
Energy Savings in MEP Systems - Building Design

Course No: M02-010

Credit: 2 PDH

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Part IV
BUILDING DESIGN

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4.1

Integrated Building Design

Integrated building design is a process of design in which multiple disciplines and seemingly unrelated aspects of design are integrated in a manner that permits synergistic benefits to be realized. The goal is to achieve high performance and multiple benefits at a lower cost than the total for all the components combined. This process often includes integrating green design strategies into conventional design criteria for building form, function, performance, and cost. A key to successful integrated building design is the participation of people from different specialties of design: general architecture, HVAC, lighting and electrical, interior design, and landscape design. By working together at key points in the design process, these participants can often identify highly attractive solutions to design needs that would otherwise not be found. In an integrated design approach, the mechanical engineer will calculate energy use and cost very early in the design, informing designers of the energy-use implications of building orientation, configuration, fenestration, mechanical systems, and lighting options.

Opportunities

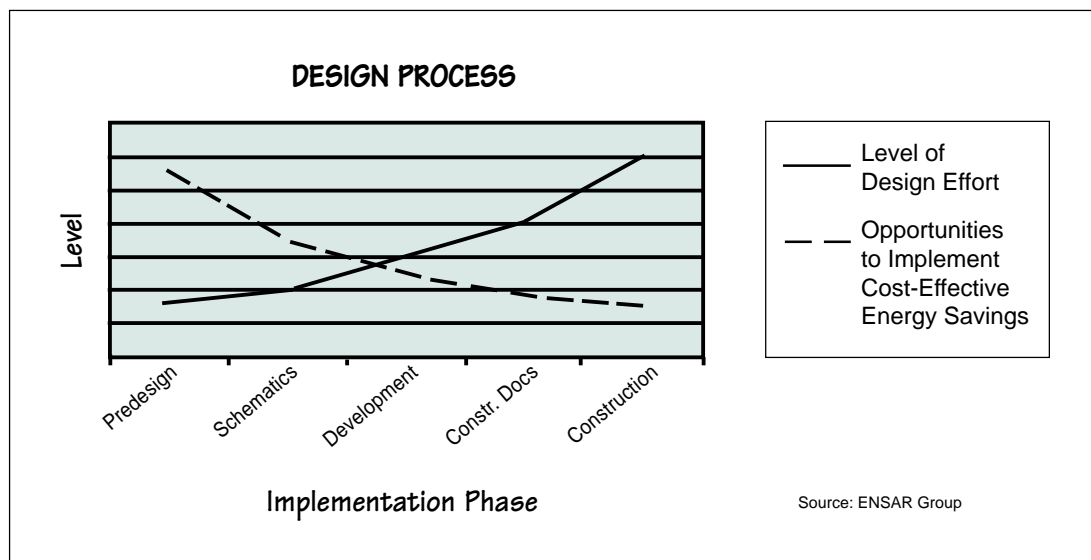
Although integrated building design can be part of almost any Federal facilities project, it is most suitable for the design of new whole buildings or significant renovation projects. Integrated building design is most effective when key issues are addressed early in the facility planning and design process. Opportunities are most easily identified through an open process of exploring how to combine low-energy-use and other greening strategies to achieve the best results.

The graph below suggests that the earlier design integration becomes a part of the process, the more successful the results will be. Conversely, if a building is designed “as usual” and then green technologies are applied to it as an afterthought, the results will probably be poorly integrated into the overall building design objectives, and the greening strategies will likely be expensive to implement.

In existing buildings, opportunities for improved building design integration exist whenever a major replacement or renovation of a building component or system is being planned. For example, if a large chiller system is to be replaced, investments in reducing the cooling loads through daylighting, improved glazing, and more efficient electric lighting may significantly reduce the size and cost of the new chiller. In some cases, cost savings from the new chiller may be greater than investments in the load-reduction strategies, so the ancillary benefits of improved lighting and lower energy consumption are obtained for free—or even at a “negative cost.”

Technical Information

Consider integrated building design strategies for all aspects of green design: improving energy efficiency, planning a sustainable site, safeguarding water, creating healthy indoor environments, and using environmentally preferable materials. Major design issues should be considered by all members of the design team—from civil engineers to interior designers—who have common goals that were set in the building program. The procurement of A&E services should stress a





Source: ENSAR Group



The Way Station (above) is an institutional building created for mental health care in Frederick, Maryland. The integrated building design used in creating it included careful siting, climate-responsive building form, energy-efficient envelope design, daylighting, passive solar heating, cooling-load reduction strategies, high-performance glazings, high-efficiency lighting and HVAC equipment, and healthy building design strategies. The net increase in construction cost for this package of measures was \$170,000, and the annual energy savings total \$38,000—a return-on-investment of 22%.

team-building approach, and provisions for integrated design should be clearly presented in the statement of work (SOW). For example, the SOW should stipulate frequent meetings and a significant level of effort from mechanical engineers to evaluate design options.

The design and analysis process for developing integrated building designs includes:

- **Establishing a base case**—for example, a performance profile showing energy use and costs for a typical facility that complies with Federal energy standards and other measures for the project type, location, size, etc.
- **Identifying a range of solutions**—all those that appear to have potential for the specific project.
- **Evaluating the performance of individual strategies**—one by one through sensitivity analysis or a process of elimination parametrics.
- **Grouping strategies that are high performers** into different combinations to evaluate performance.

- **Selecting strategies, refining the design, and reiterating the analysis** throughout the process.

Finding the right building design recipes through an integrated design process can be challenging. At first, design teams often make incremental changes that are effective and result in high-performance buildings—and often at affordable costs. However, continuing to explore design integration opportunities can sometimes yield incredible results, in which the design team *breaks through* the cost barrier.

Whenever one green design strategy can provide more than one benefit, there is a potential for design integration. For example, windows can be highly cost-effective even when they are designed and placed to provide the multiple benefits of daylight, passive solar heating, summer-heat-gain avoidance, natural ventilation, and an attractive view. A double-loaded central corridor, common in historic buildings, provides daylight and natural ventilation to each room, and transom windows above doors provide lower levels of light and ventilation to corridors. Building envelope and lighting design strategies that significantly reduce HVAC system requirements can have remarkable results. Sometimes the most effective solutions also have the lowest construction costs, especially when they are part of an integrated design.

