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Energy Efficient Building Design

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Table of Contents

Photo on the cover is of the Bighorn home improvement center in Silverthorne Colorado and is an example of daylighting. Photo Courtesy: DOE.

This course is based on the U.S Department of Energy's document "Low-Energy Building Design Guidelines, July 2001."

Introduction

Incorporating energy efficiency, renewable energy, and sustainable green design features into buildings has become a top priority in recent years as building owners seek to develop environmentally friendly facilities. Because energy-efficient buildings reduce both resource depletion and the adverse environmental impacts of pollution generated by energy production, it is often considered to be the cornerstone of sustainable design. In this course, we will be looking at what low-energy design means, specific strategies to be considered, when and where to apply these strategies, and how to evaluate their cost effectiveness.

Low-energy building design is not just the result of applying one or more isolated technologies. Rather, it is an integrated whole-building process that requires advocacy and action on the part of the design team throughout the entire project development process. The whole-building approach is easily worth the time and effort, as it can save 30% or more in energy costs over a conventional building design. Moreover, low-energy design does not necessarily have to result in increased construction costs. Indeed, one of the key approaches to low-energy design is to invest in the building's form and enclosure (e.g., windows, walls) so that the heating, cooling, and lighting loads are reduced, and in turn, smaller, less costly heating, ventilating, and air conditioning systems are needed.

The purpose of a building is neither to save - nor use - energy. Rather, the building is there to serve the occupants and their activities

In designing low-energy buildings, it is important to appreciate that the underlying purpose of the building is neither to save - nor use - energy. Rather, the building is there to serve the occupants and their activities. An understanding of building occupancy and activities can lead to building designs that not only save energy and reduce costs, but also improve occupant comfort and workplace performance.

The low-energy design process begins when the occupants' needs are assessed and a project budget is established. The proposed building is carefully sited and its programmed spaces are carefully arranged to reduce energy use for heating, cooling, and lighting. Its heating and cooling loads are minimized by designing standard building elements— windows, walls, and roofs—so that they control, collect, and store the sun's energy to optimum advantage. These passive solar design strategies also require that particular attention be paid to building orientation and glazing. Taken together, they form the basis of integrated, whole-building design. Rounding out the whole-building picture is the efficient use of mechanical systems, equipment, and controls. Finally, by incorporating building-integrated photovoltaics into the facility, some conventional building envelope materials can be replaced by energy-producing technologies. For example, photovoltaics can be integrated into window, wall, or roof assemblies, and spandrel glass, skylights, and roof become both part of the building skin and a source of power generation.

This course has been prepared primarily for energy managers to provide practical information for applying the principles of low-energy, whole-building design in new buildings. An important objective of this course is to teach energy managers how to be advocates for renewable energy and energy-efficient technologies, and how to apply specific strategies during each phase of a given project's time line.

The course begins with an overview of the technology and a few of the items to consider in designing an energy efficient building. Chapter two explains the issues affecting new building designs as it relates to specific types of buildings. Chapter three then discusses ways to introduce energy efficiency into the design process and chapter four discusses the computer modeling involved in energy efficiency designs. Finally, chapter five provides details on two projects that have successfully implemented the concepts explained in this course.

Chapter 1
About the Technology

Buildings consume roughly 37% of the primary energy and 67% of the total electricity used each year in the United States. They also produce 35% of U.S. and 9% of global carbon dioxide (CO_2) emissions.

By following a careful design process, it is possible to produce buildings that use substantially less energy without compromising occupant comfort or the building's functionality. Whole-building design considers the energy-related impacts and interactions of all building components, including the building site; its envelope (walls, windows, doors, and roof); its heating, ventilation, and air-conditioning (HVAC) system; and its lighting, controls, and equipment. This stands in marked contrast to the traditional design process, where there is generally no goal to minimize energy use and costs beyond what is required by codes and regulations.

To achieve the desired energy reduction goals, the design team must establish minimized energy use as a high priority goal at the inception of the design process. A balanced and appropriately funded team must be assembled that will work closely together, maintain open lines of communication, and remain responsive to key action items throughout the delivery of the project.

Continuing advocacy of low-energy design strategies is essential to realizing the goal. Therefore, it is important that at least one technically astute member of the design team be designated as the *energy advocate*. This team member performs many useful functions, such as:

- Introducing team members to design strategies that are appropriate to building type, size, and location.
- Maintaining enthusiasm for the integration of low-energy design strategies as central components of the overall design solution.
- Ensuring that these strategies are not abandoned or eliminated during the later phases.
- Overseeing construction to ensure that the strategies are not thwarted or compromised by field changes.

