. Use glass with a higher SHGC in spaces dominated by heating loads to take advantage of passive solar heating. Always protect occupants of daylit spaces from glare and direct beam. Glazing optical properties, shading devices, glass area, and orientation are all highly interactive in terms of their effects on heating, cooling, and lighting loads. Simulation-based sensitivity studies are the best way to balance these effects. Be aware that spaces having good daylighting designs are likely to become heating-dominated spaces; whereas without daylighting, they would be cooling-dominated spaces. Also, it may be necessary to vary the glazing visual transmittance, depending on the window orientation, space lighting conditions, and occupant lighting needs.



Designers carefully selected glazing with a low solar heat gain coefficient to maximize daylighting and minimize solar gains for the Solar Energy Research Facility at the National Renewable Energy Laboratory in Golden, Colorado.

#### **Guidelines for Good Window Design**

- **1.** Size all windows to provide the best daylighting.
- 2. Add additional windows for view glass. Frame views without overglazing the space.
- 3. Specify glazing properties to minimize heating and cooling loads, and maximize visual comfort.
- 4. Place external overhangs on south-facing windows to prevent glare and summer solar gains. Depending on simulation results, some south-facing windows may be unshaded to allow for good daylighting.
- **5.** Use interior shade devices to provide user control of glare. Windows intended to provide daylighting should have been designed to prevent glare. Do not use shading devices on these windows.

Sun angle calculators, graphical shading software, and sun charts are helpful in establishing proper shading angles for different orientations and for various dates and times. See Appendix G for detailed instructions on making and using sun path diagrams. Physical daylight models and dedicated daylighting software (usually involving ray-tracing) are useful in assessing glare.

#### **Glazing Properties**

The choice of glazing materials for the various window orientations and functions is critical for both thermal and visual comfort. Consider these glazing properties when specifying windows.

Visible Transmittance (VT or Tvis): percent of the visible spectrum striking the glazing that passes through the glazing. This value changes with angle of incidence. While it may seem desirable to maximize the visible transmittance for daylighting, doing so often results in exces-



#### Glazing effects on transmitted solar energy.

sive window brightness. In the clear, intense sunshine of Los Alamos, a reduced visible transmittance will often be the better option to maintain visual comfort in the daylit space. Lower transmittance glazing will also typically result in better distribution of daylight at a more appropriate illumination level.

- Solar Heat Gain Coefficient (SHGC): ratio of total transmitted solar heat to incident solar energy. A value of 1.0 indicates that 100% of the solar gain enters the building. A value of 0.0 indicates no solar gain is entering the space. In Los Alamos, a low SHGC is desired on east and west facades (less than 0.35). Windows shaded by overhangs on the south facade should have high SHGC (0.70 or greater). North-facing windows can typically have high SHGC values.
- Shading Coefficient (SC): ratio of solar gain of a particular glazing compared to the solar gain of clear single and double pane glazing and many tinted single pane glazing windows (term found in some older documentation). The lower the number, the less solar gain is admitted. SC = SHGC x 1.15.
- Visible and Solar Reflectance: percent visible light or solar energy that is reflected from the glazing.
- UV Transmittance: percent transmittance of ultraviolet-wavelength solar energy (0.30 to 0.38 microns). High UV penetration will fade fabrics and can damage sensitive artwork.
- U-Value: measure of the rate of conductive heat transfer through the glazing due to a temperature change between inside and outside surfaces. Often given in a winter night Uvalue and a summer day U-value format. The lower the U-value, the better the thermal resistance of the window. Current window U-values are a composite of three heat transfer components of a window: the center of glass, the edge of glass, and the window frame. The total window U-value should be less than 0.35 for LANL buildings. U-value is the inverse of R-value (U = 1/R).