References

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U.S. Air Force Environmentally Responsible Facilities Guide, Government Printing Office, 1999.

Anderson, Bruce, *Solar Building Architecture*, MIT Press, Cambridge, MA, 1990.

Contacts

Green Development Services, Rocky Mountain Institute, 1739 Snowmass Creek Road, Snowmass, CO 81654; 970/927-3807; www.rmi.org.

Sustainable Buildings Industry Council, 1331 H Street, NW, Suite 1000, Washington, DC 20005; (202) 628-7400, (202) 393-5043 (fax); www.sbicouncil.org.

4.1.1 Passive Solar Design

Passive solar systems make use of natural energy flows as the primary means of harvesting solar energy. Passive solar systems can provide space heating, cooling-load avoidance, natural ventilation, water heating, and daylighting. This section focuses on passive solar heating, but the other strategies also need to be integrated and coordinated into a whole-building design. Passive solar design is an approach that integrates building components—exterior walls, windows, and building materials—to provide solar collection, heat storage, and heat distribution. Passive solar heating systems are typically categorized as sun-tempered, direct-gain, sunspaces, and thermal storage walls (Trombe walls). In most U.S. climates, passive solar design techniques can significantly reduce heating requirements for residential and small commercial buildings.

Opportunities

New construction offers the greatest opportunity for incorporating passive solar design, but any renovation or addition to a building envelope also offers opportunities for integration of passive methods. It is important to include passive solar as early as possible in the site planning and design process, or when the addition or building is first conceived. Ideally, an energy budget is included in the building design specifications, and the RFPs require the design team to demonstrate their commitment to whole-building performance and their ability to respond to the energy targets. This commitment is emphasized during programming and throughout the design and construction process.

For retrofit projects, consider (1) daylighting strategies, such as making atria out of courtyards or adding clerestories, along with modification of the electric lighting system to ensure energy savings; (2) heat control techniques, such as adding exterior shades or overhangs; and (3) using passive solar heating strategies to allow modification of HVAC systems—perhaps down-sizing if the passive strategies reduce energy loads sufficiently.

Many buildings in the Federal inventory have passive features because they were built before modern lighting and HVAC technologies became available. When renovating older buildings, determine whether passive features that have been disabled can be revitalized.

Technical Information

Terminology. *Sun tempering* is simply using windows with a size and orientation to admit a moderate amount of solar heat in winter without special measures for heat storage. *Direct gain* has more south-facing glass

in occupied spaces and thermal mass to smooth out temperature fluctuations. A *Trombe wall* puts the thermal mass (e.g., tile floors) directly behind the glazing to reduce glare and overheating in the occupied space. A *sunspace* keeps the glass and mass separate from the occupied space but allows for the transfer of useful heat into the building by convection or a common mass wall; temperatures in a sunspace are allowed to fluctuate around the comfort range.

Highlight passive solar as a project goal. Many agencies, including GSA and DOD, already encourage the use of passive solar design and renewables in new construction and major renovation. A good general project goal is “to produce a beautiful, sustainable, cost-effective building that meets its program, enhances productivity, and consumes as little nonrenewable energy as possible, through the use of passive solar design, energy efficiency, and the use of other renewable resources.”

Incorporating energy performance goals into the programming documents conveys the seriousness of energy consumption and the use of passive solar as a design issue. For small offices, warehouses, and other smaller projects—10,000 sq ft (930 m²) or less—facility managers or their contractors can develop energy budgets easily using software such as *Energy-10*. For larger multi-zone projects (for example, laboratories or high-rise office buildings), national average energy consumption data by building type can be cited as targets to be exceeded, or more complex analyses can be run by consultants. The building program should describe an articulation that allows passive solar strategies to be effective (for example, large multistory core zones are hard to reach with passive solar). The building program should also describe requirements, such as privacy and security, that may influence the type of passive solar heating system that can be used.

Thirty to fifty percent energy cost reductions below national averages are economically realistic in new office design if an optimum mix of energy conservation and passive solar design strategies is applied to the building design. Annual savings of \$0.45 to \$0.75 per sq ft (\$5 to \$8/m²) is a reasonable estimate of achievable cost savings.

Passive solar design considers the synergy of different building components and systems. For example:

- Can natural daylighting reduce the need for electric light?
- If less electric light generates less heat, will there be a lower cooling load?
- If the cooling load is lower, can the fans be smaller?

- Will natural ventilation allow fans and other cooling equipment to be turned off at times?

Passive solar design is often more challenging than designing a mechanical system to accomplish the same functions. Using the building components to regulate temperature takes a rigorous analytical approach to optimize performance while avoiding such problems as overheating and glare.



Buildings properly designed using passive solar systems and strategies are generally more comfortable for the occupants, resulting in productivity benefits that are great relative to the building cost.

Generic design solutions or rules of thumb are of limited value. Rules of thumb may be useful in anticipating system size and type, but only early in the design process. Computer simulation provides much more accurate guidance because of the complexity of system combinations and interactions. Some of the variables involved include:

- Climate (sun, wind, air temperature, and humidity);
- Building orientation (glazing and room layout);
- Building use type (occupancy schedules and use profiles);
- Lighting and daylighting (electric and natural light sources);
- Building envelope (geometry, insulation, fenestration, air leakage, ventilation, shading, thermal mass, color);
- Internal heat gains (from lighting, office equipment, machinery, and people);
- HVAC (plant, systems, and controls); and
- Energy costs (fuel source, demand charges, conversion efficiency).

An hourly simulation analysis combines all of these parameters to evaluate a single figure-of-merit, such as annual energy use or annual operating cost.

