Fresh Air and Daylight: Designing Natural Environments

Manufacturers are providing opportunities for fresh air in buildings while integrating day lighting techniques for increased energy efficiency.

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Challenged to reduce the energy use of buildings, architects juggle their options to design for daylight and fresh air. The dualities include: opportunities to control heat-gain or provide views and natural daylight; control humidity or provide fresh air through an open window; provide an energy-efficient envelope with good passive solar orientation; or allow for the magnificent views to the north and west of the project location. Energy-efficient windows/window walls and day lighting devices are part of the solution for these environmental design dilemmas.

This article explores new manufacturing solutions to energy-efficient design problems. Topics include the components of energy-efficient windows, including thermally broken frames, sun shades and light shelves, low-voltage mechanical systems to operate window sensors and the selection of high-performance glass to meet the U.S. Environmental Protection Agency's ENERGY STAR targets.

Engineers might argue that a totally energy-efficient building would have very few windows and a very efficient mechanical system. Machine-designed humidity controls are contradicted by the demand for personal controls of fresh air. Opening a window, skylight or door may compromise the highly tuned balance of a mechanical system that can modulate fresh air intake through design and controls. Odors, allergens, volatile organic compounds released from building materials and mold hidden in air duct cavities are just a few of the pollutants that can accumulate through poor maintenance practices. Buildings are designed to become extremely efficient enclosures in order to save energy. Walls contribute more insulating values than windows. Design professionals often work with engineers to limit the effects of window openings on an energy model of a building design and new windows provide more insulating values than ever before.

A case for the environment

Humans spend 80 to 90 percent of their day inside and studies show that a controlled indoor environment needs to provide similar characteristics to the natural environment. A 1999 study of daylight and indoor air quality conducted by the Herschong Mahone Group for Pacific Gas & Electric,[1];concluded that natural light and good indoor air quality have a direct impact on student performance. This research demonstrated a significant rise in reading and math test scores in day lit schools vs. non-day lit schools. Studies of the effect of daylight in health care settings, as well, demonstrate the benefits of daylight on human well-being.[2] Other researchers have concluded that there is also a positive link between daylight and worker productivity.[3] There is, in fact, a growing body of evidence to encourage the architect to include daylight and natural ventilation in all projects. Window systems allow the architect to engage nature through design.

In addition, designers using operable windows can achieve credits through green rating and certification programs. The Leadership in Energy and Environmental Design (LEED) green building rating system provides credits for Indoor Environmental Quality and for Optimizing Energy performance based on designing for fresh air and daylight. LEED also provides credits for using products that incorporate recycled materials, and are manufactured within a local radius.

Sustainability is both the effect on the project of the component, and the life cycle impact of the making of the manufactured product. Many companies are changing their means of production, using recycled products, as well as recycling waste and reducing overseas manufacturing. Many are embracing recycling and waste policies that encourage both an increase in their bottom lines, as well as creating testaments to good stewardship. This is good news to designers who are committed to a focus on sustainable design.

One such manufacturer, for example, has developed new shipping crates made of recycled and recyclable materials, as well as continuing to add to their supplies of various certified wood products as frame alternatives. Ebrahim Nana of Nana Wall Systems, Inc. commented on research in Europe that is now evaluating materials for even higher environmental performance and better non-toxic coatings and finishes. Other companies participate in the EPA National Environmental Performance Track that establishes and tracks company goals for environmental improvements in products and manufacturing. Most provide an environmental company policy, identifying their company approach to the environment, which may include a life cycle analysis of their product.

In *Design by Climate*, the 1962 text on environmental design, Victor Olgyay urged architects to use a bioclimatic approach to design. He taught architects an approach to designing with nature — using the elements of the microclimate, solar orientation, and solar control and shading devices of each building location. In addition, the designer was instructed to understand air flow, and the principles of air stratification in buildings. Continued design development and research demonstrate that integrating day lighting and ventilation strategies into building designs results in projects that use less energy while creating healthier spaces for human performance.

Design Opportunities

It is no surprise that humans thrive in environments that are linked to nature. Among The American Institute of Architects Committee on the Environment's (COTE) 10 measures of sustainable design are principles that encourage architects to use bioclimatic design and provide daylight, natural ventilation and views to nature.