# **Designing for Daylighting**

When properly designed and effectively integrated with the electric lighting system, daylighting can offer significant energy savings by offsetting a portion of the electric lighting load. A related benefit is the reduction in cooling system capacity because the electric lighting operates less, lowering a significant component of internal gains. In addition to energy savings, daylighting generally improves occupant satisfaction and comfort. Recent studies show improvements in productivity and health in daylit schools and offices. Windows also provide visual relief, contact with nature, time orientation, the possibility of ventilation, and emergency egress. Refer to the F&OR document to recall which spaces will most benefit from daylight. Consider daylighting possibilities for every space *unless* a strong programmatic function does not allow daylight.

- Within the spaces that can use daylight, place the most critical visual tasks in positions near the window.
- Try to group tasks by similar lighting requirements and occupancy patterns.
- Carefully place the window in relation to the occupant to avoid extreme contrast and glare.

- When possible, locate computer monitors so that they are facing a window.
- Consider interior glazing that allows light from one space to be shared with another. This can be achieved with transom lights, vision glass, or translucent panels if privacy is required. Hallways can often be lit entirely by shared light.



Daylight entering the space through clerestory windows is reflected off the bright white ceiling to provide diffuse daylight throughout the ACE Hardware Store at the BigHorn Center in Silverthorne, Colorado.

## Window Design Considerations

A standard window typically provides daylight illumination to a depth of about 1.5 times the distance between the floor and the top of the window. Light shelves (see p. 64) or other reflector systems can increase this distance two or more times. As a general rule of thumb, the higher the window is placed on the wall, the deeper the daylight penetration. In most cases, daylighting designs are most effective within the first 25 feet from the window.

Daylight within a space comes from three sources:

**1.** The exterior reflected component includes ground surfaces, pavement, adjacent buildings, wide

window sills, and objects. Remember that excessive exterior reflectance can result in glare.

- 2. The direct sun/sky component is typically blocked from occupied spaces because of heat gain, glare, and ultraviolet (UV) degradation issues. Direct sun/sky is acceptable only when using patterned glass to diffuse the light.
- **3.** The internal reflected component is the daylight reflected off the surrounding wall, ceiling, and floor surfaces. Surfaces that are reflective but not specular reflectors will bounce the daylight around the room without creating uncomfortable bright spots.

Window frame materials should be light-colored to reduce contrast with the view, and should have a nonspecular finish to eliminate glare. The window jambs and sills can be beneficial light reflectors. Deep jambs should be splayed (angled to open toward the interior) to reduce the contrast around the perimeter of the window.

The most important interior light-reflecting surface is the ceiling. High reflectance paints and ceiling tiles are now available with 0.90 or higher reflectance values. Tilting the ceiling plane toward the daylight source creates a "bright" ceiling and improves the feeling of "brightness" in the space.







In small rooms, the rear wall is the next most important surface because it is directly facing the window. The rear wall should have a high-reflectance matte finish. The side walls, followed by the floor, have less impact on the reflected daylight in the space.

Major room furnishings such as office cubicles or partitions can have a significant impact on reflected light. Light-colored materials are important on those components as well.

The proportions of the room are more important than the dimensions. A room that has a high ceiling relative to its depth will have deeper penetration of daylight whether from sidelighting (windows) or toplighting (skylights and clerestories). Raising the window head height will also result in deeper penetration and more even illumination in the room.



DAYLIGHT CONTRIBUTIONS

Sources of daylight contributions.



#### Suggested room surface reflectances

- Ceilings: > 90%
- Floors: 20-40%
- Walls: 50-70%





## Effective Aperture

One method of assessing the relationship between visible light and the size of the window is the effective aperture method. The effective aperture (EA) is the product of the visible transmittance and the windowto-wall ratio. The window-to-wall ratio (WWR) is the proportion of window area compared with the total area of the wall in which the window is located. For a given EA number, a higher WWR (larger window) requires less visible transmittance.

#### Light Shelves

A light shelf is a horizontal light-reflecting overhang placed above eye-level with a transom window placed above it. This design, which is most effective on southern orientations, improves daylight penetration, creates shading near the window, and helps reduce window glare.

Exterior shelves are more effective shading devices, and actually increase the amount of light through the daylight aperture as compared to interior shelves. A combination of exterior and interior shelves will work best in providing an even illumination gradient.