The integrated interaction of many energy-efficient strategies is considered in passive solar design. These include: passive solar heating, glazing, thermal mass, insulation, shading, daylighting, energy-efficient lighting, lighting controls, air-leakage control, natural ventilation, and mechanical system options such as

economizer cycle, exhaust air heat recovery, high-efficiency HVAC, HVAC controls, and evaporative cooling.



Passive solar design is an integrated design approach optimizing total building performance rather than a single building system. This is the key to “green building” design.

Cost and technical analyses are conducted at the same time in passive solar design to optimize investments for maximum energy cost savings. It is rarely feasible to meet 100% of the building load with passive solar, so an optimum design is based on minimizing life-cycle cost: the sum of solar system first-cost and life-cycle operating costs. *Means Assemblies Cost Data* is a good source of cost information for thermal storage walls (Trombe walls) and other selected strategies. It is difficult to separate the cost of many passive solar systems and components from other building costs because passive solar features serve other building functions—e.g., as windows and wall systems.



The Trombe wall at the NREL Visitors Center in Golden, Colorado, provides passive heating and daylighting to the exhibit hall.

Photo: Warren Gretz

References

Olgyay, Victor, *Design with Climate: Bioclimatic Approach to Architectural Regionalism*, Princeton University Press, Princeton, NJ, 1963.

Watson, Donald, and Kenneth Labs, *Climatic Design: Energy-Efficient Building Principles and Practices*, McGraw-Hill, New York, NY, 1983.

Designing Low-Energy Buildings, Sustainable Buildings Industry Council, Washington, DC, 1997.

Means Assemblies Cost Data 2000, R. S. Means Company, Inc., Kingston, MA, 2000.

Contacts

FEMP offers a course on passive solar design, *Designing Low-Energy Buildings*. Call (800) DOE-EREC (363-3732) for course information.

Sustainable Buildings Industry Council (SBIC), 1331 H Street, NW, Suite 1000, Washington, DC 20005 (202) 628-7400; www.sbicouncil.org. SBIC sponsors workshops on low-energy building design and markets *Energy-10*, the software developed by NREL to aid in the evaluation of passive measures in residential and small, single-zone commercial buildings.

4.1.2 Daylighting Design

Daylighting is the effective use of natural light in buildings to minimize the need for electric light during daylight hours. When properly designed, daylighting can provide high-quality architectural lighting and can balance the thermal consequences of additional glazing. Since many Federal buildings use significant energy for electric lighting (often 30 to 50% of annual energy use), daylighting can be a very important design strategy to consider.

Opportunities

In almost all cases where lighting is needed in a building on a regular basis during the day, daylighting can be an effective solution for at least some of the lighting requirements. Daylighting should be considered in buildings such as offices, laboratories, schools, food service facilities, and other daytime-use spaces. In existing buildings, daylighting potential is greatest close to perimeter window walls.

A baseline lighting profile will help establish the potential opportunities for daylighting. The graph below illustrates the lighting profile baseline of an office building on average days for each month on a 24-hour basis. The energy saved because of daylighting is plotted in the lower negative curve. This profile indicates that daylighting provides considerable savings in this building and thus is a good candidate for further consideration.

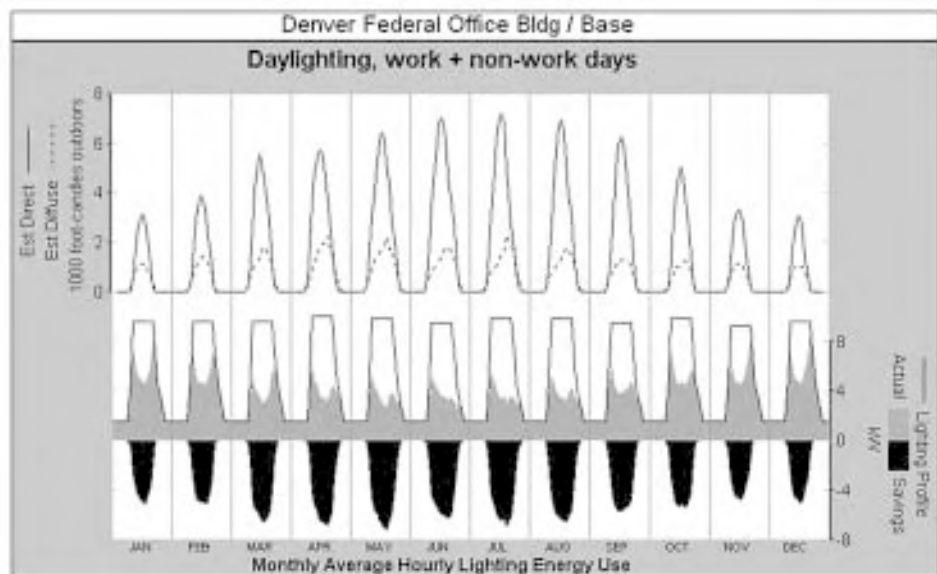
Technical Information

Windows are provided in most buildings for daylight, view, and architectural aesthetics, as well as to satisfy a basic human need to connect with nature. However, the art and science of designing effective, high-quality daylighting systems goes beyond simply adding windows in a wall. Glazing strategies responding to size, location, orientation, type, sun control, and building geometry all affect the quality and effectiveness of a daylighting design.

Achieving good daylighting is often more of an art than a technical, engineered solution. The eye's perception of light is a key part of visibility. The amount of light (typically measured in foot-candles) in a space is only one small part of the equation. The brightness of surfaces within the field of view directs the eye's perception of visibility. If the brightness difference (luminance ratio) of surfaces being viewed is too great, the darker areas seem underlit even when the amount of light is within desirable ranges.

The quality of daylight and the human need for connection to daylight cannot be emphasized enough. Human health and productivity can be enhanced with sound daylighting designs. Some studies have indicated significant increases in productivity (up to 15%) and reduced absenteeism for office workers through the use of effective daylighting. Recent studies in California demonstrate a strong statistical correlation between daylighting and improved sales in retail stores. Similarly, daylit classrooms are being shown to result in faster learning and healthier students.