As an example, IslandWood is an outdoor environmental center designed by Mithun Architects +Designers+Planners. Designers for this 70,000 sf facility in Washington State used Thermal Analysis System (T.A.S.) modeling to integrate the building form and fenestration in order to minimize heating and cooling through mechanical systems. The placement of smaller windows on the windward side of the walls used the stack effect to draw air through the building and up into the operable clerestory windows. Interior walls were designed to aid air-flow through the building. Designers continued to model ventilation and airflow throughout the schematic design.

More windows require more design initiatives for sun control. Commercial window systems can also provide custom-designed shading devices to control glare, such as those displayed on Cosby Road High School, located in Midlothian, VA. Designers may wish to employ a combination of shading strategies, which may mean custom exterior light shades combined with interior light shelves in the same window system.

Furthermore, architects such as Cheryl Walker, AIA, LEED AP of Gant Huberman Architects, are using a wide variety of integrated design approaches to daylight. Walker states, “Increasingly, our firm is integrating day lighting strategies into buildings. When truly integrated with the building energy systems, features such as performance glazing, solar shades, light shelves, and roof monitors routinely contribute to a 20 to 30 percent reduction in the building’s energy consumption. The quality of the day lit interior is frequently our clients’ favorite feature of their project.”

To meet the newest environmental challenges, manufacturers are investigating the next generation of windows with even greater energy performance. According to Joe Rapolla, representative from La Cantina Doors, “The future is in the glass and multi-coated technologies.” Maureen Faccia, Director of Marketing at Milgard Windows & Doors adds, “Smart window design, frame construction and materials, as well as insulated glass units can exceed ENERGY STAR performance standards by up to 26 percent.”

In addition, some companies are introducing tubular day lighting devices, which allow for horizontal and vertical runs of over 100 feet, providing even more opportunities for substitutions of electric lighting fixtures. The good news is that there will be more products available for architects meeting the American Institute of Architect’s call to reduce energy consumption in buildings by the year 2030.

Fresh Air

Most architects know that building occupants complain if their space is too cold, too hot, too humid or too drafty. Mechanical systems are designed to meet average temperatures within a designated human comfort zone. These systems limit personal controls for comfort, and often are compromised when someone opens a window to let in fresh air. Providing fresh air in large structures can be problematic without integrating the aspects of daylight design with ventilation strategies.

The U.S. Green Building Council reference guides for LEED recommend that designers follow the Carbon Trust “Good Practice Guide 237” (1998) for information on how to naturally ventilate an occupied space. Designers are required to use computer models and provide diagrams and calculations to demonstrate that ventilation designs meet the recommendations in the Chartered Institution of Building Services Engineers (CIBSE) Manual 10:2005, *Natural ventilation in non-domestic buildings*.

Today, the primary reference for ventilation strategies is the American Society for Heating and Refrigerating Engineers (ASHRAE) 62.1-2004, paragraph 5.1, which describes the latest ventilation guidelines. Designers follow ASHRAE standards to design for comfort zones, as illustrated in ASHRAE's bioclimatic chart. Design components that are necessary to achieve indoor comfort based on the outdoor conditions are determined through a climate analysis of the site's location.

Ventilation Strategies

In addition to providing opportunities for personal controls, architects are using ventilation strategies to assure fresh air in buildings in the eventuality of mechanical failure. The principles for designing appropriate air flow strategies from operable windows include an understanding of the microclimate surrounding the building.

Exterior wind flow patterns are important factors when determining how to cool a building or how to provide relief from vapor pressure when it is humid. Exterior wind flow can be modulated through landscaping or through the manipulation of positive air flow on a building. New design solutions to modulate temperature and humidity include the design of multi-layered glass enclosures and vegetated screens.