Light shelves on this buildings bounce light onto the ceiling for deeper daylight penetration.



Effective aperture example. Adjust the visual transmittance to maintain equal effective apertures for windows of different sizes.



Separating the view aperture from the daylight aperture with a light shelf can improve the daylighting effectiveness by bouncing light deep into the room while at the same time maintaining comfortable luminance ratios through the view aperture.

## **Toplighting Strategies**

Large single-level floor areas and the top floors of multi-story buildings can benefit from toplighting. The general types of toplighting include skylights, clerestories, monitors, and sawtooth roofs.

Horizontal skylights are an energy problem because they receive maximum solar gain in summer at the peak of the day. Their daylight contribution also peaks at midday and falls off severely in the morning and afternoon. High-performance skylight designs address these problems by incorporating translucent insulating material, reflectors, or prismatic lenses to reduce the peak daylight and heat gain while increasing early and late afternoon daylight contributions.

Another option is lightpipes, in which a highreflectance duct channels the light from a skylight down to a diffusing lens in the room. These may be advantageous in deep roof constructions.



Skylight performance.





Translucent insulating skylight panels help to offset more than 75% of the electric lighting load in BigHorn Home Improvement Center's warehouse in Silverthorne, Colorado, without significantly impacting the building's heating and cooling loads.

A clerestory window is vertical glazing located high overhead. A properly designed horizontal overhang can effectively shade south-facing clerestories from direct sunlight. It is best to slope the interior north clerestory wall to reflect the light down into the room. Use lightcolored overhangs and adjacent roof surfaces to improve the reflected component.

If calculations show that direct winter sun on work surfaces is a problem, use a lightly patterned glass in the clerestory windows to diffuse the light. Another solution to control this glare is to install interior vertical baffles at the clerestory windows.

North-facing clerestory windows do not need overhangs. Direct gain through these windows is rarely a problem. East- and west-facing clerestory windows are problematic because of glare issues and excessive solar gain. Use simulations to determine if east- and westfacing clerestories are beneficial. A roof monitor consists of a flat roof section raised above the adjacent roof with vertical glazing on one or more sides. This design often results in excessive glazing area when glazed on all sides, which leads to higher heat losses and gains than a clerestory design. The multiple orientations of the glazing can also create shading problems.

A sawtooth roof is an old design often seen in industrial buildings. Typically one sloped surface is opaque and the other is glazed. A contemporary sawtooth roof



Clerestory section shown with structure passing through and supplemental night time lighting.



Roof monitor section shown with structure passing through and vertical glazing.

may have solar-thermal or solar-electric (photovoltaic) panels on the south-facing slope and north-facing daylight glazing. Unprotected glazing on the south-, east-, or west-facing sawtooth surface results in high heat gains.

In general, designs accommodating vertical glazing are preferred. Vertical glazing minimizes unwanted solar gains and reduce, the potential for maintenance problems.

## Daylighting Integration Issues

A daylit building without an integrated electric lighting system will be a net energy loser resulting from heat losses and gains through the windows and the electric lighting system operating more than needed. An integrated lighting system has energy-efficient lighting fixtures that operate only to supplement the available daylight. The savings from reducing the electric lighting load will offset – and exceed – the added thermal loads. See Chapter 5 for lighting control strategies.

Coordinating the electrical lighting system design with the daylighting design is critical for the success of the system. The layout and circuiting of the lighting should correspond to the daylight aperture. In a typical sidelighting design with windows along one wall, it is best to place the luminaires in rows parallel to the window wall, circuited so that the row nearest the windows will be the first to dim or switch off, followed by successive rows.

To maintain the designed performance of the daylighting system, the person responsible for interior finishes and furnishings must be aware of the desired reflectance values. Dark interior finishes can compromise an otherwise good daylighting design.



Sawtooth section shown with vertical north-facing glazing, supplemental night time lighting, and roof-mounted solar panels.



Photo sensors control the dimmable electric lighting to supplement the available daylight and maintain constant illuminance levels within the Harmony Library in Fort Collins, Colorado.