The form-givers relating to daylighting design are building geometry (architectural form of interior spaces and the building as a whole), glazing strategies (size, orientation, type, location), daylighting controls (light shelves, blinds, fins), and surfaces (textures, colors). A double-loaded corridor provides access to daylight from one wall in each room, with a lower level of borrowed light in the central corridor.



The energy saved monthly as a result of daylighting in a Denver Federal office building is shown graphically in the bottom (black) profiles.

Source: ENSAR Group



There is a tremendous amount of light outdoors, and even small windows let in enough light—an important objective is to minimize the difference between the lightest and darkest points of the room.

A key component of any daylighting strategy, particularly for a large building, is careful integration with electric lighting. After all, even the best daylighting design will save energy only if it reduces the amount of electricity used for artificial lighting. Daylight controls can dim fluorescent lighting if luminaires are fitted with dimming electronic ballasts. Controlling banks of luminaires along window walls separately from interior lights enables perimeter lights to be dimmed when natural light levels are adequate, thus yielding significant savings.

Beyond the basics, advanced daylighting systems, such as light pipes, light shelves with specular surfaces for deep directional daylighting to the building core, fiber optics, tracking daylight apertures, and other techniques can provide ample daylighting when simple approaches won't solve the problem. Most of these approaches, however, will increase overall costs.



Bring daylight in high in the space, bounce daylight off surfaces, filter daylight with vegetation and architectural components, and integrate daylighting design with electric lighting, HVAC, and architectural systems.



Avoid ceiling reflections and direct sunlight or skylight in areas where extreme brightness isn't useful.

References

Evans, Benjamin H., AIA, *Daylight in Architecture*, McGraw-Hill, New York, NY, 1981.

Ander, Gregg D., AIA, *Daylighting: Performance and Design*, Van Nostrand Reinhold, New York, NY, 1995.



Source: ENSAR Group

Building 33 at the Navy Shipyard in Washington, D.C., is a retrofit of a historic building where daylighting was employed through skylights and windows.

Contacts

Windows and Daylighting Group, Lawrence Berkeley National Laboratory, Berkeley, CA; 510/486-6845, www.lbl.gov. *Tips for Daylighting with Windows* is available as a pdf file.

Center for Buildings and Thermal Systems, National Renewable Energy Laboratory, Golden, CO; www.nrel.gov/buildings_thermal/.

Daylighting Collaborative, Energy Center of Wisconsin, 595 Science Drive, Madison, WI 53711; (608) 238-4601; www.daylighting.org.

Pacific Gas & Electric Daylighting Initiative, www.pge.com/pec/daylight/.

4.1.3 Natural Ventilation

Natural ventilation is the use of wind and temperature differences to create airflows in and through buildings. These airflows may be used both for ventilation air and for passive cooling strategies. Natural ventilation is often strongly preferred by building occupants, especially if they have some control over it, as with operable windows. Studies have shown that most occupants will readily tolerate a wider range of ambient conditions if they have such control.

Before the advent of mechanical ventilation, all buildings were naturally ventilated. Since that time, climate-control expectations have risen significantly, and most building programs, codes, and regulations are based on the expectation of mechanical systems. Nevertheless, well-designed natural ventilation can often be used in conjunction with mechanical systems, creating a “mixed mode” building. Mixed-mode buildings may be designed around mechanical systems that are supplemented by natural ventilation or vice versa. The building may be designed to use both systems simultaneously or to switch from one to the other based on climate conditions or occupant demand. In a few situations, natural ventilation approaches can replace mechanical cooling and ventilation systems entirely.

Opportunities

Buildings constructed before about 1950 were almost always designed for natural ventilation, and it often makes sense to retain that function when renovating such buildings. Building types with less stringent climate-control requirements are the best candidates for natural ventilation, whether renovated or newly designed. Temperate climates with low relative humidity, such as in the northwestern United States, are best suited to natural ventilation.

Natural ventilation is most effective in increasing occupant satisfaction when it is combined with daylighting and when occupants are at least partially in control of the conditions. Unfortunately, giving control to occupants makes energy use by mechanical systems difficult to predict. Natural ventilation is most effective as an energy conservation strategy when combined with other passive cooling and cooling load reduction strategies, such as night flushing and effective shading.

Technical Information

There are two basic types of natural ventilation effects: buoyancy and wind. Buoyancy ventilation is more commonly referred to as temperature-induced

or stack ventilation. Wind ventilation supplies air from a positive pressure through apertures on the windward side of a building and exhausts air to a negative pressure on the leeward side. Shutters and louvres can also be positioned to maximize wind-induced airflow through the building. Airflow rate depends on the wind speed and direction as well as the size of apertures. Wind-driven turbine extractors are common in industrial buildings to provide natural ventilation.

In summer, the indoor-outdoor temperature difference is not high enough to drive buoyancy ventilation, and wind is used to supply as much fresh air as possible. In winter, however, the indoors is much warmer than outdoors, providing an opportunity for buoyancy ventilation. Also, ventilation is normally reduced to levels sufficient to remove excess moisture and pollutants in winter. For buoyancy ventilation, warm air in the roof rises and exhausts out of a high aperture, while cooler outdoor air comes in through an aperture at a lower elevation. Airflow rate depends on the size of these apertures, the height difference between them, and the indoor and outdoor temperatures. A “solar chimney” may be added to the exhaust to enhance the stack effect. An improvement sometimes used in arid climates is to add an evaporative cooler on top of a “cool tower”—this precools and pressurizes the inlet air and helps exhaust warm air high in the conditioned space or through the solar chimney.

Natural ventilation as a primary cooling and ventilation strategy is appropriate only under certain conditions. Temperate climates with low average humidity



OBSTACLES TO THE USE OF NATURAL VENTILATION

- *Smoke control in case of fire is more difficult and may require special equipment and/or variances in codes.*
- *Outdoor noise is difficult to manage in a building that relies on operable windows or vents.*
- *Acoustic separation between spaces can be difficult to achieve.*
- *Low pressure differences often require large apertures for desired airflow rates.*
- *Outdoor air must be clean enough to introduce directly into occupied space. If filtration is required, mechanical ventilation is necessary.*



Passive down-draft cool towers at the Visitor Center in Zion National Park (in Springdale, Utah) help bring temperatures down by cooling hot air with water at the top of the tower. This cooled air then falls into the building and onto the patio.