Air flow strategies include an understanding of the convective loop. Hot air rises and is lighter than cold air, creating a convective loop that can be manipulated by designers to draw air through a building. A "stack effect" can be created by opening the lower windows in the room to the windward side of a building and providing an outlet in the upper windows of the room on the opposite side. To be successful, each room should be modeled to determine if there are obstructions to air flow, such as room dividers. Vertical shafts can also be used to draw air through a building, however, a vertical shaft used to provide an exhaust pathway must meet fire codes. Designers need to manipulate and measure the following elements of indoor air flow:

- Interior wind flow patterns with respect to interior partitions— designing for multi-zone air-flow
- Air stratification principles, such as the location and size of inlet openings
- The effect of overhangs over windows, including exterior or interior blinds and shading devices
- Types of window openings, such as awnings, casements, pivots, and sliders

Many of these strategies can be tested by designers through building integrated modeling and evaluated by mechanical engineers throughout the entire design and construction process. The size of a building, its orientation and location can also determine the success or failure of ventilation strategies.

Window Mechanics

A window system in a wall, roof or door should open easily in order to function properly. Windows can be opened manually by individuals or low voltage controls can be provided by window manufacturers to automate the integration of window openings. Ideally, a window will open to meet the demands of changing weather patterns. Each window type has unique locking and operating characteristics.

Double-hung windows are opened by releasing the locks and pulling on the lift and should be measured by the ease of operations. Rollers should be equipped with vents and nylon roller housings containing 2 acetyl nylon rollers each. The lock should be a self-aligning, cam-action lock designed for its ease of opening, locking and unlocking.

Awning windows are often chosen by green designers to channel air flow through buildings. Some of the components of an energy-efficient fully automated awning window, or roof enclosure system include:

- Low voltage electric remote controls — U.L.I.-listed and C.S.A.-approved rain sensors
- Compatibility with frame profiles and crank mechanisms
- Computer operated controls with the ability to monitor off-site
- Temperature controls that can be set to an LED display
- Optional manual controls or interruptible power supply
- Personal controls through infrared sensors
- Safety mechanisms, which include motor reverse systems and screen interlocks
- Maintenance guarantees for durability and replacement

Window Hardware and Automated Controls

The Construction Specification Institute (CSI) provides standards for automated controls, as well as for window hardware. Designers should choose hardware that will not compromise energy efficiency through heat loss and thermal bridging. Components should be rated for ease of use and the performance values should match those of the window class for operability.

Views to Nature — Operable Glass Walls

Expansion of interior space to include exterior rooms can be challenging for energy conscious designers. In her *Not So Big House* books, architect Sarah Susanka, AIA, has shown designers how to expand small spaces by using a variety of visual tools. Operable glass walls can be effective as a means to remove the visual and physical barriers to the outdoors, increasing the sense of space and dimension of smaller building footprints.

An effective glass wall is weather-resistant and has water penetration ratings proving its ability to prevent leaks and meets or exceeds The American Society of Testing and Materials Standards (ASTM). ASTM E-283 is the"Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls and Doors Under Specified Pressure Differences." ASTM E-547 is the "Standard Test Method for Determining Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure." Occupants should not feel drafts as they sit adjacent to the windows that have large glass openings.

Many of these systems use recycled aluminum and other recycled materials in the frame construction. Some manufacturers supply options to designers to choose wood that is certified by the Forest Stewardship Council (FSC). The FSC is the only non-profit organization recognized by the U.S. Green Building Council as providing certified chain-of-custody for sustainable wood products, as well as requiring worldwide sustainable forestry practices. As with a high-performance window, the leading glass wall systems provide designers with the options to choose window glass with high-energy performance ratings, as well as good acoustic properties.

Sunshine: Natural Light

Whether the building occupant looks out on a parking lot, a busy street or a forest, windows allow a view to the sky and to natural light. Humans respond to the biological effects of daylight; that is, we respond to the circadian rhythm that affects behavior and productivity. The primary tool for designers who wish to maximize daylight into a building is to understand building orientation and solar access. Studies have proven that solar energy, radiation, warmth and light can provide environmental savings.

The components of natural sunlight include visible light, ultraviolet radiation, and infrared radiation. Visible light can cause glare on a work surface particularly in the late evening and early morning when the sun is low in the sky and if the building faces east or west. Ultraviolet rays add heat to a room. In passive solar design, an architect can store this heat as needed, particularly in a colder climate and may choose a clear glass to allow for greater solar gain. Infrared radiation is the component of sunlight which causes interior finishes to fade. Intelligent solar design includes the ability to moderate visible light while preventing glare, fading and excess heat into the design space.