Application Domain

The application domain for low-energy design is not so much a case of where the technology should be installed, but where it is integrated with the other elements of the project to produce an energy-efficient building that serves both the environmental and functional needs of its users.

When thinking about whole buildings, it is important to consider not only the discrete components and materials but how the various parts can best work together to achieve the desired results. That is what is meant by the phrase "integrated, whole-building design." Low-energy design strategies and renewable energy concepts can be applied to almost any type of new building.

Energy-Saving Mechanisms

In commercial buildings, low-energy design mechanisms range from a few high-profile architectural features that are solar responsive to the application of more conventional and often less conspicuous, energy conservation technologies. Many applications are reconfigurations of typical building components, such as a change from flat façades and roofs to those that are articulated and have surfaces designed to bounce or block direct solar rays.

The low-energy design process described in this course combines a broad range of practical systems, devices, materials, and design concepts that should be considered simultaneously whenever possible to achieve significant reductions in energy use. For most non-residential buildings, an energy-use reduction of 30% below what is required by codes and standards can usually be achieved with little, if any, increase in construction cost. Savings of 70% or more are possible for exemplary buildings, although achieving such significant reductions can be challenging in light of the demands occasioned by budgeting constraints and cost-effectiveness criteria. For example, daylighting, coupled with dimmable lighting and light-level controls, is increasingly commonplace. An effective and highly recommended energy conservation strategy, this technology cluster is an important component of low-energy building design.

A few basic energy-saving techniques should be used to reduce building energy use such as,

- Siting and organizing the building configuration and massing to reduce loads.
- Reducing cooling loads by eliminating undesirable solar heat gain.
- Reducing heating loads by using desirable solar heat gain.
- Using natural light as a substitute for (or complement to) electrical lighting.
- Using natural ventilation whenever possible.
- Using more efficient heating and cooling equipment to satisfy reduced loads.
- Using computerized building control systems.

Because energy-efficiency concepts and technologies must dovetail with all other building elements, one of the most important energy-saving tools is the use of computer modeling and design software. This strategy should be used early in the design process to analyze the efficiency and cost effectiveness of candidate strategies. Detailed computer simulation results are then referred to throughout the design process, and often through the value engineering (VE) phase, to ensure that the building will efficiently perform as intended, and that subsequent changes to the design in the interest of cost-cutting do not adversely affect performance. By using appropriate energy simulation tools in the context of a whole-building approach that emphasizes solar technologies and energy efficiency, design teams can achieve significant operating cost savings while still staying on budget.

Advantages of Low-Energy Building Design

While basic techniques and concepts are important, of greater relevance to a given building project are the specific low-energy building design techniques themselves. One key element of low-energy building design is the inventive use of the basic form and enclosure of a building to save energy while enhancing occupant comfort. Chapter Three describes a wide range of low-energy building design strategies that can be commonly applied to new buildings. Low-energy building design combines energy-conservation strategies and energy-efficient technologies.

Low-energy design represents both a load-reduction strategy and the incorporation of renewable energy sources. Many low-energy building design strategies result in an absolute reduction in the use of power produced from fossil fuels. Together these innovations can save energy, reduce costs, and preserve natural resources while reducing environmental pollution. Low-energy building design strategies (including various daylighting techniques) can also provide a renewed sense of connection with the outdoors for occupants of the building.
Low-energy design can inspire planning concepts, such as interior private offices that borrow light from open office spaces at the building's perimeter.

More difficult to measure are the increases in workplace performance and productivity that are often achieved through whole-building design and its resulting economic value. Nonetheless, organizations housed in low-energy buildings have reported that their indoor environments help retain employees, reduce tension, promote health, encourage communication, reduce absenteeism, and, in general, improve the work environment.

Chapter 2
Application

Low-energy building design techniques are application specific. This chapter provides a practical method of determining the potential use of design techniques in different types of buildings, in different climatic locations, and under various local energy cost scenarios. It also details the process and level of advocacy required to assure such strategies are considered and incorporated into the design process. It begins with the earliest project phases and continues through construction and building occupancy.