Photo: Paul Torcellini

levels are the best candidates. In cold climates, mixed-mode buildings are viable, with natural ventilation as the primary source of outdoor air on a seasonal basis. Hot, humid climates tend to have the fewest days in which natural ventilation can be used without the risk of compromising comfort.

When natural ventilation is a priority for a new building or renovation, performance requirements should not include strict limits on acceptable indoor temperature and humidity conditions; this is because extreme weather conditions are difficult to predict. Instead, clear guidelines should be established for an allowable percentage of time to stray from certain conditions. The more broadly these conditions are defined, and the larger the acceptable amount of time out of compliance, the greater the possibilities for reducing mechanical system size and usage.

Naturally ventilated and mixed-mode buildings typically have floor plates less than 40 feet (12 m) wide—the floor plates of typical new large office buildings are too big for air to move reliably across them. Cooling-load reduction strategies—e.g., shading, heat-rejecting glazing, and the use of thermal mass to dampen temperature swings—are essential to maintaining

comfortable conditions in buildings relying on natural ventilation.

Mixed-mode buildings may be designed to switch from mechanical to natural ventilation within the same space, or they may have both types of ventilation occurring simultaneously in separate spaces. Running both natural and mechanical ventilation simultaneously in the same space will usually lead to excessive energy use, especially if mechanical cooling or heating is active. In humid climates, switching back and forth between mechanical and natural ventilation may *increase* energy use, as the mechanical cooling system has to work harder to remove latent heat (moisture) that accumulates in the air and in materials in the building.

Design for passive airflow is complex, especially in large buildings. Specialized *computational fluid dynamics* (CFD) software is valuable in understanding airflow under different conditions, but such software is expensive and time-consuming to learn. Engineering firms with expertise in natural ventilation should have CFD software or access to it. The design of simple structures, such as livestock barns, often relies on simple but effective hand calculations to size the natural ventilation apertures.

For any building type, an understanding of local climate conditions is essential for good natural ventilation design. The free *Climate Consultant* software from the University of California at Los Angeles provides graphic displays of temperature and humidity conditions for most U.S. locations. It can be downloaded from www.aud.ucla.edu/energy-design-tools/.



Mixed-mode buildings tend to be more expensive than either mechanically ventilated or naturally ventilated buildings because of the duplication of air movement systems.

References

Allard, Francis, ed., *Natural Ventilation in Buildings*, James and James, London, 1998.

Givoni, Baruch, *Climate Considerations in Building and Urban Design*, John Wiley & Sons, New York, NY, 1998.

4.2

Building Envelope

The building envelope is a critical component of any facility since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, walls, windows, and doors, the envelope controls the flow of energy between the interior and exterior of the building. The building envelope can be considered the selective pathway for a building to work with the climate—responding to heating, cooling, ventilating, and natural lighting needs.

Opportunities

For a new project, opportunities relating to the building envelope begin during the predesign phase of the facility. An optimal design of the building envelope may provide significant reductions in heating and cooling loads—which in turn can allow downsizing of mechanical equipment. When the right strategies are integrated through good design, the extra cost for a high-performance envelope may be paid for through savings achieved by installing smaller HVAC equipment.

With existing facilities, facility managers have much less opportunity to change most envelope components. Reducing outside air infiltration into the building by improving building envelope tightness is usually quite feasible. During reroofing, extra insulation can typically be added with little difficulty. Windows and insulation can be upgraded during more significant building improvements and renovations.

Technical Information

WINDOWS

Glazing systems have a huge impact on energy consumption, and glazing modifications often present an excellent opportunity for energy improvements in a building. Appropriate glazing choices vary greatly, depending on the location of the facility, the uses of the building, and (in some cases) even the glazing's placement on the building. In hot climates, the primary strategy is to control heat gain by keeping solar energy from entering the interior space while allowing reasonable visible light transmittance for views and daylighting. Solar screens that intercept solar radiation, or films that prevent infrared and ultraviolet transmission while allowing good visibility, are useful retrofits for hot climates.

In colder climates, the focus shifts from keeping solar energy out of the space to reducing heat loss to the outdoors and (in some cases) allowing desirable solar radiation to enter. Windows with two or three glazing



Source: Lawrence Berkeley National Laboratory



By taking an integrated approach to combining building envelope and lighting components, even greater energy savings and increased occupant comfort can be attained. The photos above show dynamically controlled window and lighting systems implemented by the Lawrence Berkeley National Laboratory at the Oakland, California, Federal Building. The blinds adjust, and electric lights dim, in response to real-time variations in sun and sky conditions. Lighting energy savings were 20% in winter and 30–50% in summer. Overall cooling savings for the summer were 5–15%.

layers that utilize low-emissivity coatings will minimize conductive energy transmission. Filling the spaces between the glazing layers with an inert low-conductivity gas, such as argon, will further reduce heat flow. Much heat is also lost through a window's frame. For optimal energy performance, specify a low-conductivity frame material, such as wood or vinyl. If metal

frames are used, make sure the frame has thermal breaks. In addition to reducing heat loss, a good window frame will help prevent condensation—even high-performance glazings may result in condensation problems if those glazings are mounted in inappropriate frames or window sashes.

Fenestration can be a source of discomfort when solar gain and glare interfere with work station visibility or increase contrast and visual discomfort for occupants. Daylighting benefits will be negated if glare forces occupants to close blinds and turn on electric lights, for example, to perform visual tasks optimally.

Facility managers should choose appropriate window technology that is cost-effective for the climate conditions. Computer modeling, using a tool such as *DOE-2* or *Energy-10*, will help determine which glazing system is most appropriate for a particular climate. In coastal California, for example, single glazing may be all that can be economically justified, while in both hotter and colder climates, more sophisticated glazings are likely to be much more effective.