#### Daylighting Resources

Physical models are an effective way to analyze daylighting performance. Even simple models can begin to inform the designer of how daylight will behave in the building. For more detailed studies, the model should be at least 1" = 1' scale. This size model allows easy viewing to assess the daylight contribution and potential glare sources. The daylight apertures must be accurately modeled and the model must include the reflectance values of the surface materials. The model can then be tested on the actual site or under artificial sky conditions in a daylighting laboratory. A sundial for 36° north latitude (Los Alamos) attached to the model base allows the designer to simulate various dates and times of the year.

Computer analysis is another method of testing daylighting solutions. Several lighting programs such as *Lumen-Micro*,<sup>M</sup> *Radiance*,<sup>M</sup> and *Lightscape*,<sup>M</sup> have daylighting calculations. Typically, a three-dimensional digital model is constructed using computer-aided design software that is then imported into the lighting software. The programs then require the operator to define all surface characteristics, sky conditions, location, date and time. *Lumen-Micro* and *Radiance* can produce photo-realistic renderings of the proposed design, while *Lightscape* is useful for less detailed analyses early in the design process.



Sundial for use with a physical model.



Illustration of how to use a sundial with a physical model.

## **Passive and Active Solar Systems**

Passive and active solar systems provide sustainable methods of heating, cooling, and powering the buildings at LANL. Based on a careful analysis of the loads and the energy needs across the seasons, these systems can be used to supplant, or at least augment, off-site energy sources.

The Los Alamos high-altitude, dry and sunny climate offers great solar opportunities (see Appendix B). Passive systems can be incorporated into the design in a way that not only saves resources but celebrates the process as well. Always consider the potential benefits of energy efficiency and passive solar strategies early in the design process using computer simulation tools.

### Thermal Storage

Internal thermal mass has the ability to help moderate the interior temperature swings of the building in spite of variable internal loads and fluctuating exterior temperatures. It can also be used as a heat storage component in a passive heating and cooling system. In a heating mode, the mass will absorb solar heat and internal gains during a sunny day and then reradiate that heat later when it is needed. As a summer cooling strategy, the mass can be cooled with night air so that it is ready to absorb heat during the following day. Closing the pre-cooled building during the day will allow internal gains to be absorbed by the mass until it is flushed again later that evening. There are two types of thermal mass. One type is the solar-heated mass that is in direct contact with sunlight, such as floors and thermal storage walls. The other type is the distributed mass of the entire building.

Providing internal mass is counter to most standard building practices that strive for lightweight construction. Mass is typically available in the building's structure, in concrete floor slabs and exterior wall construction. To absorb and release heat on a daily cycle, the mass must be exposed to the interior space, and not covered with carpets, wall-coverings, or fireproofing. One of the largest sources of heat loss in





Installing rigid insulation under a floor slab minimizes conductive losses to the ground. Ground losses in welldesigned buildings without slab insulation can be the greatest source of heat loss in these buildings.

This Trombe wall design incorporates windows to provide daylighting. Horizontal elements in front of the Trombe wall shade it during summer.

buildings today is through the floor slab. Rigid insulation under a floor slab is important to minimize conductive losses to the ground and allow the slab to better moderate the interior thermal conditions. Insulate massive exterior walls on the *outside* surface of the mass to decouple the mass from the external environment and improve thermal performance of the wall.

Water is a very effective thermal storage medium because of the high thermal capacity, and high effective diffusivity. Detail water storage systems carefully to avoid leakage.

#### Trombe Wall

A Trombe wall, or thermal storage wall, is a mass wall, with an airspace and an exterior glazing surface. The wall gathers solar heat through the glazing and a black or selective coating absorbs the heat. The heat moves slowly through the wall to help heat the interior several hours later. In Los Alamos, the Trombe wall should be adequately shaded from summer sun. Trombe walls are appropriate for providing supplemental heat and for building spaces with low levels of thermal control such as warehouses, loading docks, or storage areas.