For a particular project, the specific energy-saving techniques, strategies, and mechanisms to be deployed will vary greatly, depending on building and space type. Their selection and configuration will also be influenced by:

- Climate,
- Internal heat gains from occupants and their activities, lights, and electrical equipment,
- Building size,
- Illumination requirements,
- Hours of operation, and
- Costs for electricity and other energy sources.

In reviewing this list, one can quickly grasp that strategies specific to a particular building or space may not work nearly as well in another application. Therefore, some general guidance about building and space types will prove useful in understanding the factors that lead to significant energy use in buildings and in identifying the strategies that can yield optimum savings.

It is essential that the team appreciate that a successful design solution under one set of circumstances may not be appropriate or cost effective for a different building type, size, or configuration; the same building type constructed in a different climate; or where variable energy costs apply.

Applications Screening

The use characteristics discussed below are representative of new building projects. The first step toward assuring low-energy building design for a particular project is to understand the energy implications of the structure's basic form, organization, and internal operations. These criteria will dictate the relative importance of strategies to be deployed for heating, heat rejection, lighting, and, in some cases, hot water. The term *heat rejection* is used (as opposed to cooling) based on the idea that a fundamental goal of low-energy building design is to greatly minimize the need for, and dependence on, mechanical cooling.

It is important for those involved in building design projects to know how and why office buildings, laboratories, hospitals, warehouses, and various residential building types use energy. Each of these will be summarized later, but first, some background information should prove useful in forming a basis of understanding.

Perhaps the most basic division is that of houses and larger, non-residential buildings. Houses are the most common example of skin-load-dominated buildings, because their energy use is predicated by heat gain and loss through the building enclosure or skin (also known as the envelope, e.g., walls, windows, roof, floor). Houses and other skin-load dominated buildings primarily require heat in cold climates, cooling in hot climates, and very little energy of any type (except hot water) in benign climates like San Diego. For low-energy performance, it is common for houses and other *skin-load-dominated* buildings to be well-insulated and to invite the low winter sun in while keeping it out (through shading and proper building orientation) during the summer.

Simplistically, larger non-residential or commercial buildings are often referred to as *internal-load-dominated* buildings because a large portion of their energy use is in response to the heat gains from building occupants, lights, and electrical equipment (e.g., plug loads for computers, copiers). As a result of these internal heat sources, internal-load-dominated buildings are often designed to turn their backs on the sun, and further reduce solar gain through the use of tinted and reflective glass. There is some logic to this, but such an approach is too universal and precludes some of the most beneficial low-energy design strategies. Moreover, it often is too simplistic to think of a building with offices as simply an office building. The structure is also likely to have a lobby and circulation spaces, a cafeteria, a computer room, meeting rooms, and other spaces that have environmental needs and thermal characteristics that are very different from those of offices. Ideally, design strategies should first satisfy the needs of each individual space or zone. This requires careful attention during the programming phase of the project.

Evaluating a specific project for selecting and integrating low-energy design strategies starts with an understanding of the following factors.

Climate

Not just is it hot or cold, but how humid is it? Is it predominantly clear or cloudy, and during what times of the year? Clear winter climates are well matched with spaces that incorporate passive solar heating strategies. In contrast, spaces (and buildings) in clear summer climates generally require a high degree of sun control. Clear climates also make the best use of light shelves—horizontal surfaces that bounce daylight deeper into buildings. Even the site-specific and seasonal nature of the wind needs to be understood if natural ventilation strategies are to be incorporated into a building design.

Internal Heat Gains

The heat gains from building occupants, lights, and electrical equipment can be thought of as the interior climate and should not be generalized. Instead, during the early programming of the project, the heat gains anticipated from these sources should be quantified for the various spaces where they apply. In some cases, such as in storage buildings and other areas with relatively few occupants and limited electrical equipment, these heat gains will be minor. In other instances, the presence of intensive and enduring internal heat gains may be a determining factor in HVAC system design. Examples of intensive and enduring influences include activity-based gains, such as those produced by cafeterias and laundry facilities (where increased humidity is also a factor), and technological or industrial gains, such as the heat produced by mainframe computers or heavy machinery. These factors should be identified early on, and appropriate design strategies investigated (such as heat recovery or using a closed-loop heat pump system).