In the Northern Hemisphere, as the sun moves across the sky in an east–west axis, solar radiation varies across the face of a building. The south building façade will be the warmest throughout the year. The east and west façades will be colder in the winter and warmer in the summer. The north façade of a building will not receive any direct sunlight, only diffused daylight. The amount of solar energy available to heat a building varies throughout these natural cycles. In addition, in the summer, the angle of the sun is higher in the sky than it is in the winter. These solar angles can be calculated to determine how much daylight will be allowed into interior spaces. An easier procedure is to use one of the many solar calculators available in most computer software programs, which can show a variety of options depending on the latitude and longitude coordinates of the project.

Daylight Devices

Neither a wall, a window, a skylight or a roof, tubular daylight devices (TDD) have now achieved their own section in the Construction Specification Institute's (CSI) Division 8, which identifies doors and window properties. TDDs use refractive and reflective technologies to direct diffuse daylight into interior spaces from rooftop openings. Technological advances allow for long horizontal runs, as well as providing the ability for designers to dim these natural sunlight fixtures. They can be used in place of electric lights providing a static distribution pattern. The only difference is that the TDD allows for the welcome shifting light levels of natural daylight as it reflects the exterior sunlight condition. TDDs are combined to work with automated lighting to provide a constant source of lighting to any type of interior environment, from displays, conference rooms, offices and even large warehouses. The following three factors are important to specifying a TDD:

1. The optical efficiency of the TDD and the percentage of light that travels from the roof to the interior space
2. A low U-Factor, which measures the resistance to heat loss through the system
3. A low Solar Heat gain coefficient, which is a measure of how well the TDD blocks heat admitted through the product.

TDDs collect daylight not through mirrors, but through angled indices, which as Neall Digert of Solatube International states, "Shatter the light to use optics to overlap 100 percent of the sun's rays, which minimizes the potential of glare to diffuse and focus daylight."

Daylight Harvesting

Designers use their knowledge of the sun's angles to design light shelves, as well as light shades to manipulate sunlight. Daylight harvesting can be provided through the use of light shelves installed either to the interior or exterior of a window system.

A window can be divided into two sections. Vision panels are windows within the vision range of an average adult, typically any window below 7 feet. After calculating the solar angle from grade, the designer can determine the length of a light reflective shelf that will interrupt the solar angle of daylight and penetrate the interior of the building. Direct daylight can cause glare on the work plane. A highly reflective light shelf below an upper window deflects light onto other surfaces in the interior. The length of the shelf, the angle and the orientation determine how deeply sunlight will travel. Light is diffracted at a 90 degree angle and additional diffractions within a space can occur by designing ceiling surfaces, as well as additional interior light shelves, which continue to reflect daylight throughout the structure.

Direct sunlight can be deflected away from a building in hot climates or directed to a building in cold climates. Designers often choose to orient buildings so that the north and south faces have the longest solar exposures. This orientation provides greater solar gain for passive solar strategies. In many cases the program of a building requires that the building has longer exposures to the east or west. Shading devices for these exposures must be designed as vertical attachments. The length of these devices can also be calculated through modeling programs based on the latitude and longitude of the project location.

Window blinds are another means to modulate daylight. Window blinds can be used to decrease the air conditioning load caused by solar heat gain. Most blinds can be pivoted to direct and diffuse the sun's rays throughout the day. Blinds can be specified in both vertical and horizontal shade configurations. Dust, airborne allergens and replacement costs from damage are common problems for this convenient solution. Some window systems provide the alternative of blinds sealed within the panes of glass where they are maintenance-free, minimally invasive to interior space and conform to stricter fire ratings of commercial spaces. This solution also provides the opportunity to open the window while still modulating the daylight.

Window Glass Technologies

Building envelopes that protect a building from sun, wind and rain, as well as provide insulation, ventilation and daylight were the dream of Michael Davies. In the 1980s, Davies envisioned these "walls for all seasons" as *polyvalent*.[4] Window glass is required to meet greater-than-ever standards for performance, providing a barrier for unwanted solar radiation while allowing the greatest amount of visible light into the spaces. Windows can comprise between 10 percent to over 25 percent of a heating load of a building and even more of the cooling load. Architects can specify windows with multiple panes of glass, with solar controlled coatings, low emissivity and low-conductance gas fills.