## Passive Cooling Strategies

The first step in passive cooling is to minimize the cooling load by providing effective external window shading and not oversizing the windows. Glazing selection is also important in reducing the solar loads on the building. In addition, turn off or dim electric lighting systems to take full advantage of the daylighting entering the building while at the same time reducing cooling loads. Finally, minimizing plug and equipment loads will also help the cooling loads (see Chapter 5). Movable awnings, roll-down shades, or shutters can also shade building surfaces.



Trombe walls absorb heat during the day and release it into the space at night. An overhang shades this Trombe wall in summer when passive heating is not needed. View glass above this Trombe wall provides daylight to the interior space.



Trombe wall cross section with daylighting aperture.

Landscaping can help reduce cooling loads. However, the building design should not rely on landscaping for shade because it takes years for new landscaping to mature, and then mature landscaping may die or be damaged. Low-fire-hazard landscape materials that shade building surfaces can help reduce the solar impact on the building envelope. Plantings may also be beneficial in blocking winter wind or channeling summer breezes. Chapter 7 contains more information on climate-sensitive landscaping.

#### Natural Ventilation

Los Alamos has many days when favorable outside temperatures can help condition the building. Take advantage of these conditions and use natural ventilation to reduce mechanical cooling loads. Natural ventilation systems work well whenever a traditional economizer cycle is a good design decision.

The building architecture will impact the success of a natural ventilation design. Operable windows located high in spaces can release hot air. Operable clerestory windows can easily provide all the ventilation requirements of a space, especially in high-bay areas. Tall ceilings produce a "stack effect" by inducing air movement as the warm air is drawn out through the high windows. Carefully coordinate the automatic control of these high, operable windows with the mechanical system design. Turn off the mechanical system when windows are open.

Under certain conditions, natural ventilation can be augmented with air movement from ceiling fans or outdoor breezes.



Window actuators automatically open these clerestory windows for natural ventilation cooling. Warm air is drawn out the high windows because of the stack effect. Natural ventilation is most appropriate in dry climates having large diurnal temperature swings.

#### **Evaporative Cooling**

Evaporative cooling is an adiabatic process in which warm dry air takes on moisture, lowering its temperature in the process (direct evaporative cooling). Indirect evaporative cooling can lower the air temperature without adding moisture to the building air by using a heat exchanger between the evaporatively cooled air (which is then purged to the outside) and the building supply air. A combined indirect/direct evaporative cooler extends the design conditions under which evaporative cooling can sufficiently meet space conditioning requirements.

Most evaporative cooling systems are "active" in the sense that blowers are used (see Chapter 5). A passive alternative is the "cooltower" approach. This strategy involves integrating with the building architecture a tower with wetted surfaces exposed to the air. As the air hits the wet pads, it takes on moisture and cools. Because this moist air is denser than the surrounding air, it falls down the tower and into the building and generates a self-perpetuating air current, a form of natural ventilation.

The Los Alamos water supply has a high mineral content that can quickly clog evaporative pads. Check the water supply properties before using evaporative cooling.

### Passive Solar Heating Strategies

The Los Alamos climate provides good opportunities for passive solar heating. The basic passive solar heating systems are direct gain systems (sunlight entering a window), indirect gain systems (sunspaces or atria), and thermal storage walls (Trombe walls). In warehouses or storage areas with only periodic occupancy, passive solar heating may be sufficient for all the space heating needs.

Glare can often be problematic in direct passive solar heating designs. Areas such as break rooms, hallways, and entries can tolerate direct solar gains for supplemental heating because glare is not a big issue in these spaces.



Cool moist air generated by air flowing through a wet medium at the top of the cooltower "drops" through large openings at the tower base to cool the space.



Downdraft cooltower at the Zion National Park Visitors Center, Springdale, Utah.

Use computer simulations to evaluate the effect of more glazing on the annual energy loads before increasing the amount of glazing on the building for more winter solar gains. Some spaces having high internal loads may not need additional heating, even in the winter. In these spaces, size the glazing to only provide the desired amount of daylight. Overhangs must be properly sized to avoid overheating of the space during the summer. If incorporating passive solar heating strategies, then select glazings having a high SHGC to maximize the passive solar potential.