Building Size

In a low-energy building, both the indoor and outdoor climates exert a powerful influence on all aspects of building design. Sometimes, they complement one another, such as the case of a building with a lot of internal heat gains sited in a very cold climate. At other times, however, the two climates are antagonistic, such as when there are a lot of internal heat gains in a very hot climate. Understanding the implications of these factors is fundamental to determining appropriate low-energy design strategies for a particular building project. Under hot/hot conditions, buildings with large footprints and a large amount of floor space far from the exterior of the building will require heat removal in the interior zones (generally by mechanical cooling) all or much of year.

The other basic planning approach is to position all spaces that can benefit from connection to the outdoors in proximity to exterior walls. To achieve this, buildings become much narrower, with a maximum width of about 70 feet. Such an approach to building size must, by necessity, be introduced very early in the design process. Also, recognize that not all spaces need or want to be exposed to the exterior, including many areas of complex building types like hospitals. These spaces often function better as interior placements within a wider and more compact building form.

Lighting Requirements

The lighting needs of a building's various spaces need to be identified, both quantitatively and qualitatively, as part of the environmental programming conducted early in the project. Many spaces, including lobbies and circulation areas, require general ambient lighting at relatively low foot-candle levels (10 foot-candles or less). Such spaces are ideal candidates for daylighting. In contrast, some spaces are used for demanding tasks that require high light levels (50 foot-candles or more) and a glare-free environment. Here the design team's attention may shift from daylighting to a very efficient electrical lighting system with integrated occupancy sensors and other controls.

Hours of Operation

Typically, on a per-square-foot basis, the most energy-intensive building types are those in continuous use, such as hospitals. In these buildings, the balance of heating and heat removal (cooling) may be altered dramatically from that of an office building with typical work hours. For example, the around-the-clock generation of heat by lights, people, and equipment will greatly reduce the amount of heating energy used and may even warrant a change in the heating system. Intensive building use also increases the need for well-controlled, high-efficiency lighting systems. Hours of use can also enhance the cost effectiveness of low-energy design strategies, such. In contrast, buildings scheduled for operations during abbreviated hours (including seasonal occupancy facilities), should be designed with limited use clearly in mind.

Energy Costs

The cost for energy, particularly electrical energy, for most non-residential buildings is a critical factor in determining which design strategies will not only conserve energy, but will also be cost effective. In most locations in the United States, electricity more expensive than natural gas per Btu. This disparity can, at times, be capitalized upon by introducing design strategies that affect a trade-off in energy use. For example, increasing the glass area and the commensurate daylight entry can save expensive electrical use but, at the same time, occasion the purchase of additional (but relatively low-cost) heating energy. However, such an example should not be misconstrued as indicating that daylighting requires an excessive amount of glass, as that is just not the case. Daylighting primarily requires placing the glass carefully and selecting the appropriate glazing.

To the greatest extent possible, the life-cycle benefits of various design strategies should be investigated for the range of energy-cost scenarios deemed plausible. For some strategies—particularly those that affect the amount of heating energy used— the energy mix may be of lesser importance. In other cases, however, rate structures, particularly those based on peak electrical demand, may significantly affect the economic impact of strategies such as daylighting.

Typical Cost for One Million BTU,

Natural Gas,

$$\frac{1{,}000{,}000\ Btu * \$0.60}{100{,}000\frac{Btu}{Therm} * 0.75\ eff} = \$8.00\ per\ million\ BTU$$

Electricity,

$$\frac{1{,}000{,}000\ Btu * \$0.08}{3{,}413\frac{Btu}{kWh} * 1.00\ eff} = \$23.44\ per\ million\ BTU$$

Building Types: Characteristics and Profiles

The following brief descriptions give broad categories of building types and some likely successful strategies for consideration.

Residential Buildings

In cold climates, the classic, skin-load dominated building type really benefits from using high-performance, low emissivity (low-e) windows and high levels of insulation. In many cold climates, residential buildings can also significantly benefit from passive solar heating, so long as a reasonable amount of heat-absorbing thermal mass is incorporated into the design. In hot climates, solar control is paramount, based on the need to keep cooling loads and costs under control. It is also important to take advantage of the opportunity for passive or active solar water preheating. For remote structures that do not have easy access to the utility grid, photovoltaic systems should be considered as the primary, or sole, source of electricity.

Small Non-Residential Buildings

This profile describes buildings in which lighting and internal gains play a relatively small role in the building's energy balance. Such buildings are the heart and soul of low-energy building design, as a multitude of low-energy building design strategies can be successfully applied to their construction.