The skin of a building responds to the demands of a climate for heating and cooling. Adding layers to a window increases its insulation values and can minimize heat loss or heat gain in hot or cold climates. The space in between the layers of glass provides insulation by means of an air space. Newer window products include the use of low-conductivity gases such as argon or krypton. Argon is produced by the partial distillation of liquid air, and it is inexpensive to produce since it is already a byproduct of liquid oxygen and liquid nitrogen. Inert argon gas is not flammable, will not explode and is not toxic to the environment, according to the Canadian National Occupational Health & Safety Resource Center. Krypton has even greater insulating properties and it is also nontoxic. These materials increase the energy performance of windows.

Window coatings provide a barrier to the invisible, yet harmful infrared and ultraviolet rays that comprise over 60 percent of the solar spectrum. Low-E coatings are made of metallic oxides bonded in thin layers to glass surfaces and act like a mirror to reflect the rays of the sun. Coatings change the appearance of a window and designers who want to "tune" window performance to orientation of the building façade should be aware of this consequence. New products on the market are coatings that increase the visible light transmittance above 65 percent (a clear single-pane window has a 90 percent visible light transmittance), while having a solar heat gain efficiency rating of .27 (a clear single-pane window has a solar heat gain rating of .87).

Labeling Daylight, Fresh Air and Energy Efficiency

Many architects are familiar with ENERGY STAR, which is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. Residential windows, doors and skylights are labeled with the ENERGY STAR logo, which provides the National Fenestration Ratings Council (NFRC) ratings for window performance.

The NFRC website states, "We're Changing the Way America Shops for Windows, Doors and Skylights."[5] This nonprofit organization administers the independent rating and labeling systems architects rely upon to assure that they are specifying an energy-efficient window, door, or skylight. The NFRC was founded in the 1970s in response to that decade's energy crisis. In the 1992 Energy Policy Act, the NFRC was approved as the national performance and energy labeling organization. Manufacturers apply to the NFRC for certification. Products that achieve the NFRC label are tested in accordance with NFRC test methods and standards. The components on the NFRC label rate the design performance values that will maximize the energy efficiency of smart windows, frame components, and window walls.

An ENERGY STAR window with an NFRC label will have the following characteristics. The label will identify the manufacturer and the type of window, and this description will include the frame components, type of glazing, type of air or gas between the glazing and the type of operation. Energy performance ratings include values for the following factors:

- The **U-Value** is a measurement of the resistance to heat loss. This factor includes the insulating performance of the entire window system. The lower the U-Value, the better the window will provide a barrier to thermal changes. In comparison, the insulation in a wall system is designed to resist heat gain and is measured as an **R-Value**, the inverse of the U-Value. A high R-Value predicts better performance of the wall insulating system In a northern climate a recommended R-Value, will resist almost one-half of all heat loss. For example, designers might specify R-48 insulation values in Michigan or New England. In contrast, a window U-Value rates the heat gain through the entire window system, frame, glass, airspace and additional coatings or gas fills. An energy efficient window will have a U-Value below 0.35 and newer products are now approaching U-Values of .20

- The **Solar Heat Gain Coefficient** (SHGC) measures the fraction of incident solar radiation enters a building. This number ranges from zero to one. Different climate zones require different SHGC ratings. If a designer is using a passive solar strategy, then a higher SHGC rating is desired. Designers sometimes are challenged to trade visible clarity in windows with a low SHGC rating, which might be preferred in cooler climates

- **Visible Transmittance** (VT) is the clarity of light through a window. This number is measured from 100 percent transmittance to zero. Single pane clear glass windows have about 90 percent visible transmittance; however, some coated windows have less than 50 percent transmittance.

- **Air Leakage** (AL) determines how comfortable a person will feel next to a window or door. This measurement is listed as the amount of cubic feet of air through one square foot of window area. Heat loss or heat gain, drafts are all prevented by a window with a low AL rating.