Los Alaho

#### Active Solar Heating Systems

Typical applications of active solar heating include domestic hot water heating, space heating (air or water), and ventilation air preheating. Of these, ventilation air preheat tends to be the most economical.

First, determine that the building use is appropriate for an active solar application. Determine the feasibility of using active solar systems in conjunction with the overall mechanical system design (see Chapter 5).

Solar hot water system collectors can be either mounted directly on the building or rack-mounted near the building. Installation is usually simpler and the collectors are more attractive if they are integrated into a roof surface or installed flush with it. Even if solar collectors are not part of the initial design, it may make sense to design roof surfaces with future solar installations in mind.

A general rule of thumb is that the vertical tilt angle of the south-facing collector should equal the latitude angle (36° for Los Alamos) for year-round use such as domestic hot water heating. A solar space heating system would benefit from a steeper tilt angle (about 50°) to maximize solar gain in the winter, when the sun is lower in the sky. The collectors should have an unobstructed view of the sun path from at least 9:00 a.m. to 3:00 p.m. throughout the year. Beware of light reflecting off the glass-covered collectors as it can create uncomfortable glare in nearby buildings.



The tilt angle is measured from horizontal upward, facing true south.

Sustainable Design Guide



The solar domestic hot water system for the LANL Otowi Building is mounted flush with the roof.

Chapter 4 | The Building Architectural Design

#### Transpired Solar Collector

A transpired collector is a simple, efficient method of heating ventilation air. The system consists of a dark, south-facing, perforated, metal surface that also acts as the building's exterior protective skin. The sun heats the dark perforated wall. A centrally located fan at the top of the wall draws air through the perforations. The air is heated as it travels up behind the heated wall. The fan then distributes the warm air into the interior space.





The transpired solar collector is the only heating system for this small waste handling facility at the National Renewable Energy Laboratory in Golden, Colorado.



Transpired solar collectors are the most efficient active solar heating systems, having efficiencies exceeding 60%.



Red transpired solar collector installed as a retrofit on the entire south wall of the Federal Express building in Englewood, Colorado. Almost any dark color can be used for the perforated wall, giving some architectural flexibility. Choosing colors other than black has only a small effect on the system performance.

## Solar Electric Systems

Solar electric systems (also known as PV systems) use the direct conversion of sunlight to direct current (DC) electricity. The four major types of PV cells in order of highest to lowest performance and cost are single crystal, polycrystalline, thin film, and amorphous silicon cells. The cells have a long life and are almost maintenance free. The cells are assembled into modules and the modules are connected into arrays. The type of cell connection determines the voltage and current of the array. The power generated by a PV array is instantaneous direct current while the sun shines. Most systems include alternating current (AC) inverters and some include batteries for storage.

PV systems may be stand-alone or utility-grid-integrated. A stand-alone system is applicable to remote locations that are at least one-quarter mile from utility connections. For stand-alone systems, a fuel generator and/or batteries may be used to provide electricity during periods of insufficient solar radiation. A grid-integrated system supplements utility power. In buildings having an uninterruptible power supply (UPS) system, the PV system can charge the UPS battery bank and supply supplemental power to the building.

Like active solar collectors, PV arrays may be mounted directly on the building or on nearby racks. Buildingintegrated PV modules are available as roofing tiles, shingles, standing seam metal roofing, spandrel panels, or as partially transparent shading elements. The building site might incorporate PV arrays as shading devices for parking areas, pedestrian walkways, or outdoor gathering spaces.



PV modules integrated as a part of the standing seam metal roof system.



The method for installing a PV-integrated standing seam metal roof is the same for a similar type roof without PV.

PV systems are still quite expensive when grid power is available, but improvements in efficiencies, manufacturing, and storage systems promise to reduce the total system cost of future PV installations. It may be desirable to plan building surfaces with proper solar access and wiring access points for a future PV system. PV systems sometimes make economic sense when very high-quality, uninterruptible power is needed.