A good example of this type of building is a visitor center at a National Park. Visitor centers are among the most advanced energy-conserving structures. They generally have a robust budget, allowing the purchase of durable materials. They are normally located in severe (either hot or cold) climates inaccessible to utilities; they have a natural connection with the outdoors; and the structures present an opportunity to interpret the resource-conservation mission of the agency to the visiting public. These structures typically combine a need for window area, massive construction, and a tolerance for temperature swings—all of which are highly compatible with low-energy building design. Daylighting is another key strategy for deployment in these building types.

Urban Office Buildings

This building type evinces characteristics commonly found in major urban centers. Land is often expensive and must be used at a high density. The building is typically dominated by one repetitive use—office space—although it may also contain a number of other uses such as support facilities. These buildings are often landmarks or showpieces. In highly controlled areas like Washington, D.C., this translates into height limits and tight controls over façade treatment. In most cities, however, there are few controls on the style or height of downtown office buildings.

As a result, many of these buildings include or consist of towers that shade and are shaded by neighboring buildings, a factor that may significantly affect the design and sizing of the mechanical cooling system.

Curtain walls are, by far, the most common enclosures for downtown office buildings, but most curtain walls are classic examples of a “building as a fortress against the environment” philosophy. The low-energy building design strategy for flat curtain walls is typically defensive in nature, limiting the boring and often unattractive result from the overuse of glass and by a lack of orientation-specific façades. Fortunately, there has been somewhat of a stylistic revolt against all-glass buildings, which has led to more articulated façades, variation in building façade treatments, and a resurgence in the use of masonry. All of these factors greatly enhance low-energy building design possibilities by creating opportunities to tune façades to suit their orientation and the activities taking place behind them. In most cases, thoughtful strategies will be needed to reduce solar gain. Exterior sunscreens or new glazing types (fritted, shaded) can both enliven the façade and provide substantial cooling load reduction.

An excellent way to take advantage of low-energy building design is to move as many private offices away from the façade as possible. In this way, more light can be directed further into the building, and more of the building’s users can enjoy access to views and natural lighting. This scenario often yields increases in productivity and enables the adoption of more energy-efficient HVAC strategies.

If an atrium is involved, it should be located and designed to substitute natural lighting for artificial lighting, to minimize cooling loads, and to take advantage of solar heating, if it is needed. The location and shape of the atrium will be highly building-specific. In general, taking full advantage of the unique opportunities of each urban site requires considerable expertise, particularly because of shading from surrounding buildings and the complex interactions among lighting, HVAC, façade design, orientation, and climate.

Courthouses

This building type typically entails highly complex and interrelated space programming. Many diverse functions must be accommodated, sites are often constricted, and the professional occupants are demanding. In addition, courthouses often serve a ceremonial function. In many cities, they are the most prestigious and conspicuous of buildings. Their typically urban location often requires sensitivity to surrounding buildings with historical styles and value and most certainly will require careful integration into the existing urban plan. Oftentimes, the functional needs of courthouses (i.e., security requirements) must be fully satisfied before energy-based programming concerns can be addressed, and solar design strategies may not always apply to this building type. Still, low-energy design opportunities abound, especially in terms of efficient lighting, HVAC systems, equipment, and controls. It is also worthwhile to note that many of the design issues described for urban office buildings will also apply to courthouses.

Hospitals

These facilities tend to have a lot of small spaces, many of which need to be windowless. Offices and patient rooms can be thought of as small, mixed-use areas that incorporate both residential and commercial features. Cafeterias and public lobbies present special opportunities for daylighting. Overall, this building type has many spaces that require large quantities of outside ventilation air. Therefore, ventilation-air heat-recovery systems that are not prone to cross-contamination are particularly useful in these applications— especially in very cold climates. The around-the-clock nature of hospitals is a perfect opportunity to incorporate very efficient and well-controlled lighting and power systems.

Laboratories

Laboratories are an energy-intensive building type that often consumes more than 200,000 Btu per square foot, due to large ventilation requirements and in part to the long operating hours (two or three shifts) that are typical. The laboratory working environment normally requires enormous amounts of ventilation air to ensure good indoor-air quality, often making heat recovery systems cost effective.