WALLS AND ROOFS

For buildings dominated by cooling loads, it makes sense to provide exterior finishes with high reflectivity or wall-shading devices that reduce solar gain. Reflective roofing products help reduce cooling loads because the roof is exposed to the sun for the entire operating day. Specify roofing products that carry the ENERGY STAR® roof label—for low-slope roofing products, these have an initial reflectivity of at least 65%. ENERGY STAR roof products are widely available with single-ply roofing, as well as various other roofing systems.

Wall shading can reduce solar heat gain significantly—use roof overhangs, window shades, awnings, a canopy of mature trees, or other vegetative plantings, such as trellises with deciduous vines. To reduce cooling loads, wall shading on the east and west is most important, though especially for buildings with year-round cooling loads, south walls will benefit from shading as well. In new construction, providing architectural features that shade walls and glazings should be considered. In existing buildings, vegetative shading options are generally more feasible.

INSULATION

With new buildings, adding more wall insulation than normal can be done for a relatively low-cost premium. Also consider thermal bridging, which can significantly degrade the rated performance of cavity-fill insulation that is used with steel framing. With steel framing, consider adding a layer of rigid insulation.

Boosting wall insulation levels in existing buildings is difficult without expensive building modifications. One option for existing buildings is adding an exterior insulation and finish system (EIFS) on the outside of the current building skin. With EIFS, use

only systems that include a drainage layer to accommodate small leaks that may occur over time—avoid *barrier-type* systems.

Roof insulation can typically be increased relatively easily during reroofing. At the time of reroofing, consider switching to a *protected-membrane* roofing system, which will allow reuse of the rigid insulation during future reroofing—thus greatly cutting down on landfill disposal.

While we think of insulation as a strategy for cold climates, it makes sense in cooling climates as well. The addition of insulation can significantly reduce air conditioning costs and should be considered during any major renovation project. Roofs and attics should receive priority attention for insulation retrofits because of the ease and relative low cost.

Insulation is a guideline item under RCRA §6002 and should be purchased with recycled content. Federally funded projects are required to use insulation materials with minimum recycled content that varies depending on the type of insulation. Also consider the ozone-depletion potential of rigid insulation materials. Most extruded polystyrene and polyisocyanurate insulation is produced with ozone-depleting hydrochlorofluorocarbons (HCFCs), though ozone-safe alternatives are beginning to appear.

Contacts

Oak Ridge National Laboratory, Bldg 3147, P.O. Box 2008 – MS6070, Oak Ridge, TN 37831; (423) 574-5207; www.ornl.gov/roofs+walls. DOE *Insulation Fact Sheet* available online.

ENERGY STAR Roof Products Program, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC 20460; 202/564-9124; www.epa.gov/energystar.



Photo: Craig Miller Productions and DOE

Installation of light-colored roofing to better reflect sunlight and reduce interior temperature.

4.2.1 Windows and Glazing Systems

Windows, and glazing systems in general, can provide daylighting, passive solar heat gain, natural ventilation, and views. Glazings can be vertical or sloped, wall-mounted or roof-mounted. While a vitally important building component, glazing systems can also be the weakest point in the building envelope—relative to heat loss, unwanted heat gain, moisture problems, and noise transmission. Through proper design, careful analysis, and proper installation, glazing systems allow buildings to work with the climate to reduce energy use as well as enhance human comfort and productivity.

Opportunities

Opportunities to ensure that glazing systems will be effective and climate-responsive are greatest very early in the planning and design process both for new buildings and for existing buildings undergoing renovation. Renovations afford opportunities for replacing older, single-glazed, and either clear or darkly tinted windows. Window and glazing modifications can be considered independently of other building changes, but changes will be most cost-effective when carried out as part of a broader upgrade of the whole building. Improving the energy performance of windows without replacing the window units themselves may be feasible by adding shading devices on the exterior, an extra glazing layer (storm panel) on the interior or exterior, or window treatments (such as shades, drapes, shutters, or window films) on the interior.

Technical Information

Windows and glazings are specified by solar heat gain coefficient (SHGC), U-factor (thermal transfer rate), air-leakage rate, visible light transmittance, and materials of construction. The glazing configuration, frame materials, and quality of construction will determine the environmental impact, maintenance, durability, and potential for disassembly for reuse or recycling at the end of its life.

Issues to be considered in the selection of windows and glazings include the glazing system (see below), framing materials and design, finishes used on framing components, window operation (for operable units), and how windows or glazing units are sealed at the time of installation to ensure a weather-tight envelope.

Windows and glazings allow heat movement via conduction across the glazing and the frame, via air leakage at the frame gaps and between the frame and wall, and via the transmission of solar and heat radiation through the glazing. Window thermal performance should be compared by using the whole-window

U-factors, as specified by the National Fenestration Rating Council (NFRC). These unit values account for the glazing, frame, and glazing spacers in insulated-glass units. The lower the U-factor ($\text{Btu}/\text{ft}^2 \cdot \text{F} \cdot \text{hr}$), the better the performance. U-factor is the inverse of R-value ($U=1/R$). The U-factor of double clear glazing is about 0.5 (R-value about 2).

Types of glazing include clear, tinted, reflective, low-emissivity (low-e), and spectrally selective. Some low-e coatings are on suspended plastic films (Heat Mirror®). There are also some advanced high-tech glazing systems available or under development, including electrochromic (tinted by applied voltage), photochromic (tinted by light intensity), thermochromic (tinted by heat), photovoltaic (power-generating), and transparent insulating.

Low-e coatings have revolutionized glazing design in the past twenty years, dramatically boosting energy performance. These very thin coatings of metal (typically silver or tin oxide) allow short-wavelength sunlight through but block the escape of longer-wavelength heat radiation. There are two types of low-e coatings: soft-coat (vacuum-deposited) coatings that have to be protected within a sealed insulated glass unit; and hard-coat (pyrolytic) coatings that are applied when the glass is still molten and are durable enough to be used on single-pane glazings. Soft-coat low-e coatings generally block heat loss better, but they also block more of the solar heat gain and thus aren't as good for south-facing glazing on passive solar buildings.