60-kW roof-mounted PV system offsets 50% of the annual electrical load of the Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio. The building design must consider the safety of the occupants, protection of the building, and preservation of building functions as top priorities. LANL operational and facility safety and security is another top priority. Specific design requirements for elements including, but not limited to, exterior lighting, security fencing, vaults, vault-type rooms, computer networks, interior and exterior intrusion alarms, monitoring alarms, access control systems, and facility-wide administration requirements are contained in the LANL document "General Security, Laboratory Implementation Requirements LIR 406-00-01.0" (Attachments 2 and 8).

Most strategies that improve energy efficiency and building performance will tend to enhance building security by promoting independence in building energy use. A building less dependent on electric lighting and mechanical cooling can provide functioning space in times of power outages. A building that uses significantly less fossil fuel is less impacted by foreign shortages or embargoes. A standby power system operated by PV may allow the building to function well into an extended power outage.

Other safety threats affect high-performance buildings just as they would affect any building. Building controls and air distribution systems must be protected from sabotage. At a minimum, the ventilation or make-up air intakes should be protected from possible contamination or tampering.



# **Accommodating Recycling Activities**

It is estimated that the typical office building generates approximately one pound of waste per day for every occupant. Design features encouraging recycling help divert waste from over-burdened landfills. They also save virgin materials and a large component of the energy necessary to process materials into final products. For example, recycling aluminum can save up to 95 percent of the energy used to first produce the aluminum.

Identify the potential waste streams that the facility will produce (Chapter 2). Formulate plans to handle the separation, collection, and storage of common recyclable materials such as paper, glass, plastics, and metals. Make the collection points easily accessible to occupants. For example, separate chutes in a multistory building may be dedicated for the various recyclables. In low-rise buildings, provide at least one collection point on each floor level. Design the loading dock or dumpster area for easy central collection. Identify all recycling needs and facilities during the design phase and incorporate them into the building plans. Making these decisions early can save floor space by avoiding later placement of recycling collection centers after the building is occupied.



Typical makeshift recycling collection center in office spaces can be avoided if recycling activities are anticipated and accounted for during the design phase.



Waste haulers typically remove recyclables from central collection areas. Employees can be encouraged to bring recyclables from home to increase the volume for more frequent pickups by the waste hauler.

	Standard Practice/	Better	High Performance
Relationships of Interior Spaces	○ No attention to daylight or energy issues	<ul> <li>Highly occupied spaces located near perimeter</li> </ul>	<ul> <li>Highly occupied spaces on south and north sides, spaces grouped for optimal energy zone configuration</li> </ul>
Siting the Building	<ul> <li>No attention to solar access or prevailing winds</li> </ul>	<ul> <li>Site review for adequate solar access at fenestrations and solar collectors</li> </ul>	<ul> <li>Site review includes attention to impact of the project on neighboring buildings, potential future threats to solar access</li> </ul>
Building Orientation	<ul> <li>No attention to sun paths or wind directions</li> </ul>	<ul> <li>Facades with most fenestrations oriented to the south and north</li> </ul>	$\bigcirc$ Roof slopes oriented for solar collection
Massing	$\bigcirc$ No attention to energy or daylighting	<ul> <li>Building shape slightly elongated to increase perimeter zone for daylighting</li> </ul>	C Elongated or finger-plan shape with most occupied spaces along north or south wall
Energy Simulations	<ul> <li>Only done to comply with DOE Order</li> <li>430.2A Title II reporting requirements</li> </ul>	<ul> <li>Used during design development to evalu- ate energy-related details</li> </ul>	<ul> <li>Used throughout the design process to inform key decisions</li> </ul>
Glazing Selection	<ul> <li>Double-glazed insulated units throughout, possibly tinted</li> </ul>	<ul> <li>Low-solar-gain, low-e glazing used throughout</li> </ul>	<ul> <li>Glazing U-value, visible transmittance, and solar heat gain coefficient optimized for each elevation and application</li> </ul>
Daylighting	<ul> <li>Perimeter spaces receive some daylight through view glazing</li> </ul>	<ul> <li>High windows, skylights, and increased perimeter extends the usefulness of the daylighting</li> </ul>	<ul> <li>Light shelves, overhead glazing, and electric light integration designed using daylight design software and/or physical models to maximize daylighting and the resulting energy savings</li> </ul>
Thermal Storage	○ Not considered	<ul> <li>Some exposed mass provided in the build- ing to moderate temperature swings</li> </ul>	<ul> <li>Extensive exposed mass linked to night- flushing to reduce cooling loads</li> </ul>
Natural Ventilation	<ul> <li>Not provided</li> </ul>	<ul> <li>Operable windows enhance occupant satisfaction, but lack building control integration</li> </ul>	<ul> <li>Operable windows linked to building control system for optimal energy benefits and occupant satisfaction. Building designed to maximize air flow patterns and stack effect.</li> </ul>
Solar Electricity (PV)	Not considered	<ul> <li>Building designed for future PV, including electrical conduit and power panel availability</li> </ul>	<ul> <li>Building-integrated PV panels generate electricity and contribute architecturally</li> </ul>