If there is a considerable demand for hot water, preheating the water using solar energy is recommended, particularly for facilities located in clear climates. This building type can often benefit from daylighting, but because the walls tend to be occupied with equipment, it is appropriate to consider either high windows or top-lighting by roof monitors on the upper floor. Either way, avoiding glare is crucial. Circulation corridors along southern façades can function as solar-heated sunspaces. Sunlight on south façades can be "bounced" through high glazing by way of light shelves. Depending on the regional climates, thermal mass walls for heat storage between labs and corridors may also make sense. The corridors can double as pleasant meeting and lounge spaces, while serving as a buffer to the south sun, thus permitting wider temperature swings than would be permissible in the main labs. On north-facing walls, small, well-spaced view windows can double as a source of diffuse daylight.

Incorporating atriums into laboratory buildings also makes sense, both as a means of bringing natural light into the labs and providing casual meeting spaces adjacent to the labs. West façades may serve as good locations for windowless lecture halls. Cafeterias can use direct gain, or in some temperate climates, might even have a fabric roof.

Warehousing/Shipping/Repairing

These activities are typically carried out in one-story buildings with high ceilings. Offices, supervisory booths, employee services, restrooms, and loading docks often complement a main un-partitioned space. For roof and wall assemblies, steps must be taken to counteract heat loss due to continuous metal contacts throughout the construction. Though not limited to metal components, this process is known as thermal bridging, which can significantly compromise the resistance value of insulation. In climates with hot summers, a white or reflective roof is advisable.

If lighting can be controlled electronically through light sensors and other devices, natural lighting strategies can be very useful. If the budget does not allow for proper roof monitors with vertical glass facing south or north, consider using high windows along the south and north walls with south-facing glass shaded by properly designed overhangs. Exercise care in using scattered skylights, as they can create glare and let in excessive amounts of solar heat.

If the building is subject to around-the clock use, large high-intensity discharge (HID) lamps are appropriate when arranged in such a way as to light between inventory stacks when daylight is unavailable. Interior surfaces should be light-colored to reflect light. If the building is used intermittently, more and smaller HID or fluorescent lamps that easily switch on and off should be used. HVAC should be localized to work areas, with the overall building maintained at the maximum temperature range needed for its contents and the proper operation of machinery.

Campus Layout

This profile describes a wide variety of building types where space adjacency requirements are not crucial, and there is ample site area availability. Possible building types include rural or suburban office buildings, training and classroom facilities, some laboratories, and other multi-family housing.

If the buildings can be spread out, more of the interior space will be close to an outside wall. A campus plan makes the most sense in designing buildings for housing and classroom use, where deep interior spaces are inappropriate. Compared to a compact building form, the campus plan generally costs more at the outset, based on the need for a larger site, the cost of added building enclosures, and added lengths for service connections. When life-cycle economics are taken into account, these additional costs can be justified if the additional exposure is used to optimum advantage and daylighting and natural ventilation are brought into play.

For spaces that can benefit from passive solar heating, it is essential that south-facing solar glazing be clear of any shade during the heating season, even deciduous trees. The bare branches of trees can change a sunspace from one that provides useful heat into one that does not. In very cold climates, it is worth considering a partially earth-sheltered building, especially in the context of a sloping site.