Spectrally selective glazings are a special type of glazing used mostly in commercial buildings. These should be specified in climates where solar gain in the summer creates large cooling loads and where daylight also is desired. The coatings allow visible portions of the solar energy spectrum to be transmitted, but they block infrared and ultraviolet portions of the spectrum that introduce heat primarily.

The gap between multiple panes of glass also influences heat flow. The space may be filled with air or a high-conductivity gas such as argon or krypton. Because these gases have lower thermal conductivity than air, they result in lower U-values. While krypton is significantly better than argon, it is also a lot more expensive and therefore rarely used. Low-conductivity gas fills are particularly important when low-e coatings are used on the glass, because the coatings result in a higher difference in temperature across the interpane space.

In renovations—particularly of historic buildings—aluminum, metal, and vinyl panning and receptor systems provide a weathertight, finished covering for



Photo: Warren Gretz

NREL's Solar Energy Research Facility is designed to use natural lighting. South-, east-, and west-facing windows are specially coated with six different, graduated glazings to mitigate unwanted heat or glare from the sun. Windows facing east and west are also outfitted with "smart," motorized window shades. Each shade has a photovoltaic sensor to detect the sun's intensity and automatically raise or lower the shade to prevent glare and heat gain.

placement over existing wood frames. This simplifies installation of new units and eliminates the removal of old frames. Separate interior or exterior glazing panels can also often be added to single-pane windows in historic buildings to boost energy performance without significantly altering the building's appearance.



Wood frames may be a better material from an environmental standpoint (if the wood is from a certified well-managed forest), but they may have greater life-cycle costs because of their shorter life, and higher maintenance costs compared with metal, vinyl (PVC), and fiberglass windows. When selecting frame materials, weight heavily the thermal performance and maintenance—not just the initial environmental impacts of the material.

To select windows for the best overall energy performance, first conduct an analysis that accounts for inward and outward energy flows throughout the

year. Various computer software tools can be used for this analysis, including *DOE-2* and *Energy-10*.

Sound-control (acoustical) performance of windows can be improved by ensuring that windows are airtight, increasing the thickness of the glass, adding additional glazing layers, and specifying *laminated* glass with a plastic interlayer.

The choice of either fixed glazing units or operable units should be based on site-specific and climate-specific opportunities and constraints. Casement, pivoting, and awning windows offer the greatest opening area for natural ventilation and utilize compression seals that provide the best method of sealing the joint between sash and frame. Fixed windows provide the best thermal performance because of fixed seals; these can be designed to satisfy acoustical and security concerns as well.



Glazings that insulate poorly and frames that are highly conductive will have a cold interior surface during winter months, and condensation may occur on the inside of the glass and frames. This can damage window frames, sills, wallboard, paint, and wall coverings. A more thermally efficient window and a nonconductive frame with thermal breaks are less likely to result in condensation. Avoid metal frames that lack thermal breaks.

References

Carmody, John, Steve Selkowitz, and Lisa Hescong, *Residential Windows*, W. W. Norton & Company, New York, NY, 1996.

Franta, Greg, et al., *Glazing Design Handbook*, The American Institute of Architects, Washington, DC, 1996.

Certified Products Directory: Energy Performance Ratings for Windows, Doors, Skylights, 9th Edition, National Fenestration Rating Council, Washington, DC, December 1999.

Contacts

The FEMP Help Desk, (800) DOE-EREC (363-3732) can provide window evaluation software developed by Lawrence Berkeley National Laboratory.

The National Fenestration Rating Council (NFRC), 1300 Spring Street, Suite 500, Silver Spring, MD 20910; (301) 589-6372; www.nfrc.org. (Both printed and online versions of *NFRC Certified Product Directory* are available.)

4.2.2 Insulation

Insulation ranks as one of the best means of saving energy in buildings, reducing utility bills, and improving air quality. Insulation provides resistance to the flow of heat from a building's exterior to its interior, and vice versa. Thermal resistance is measured in R-value, the inverse of U-factor (the measure of heat flow through a material in Btu per square foot per hour for each °F difference in temperature). Insulation is primarily either loose-fill, batt, rigid boardstock, or foamed-in-place. Along with air barriers and vapor retarders, insulation controls the passage of sensible and latent heat and prevents condensation within wall and ceiling cavities. Though we take it for granted, only since the 1950s has insulation become widely available, inexpensive, easy to install, fire-retardant, resistant to pests, and able to retain these properties over time. It represents only a small portion of building costs, but insulation has a major impact on operating costs. So, selecting the proper insulation is one of the most economical and effective ways to reduce the operating costs and environmental impacts of a Federal facility.

Opportunities

Facility planners should specify R-values that minimize life-cycle costs for all new construction. Codes and standards dictate minimums, but it can be cost effective to use more. Improving the insulation in existing buildings, especially older ones, can also be cost effective and beneficial to occupants' health and comfort. Insulation can easily be added to attics or under floors, but retrofitting cavity insulation in walls is usually expensive and disruptive. It is less disruptive to add wall insulation on the exterior—for example, with an exterior insulation and finish system—giving a dilapidated exterior a new look. The best time to consider upgrading wall insulation is during a renovation. In reroofing, for example, insulation levels can easily be increased when exterior, low-slope insulation is being removed and reapplied (see Section 7.1.4, *Low-Slope Roofing*). Tapered insulation provides the desired slope to drains, increasing the roof membrane's life. Gasketing and caulking are integral to insulating envelopes for energy efficiency; they can be done either independently or during insulation upgrades.

Technical Issues

Selection issues for insulation include R-value performance (including changes over time), environmental impacts during manufacture, recycled content, whether HCFCs were used in manufacture, durability, waste generated, and potential health hazards. The insulation selected should conform to the relevant fire

rating, pest-resistance, and product standards of ASTM and others. ASHRAE 90.1 specifies insulation requirements for various building envelope components, depending on heating degree-days and other factors.