#### Additional Resources

Daylighting for Commercial, Institutional, and Industrial Buildings, Consumer Energy Information, EREC Reference Briefs. *www.eren.doe.gov/ consumerinfo/refbriefs/cb4.html* 

Tips for Daylighting with Windows: The Integrated Approach, Lawrence Berkeley National Laboratory. *http://windows.lbl.gov/pub/designguide/ designguide.html* 

*Sun, Wind & Light,* Second Edition. G. Z. Brown and Mark DeKay, John Wiley and Sons, New York, NY, 2000

General Security, Laboratory Implementation Requirements. LANL document LIR 406-00-01.0 (Attachments 2 and 8)

*IES Lighting Handbook,* Ninth Edition. Illuminating Engineering Society of North America, New York, NY, *www.iesna.org* 

Advanced Building Guidelines, 2001 Edition. New Buildings Institute, White Salmon, WA.: *www. newbuildings.org*  *Daylighting Performance and Design.* Gregg D. Ander, AIA, Van Nostrand Reinhold, New York, NY, 1995.

Architectural Lighting, Second Edition. M. David Egan and Victor Olgyay, McGraw-Hill, New York, NY, 2002.

Concepts and Practice of Architectural Daylighting. Fuller Moore, Van Nostrand Reinhold, New York, NY, 1985.

Daylighting Design and Analysis. Claude L. Robbins, Van Nostrand Reinhold, New York, NY, 1986.

*The Passive Solar Energy Book.* Edward Mazria, Rodale Press, Emmaus, PA, 1979.

International Energy Agency Building Simulations Test (IEA BESTEST) and Diagnostic Method. R. Judkoff, J. Neymark, NREL/TP-472-6231, National Renewable Energy Laboratory, Golden, CO, 1995.

Lumen-Micro by Lighting Technologies, *www.lighting-technologies.com/* 

Radiance http://radsite.lbl.gov/radiance/HOME.html

Lightscape by Autodesk, http://usa.autodesk.com/ adsk/section/0,,775058-123112,00.html

Building Energy Software Tools Directory, *www.eren. doe.gov/buildings/tools\_directory/subject.html* 

FEMP Federal Technology Alert, Transpired Collectors (Solar Preheaters for Outdoor Ventilation Air), www. eren.doe.gov/femp/prodtech/transfta.html

FEMP Low-Energy Building Design Guidelines, www. eren.doe.gov/femp/prodtech/low-e\_bldgs.html

FEMP Technology Profile: Transpired Collectors, www. pnl.gov/techguide/36.htm

Zion National Park Visitor Center: Significant Energy Savings Achieved through a Whole-Building Design Process, www.nrel.gov/docs/fy02osti/32157.pdf

Sustainable Building Technical Manual, www. sustainable.doe.gov/pdf/sbt.pdf