- **Condensation Resistance** is a measurement from zero to one hundred which is not always on an ENERGY STAR or NFRC label. Condensation will form on the inside of a window when the there is a temperature change between surfaces from hot to cold. Condensation varies by climate and this measure is used to compare the potential of a product to resist condensation, not an absolute value.

U-factors, Solar Heat Gain Coefficients, Visible Transmittance, Air Leakage, as well as Condensation Resistance are important values to evaluate which window system to choose when specifying a high-performance window. The NFRC and ENERGY STAR provide baselines for performance, which evaluate the entire window system.

	Center of Glass (glass only)	Total Window (including frame & glass for a Casement)	Notes
Double Glazing with 11/16” Insulating Glass (IG)			
Clear IG			
U-factor	0.49	0.49	Lower U-factor means the product is a better insulator
SHGC	0.78	0.54	Lower SHGC means less heat gain
Visible Light	82%	57%	
Triple Glazing with 11/16” Low-E Insulating Glass (IG) and Low-E triple glazing panel			
U-factor	0.16	0.27	Lower U-factor means the product is a better insulator
SHGC	0.36	0.24	Lower SHGC means less heat gain
Visible Light	60%	38%	

Performance values of window glass are increased by high-performance casement window frames.

(Source: Pella® Windows and Doors)

Architects usually specify windows through a frame manufacturer. Window frames vary from residential to commercial grades constructed of aluminum, wood, fiberglass, vinyl or combinations of these materials. Most of these products have similar insulating factors. Higher values for performance are easier to acquire through residential windows. High performance frames prevent thermal bridging of heat or cold from the outdoors to penetrate indoors. Frames prevent condensation, air leakage and may significantly increase the performance values of the entire window.

The components of a residential energy-efficient window system include:

- Frames that reduce heat transfer
- Multiple panes of glass with air, or gas, such as argon or krypton, which increase the insulation values of the window
- Special coatings or Low–E glass products, which reflect infrared and ultraviolet light. Infrared light adds heat to the interior and ultraviolet light causes fading of interior finishes.
- Warm edge spacers made of steel, foam, fiberglass or vinyl to reduce heat flow and prevent condensation

Designers choose the window performance value based on the climate zone of the project's location. Although windows are just one component of an energy-efficient building envelope, by choosing a window with a performance U-Value of 0.35 or less, designers will choose a window which will provide greater energy efficiency. Some triple pane windows with Low-E coating are approaching U-Values of .20, which can translate into substantial energy savings.

It is not always possible to choose the most energy-efficient window system. While commercial window products can also have the recommended NFRC labeled components, many of the commercial systems may not achieve the higher U-value ratings of the residential products. Architects should choose the highest performing window glass product and carefully detail the installation to prevent heat transfer.

Although window manufacturers can replicate the frames of a historic building design, the choice of glass product may be determined by preservation requirements. The National Trust for Historic Preservation allows a wide variety of solutions for replacement windows. Although single-pane, clear glass windows, will allow the designer to replicate a historic profile, the impact on energy budgets may be prohibitively expensive. "We wanted an insulated glass unit, but it had to have the same light reflectance and similar transmittance [as the original plate glass]," said Principal-in-Charge Kevin Harden. He chose a Low-E insulating glass with argon gas in operable double-hung windows that allow natural ventilation. Through this configuration, the designer was able to maintain the historic façade, updating the envelope to meet current energy standards.

A Vision for the Future

In their book, *Smart Materials and Technologies*, Michele Addington and Daniel Schodek call for new materials that would form new boundaries between the outside and inside environments we live in today.[6] These authors state that "no other group in the architecture field has embraced smart materials as wholeheartedly as have the designers and engineers responsible for façade and enclosure systems."[7]

As previously noted, building envelopes (which can protect a building from sun, wind and rain, as well as provide insulation, ventilation and daylight) was a dream of Michael Davies. His vision included dynamic façades that changed with the season, as well as the passage of the sun throughout each day. New windows, walls, roofs and daylight devices will allow designers to customize their designs to climate using the natural resources of the planet, such as fresh air and daylight as energy resources. The goal is to create shelter that energizes human behavior by design.