R-value depends on the properties of the material, the thickness of the insulation layer, and the packing density. Though R-values per inch of thickness vary considerably, the table shows representative values for several common insulating materials.

R-VALUES FOR SOME COMMON INSULATING MATERIALS

Material	R-value per Inch Thickness (°F-ft ² -h/Btu/inch)
Mineral Fiber	3.3 to 4.3
Glass fiber	4.0
Perlite	2.8 to 3.7
Polystyrene	3.8 (expanded) 5.0 (extruded)
Cellular Polyisocyanurate	5.6 to 7.0
Cellulose, loose fill	3.1 to 3.7
Polyurethane, spray-applied foam	5.6 to 6.2
Cotton, batt	3.4

Source: 1997 ASHRAE Fundamentals Handbook; cotton data from Environmental Building News, Vol. 9, No. 11 (November 2000).

Minimum recycled content of different types of insulation is specified in the recycled-content procurement guidelines of RCRA §6002. Insulation used in Federally funded projects exceeding \$10,000 must meet these standards.

The ozone-depletion potential of rigid boardstock and foamed-in-place insulation has been reduced by manufacturing innovations and materials. The chlorofluorocarbons (CFCs) used as blowing agents in most foam insulation have been replaced either with HCFCs, which are about 10% as damaging to ozone, or with hydrocarbons, which do not deplete ozone. The HCFC-141b used in some polyisocyanurate and spray polyurethane should be phased out by Jan. 1, 2003; the HCFC-142b used in some extruded polystyrene (XPS) should be phased out by 2020, with a production cap in 2010. Ozone-safe polyisocyanurate and spray polyurethane appeared in the late 1990s.

Fiberglass insulation has a high recycled glass content and includes post-industrial recycled glass cullet from window manufacturing. An increasing percentage is recycled glass from beverage containers. Some fiberglass insulation batting is encapsulated in plastic wrap. This insulation is available without a phenol formaldehyde binder.

Mineral wool insulation is made from either iron-ore blast furnace slag (slagwool) or natural rock (rockwool). Mineral wool is fire-resistant and effective at blocking sound.

Cellulose insulation contains post-consumer recycled newspaper and fire-retardant borates and ammonium sulfate.

Cotton insulation is made from recycled cloth. Borates are added for fire- and pest-resistance.

Expanded polystyrene (EPS) insulation contains no ozone-depleting substances and can be made with recycled polystyrene. Though usually produced at low density—about 1 lb/ft³ (16 kg/m³)—higher density EPS is also available. In those cases, structural and R-value properties are closer to those of XPS. Below-grade EPS is widely used for insulated concrete-form products.

Spray-in open-cell polyurethane insulation is popular in lightframe construction. It can also be used for filling masonry block. Open-cell polyurethane contains neither ozone-depleting blowing agents nor formaldehyde.

There are diminishing economic returns as insulation thickness increases. Designers or facility managers should analyze life-cycle costs (LCC) to determine optimal insulation levels for minimizing LCC costs.

Thermal bypasses in the building can significantly reduce the effectiveness of insulation, which is why the R-value of wall insulation used with steel studs is significantly lower (see the table below).

Settling, dust, and moisture accumulation reduce the R-value of loose-fill and batt insulation, especially in vertical wall cavities. Skilled, careful installation should avoid or minimize problems.

Measures to protect both the installer and the insulation must be taken during any installation, and a

continuous barrier (e.g., drywall) should be installed between the insulation and the occupied space to protect building occupants.

Be aware of the health hazards associated with asbestos. Asbestos is a proven carcinogen. It is prohibited in new construction; when found in existing buildings, it is usually left in place and encapsulated. When asbestos must be removed, all regulations and methods for removal, transportation, and disposal should be followed.

Moisture in the exterior wall cavity occurs when water is trapped in the cavity by impermeable surfaces. Condensation can occur if the dew point temperature occurs anywhere within the cavity. Managing moisture in the building envelope requires an understanding of the climate, the drying potential of wall cavities, and the interior space conditioning method. In northern (cold) climates, the interior side of wall cavities should be less permeable than the exterior side; just the opposite is true in warm climates with mechanically cooled buildings. Using rigid insulation on the exterior side of wall framing is one effective way to deal with moisture.

References

Lstiburek, Joseph, P. Eng., and John Carmody, *Moisture Control Handbook*, Oak Ridge National Laboratory, Oak Ridge, TN, 1991.

Wilson, Alex, “Insulation Materials: Environmental Comparisons,” *Environmental Building News*, Vol. 4, No. 1, January 1995; BuildingGreen, Inc., Brattleboro, VT.

Contacts

Building Thermal Envelope Systems and Materials (BTESM) Program, Oak Ridge National Laboratory, P.O. Box 2008 – MS6070, Oak Ridge, TN 37831-6070; (423) 574-5207; www.ornl.gov/walls+roofs/.

IMPACT OF FRAMING ON WALL R-VALUES

Combined Insulation & Framing R-Value			
Framing Material & Spacing	Insulation R-Value	Wood-Framed Walls	Steel-Framed Walls
2x4 16" on-center	R-11 (RSI-1.9)	R-9.0 (RSI-1.6)	R-5.5 (RSI-0.1)
	R-13 (RSI-2.3)	R-10.1 (RSI-1.8)	R-6.0 (RSI-1.0)
2x6 16" on-center	R-19 (RSI-3.3)	R-15.1 (RSI-2.7)	R-7.1 (RSI-1.2)
	R-21 (RSI-3.7)	R-16.2 (RSI-2.9)	R-7.4 (RSI-1.3)
2x6 24" on-center	R-19 (RSI-3.3)	R-16.0 (RSI-2.8)	R-8.6 (RSI-1.5)
	R-21 (RSI-3.7)	R-17.2 (RSI-3.0)	R-9.0 (RSI-1.6)

Notes: Assumes C-channel steel studs; steel-framing data from ASHRAE Standard 90.1; wood-framing values calculated using parallel-path method.

Source: *Environmental Building News*, Vol. 3, No. 4 (July/August 1994)