Renovations

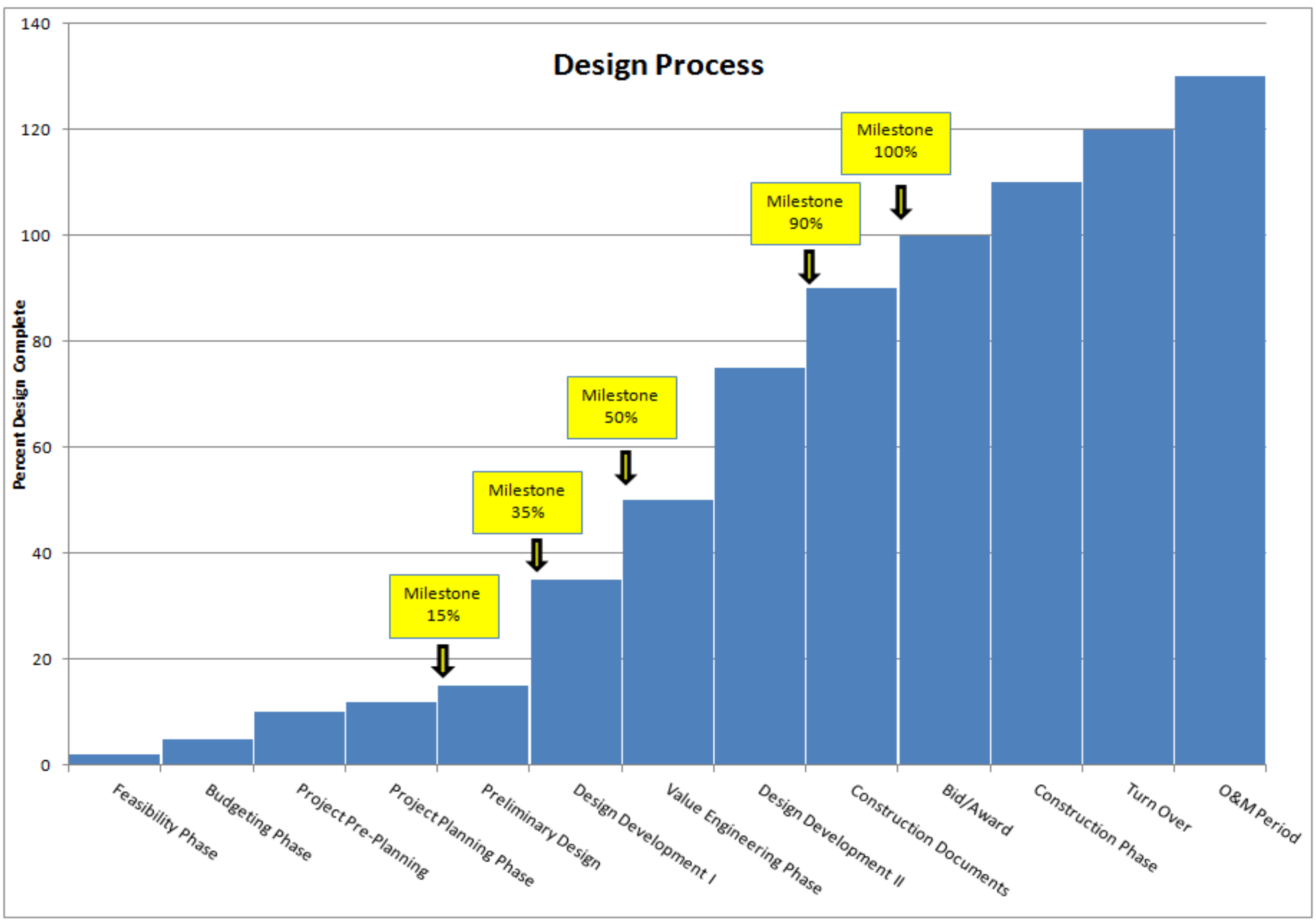
Renovating and reusing a building makes it low energy and sustainable in another very important way. Much less energy is needed to produce construction materials and deliver them to the site when the building's basic shell is being reused. Older buildings, in particular, often make excellent candidates for low-energy design that utilizes their mass, higher ceilings, and narrower building form. Many aspects of low-energy building design are applicable to many large-scale renovation projects. The only strategies that are clearly precluded are those based on siting, building form, or orientation. While these established features can limit a building's low-energy performance potential, renovations can still reduce energy costs by 20% to 30%.

Chapter 3
Integrating Low-Energy Concepts into the Design Process

Integrating low-energy concepts into new construction may involve many different points in the design process. This chapter looks at how low-energy concepts are involved in these areas,

1. Feasibility
2. Design Development II
3. Budgeting
4. Construction Documents
5. Project Pre-Planning
6. Bid Solicitation/Contract Award
7. Project Planning
8. Construction
9. Preliminary Design
10. Turn-Over
11. Design Development I
12. Warranty
13. Value Engineering
14. Post Occupancy Evaluation

The chart shown below outlines the steps to the design process and the major milestones from the feasibility stage to the operation of the new facility.



We will review each step in the design process, beginning with the feasibility phase.

1. Feasibility Phase

The feasibility phase is normally when building managers or other decision makers determine that a project will be built to address a particular need. At this stage, the enabling premises of low-energy design and construction need to be defined and established. Think of this as the time when the seeds of the overall sustainable design and construction strategies are sown, and the framework is established for decisions to be made and actions to be taken throughout the design and construction process. Defining parameters; establishing general goals; and identifying policies will guide and propel the process.

During the feasibility phase, architects and engineers develop a capital project scope and planning document that provides a design program, an implementation strategy, and a budget assessment. Identifying these elements early is essential to establish project feasibility, support project selection, and coordinate project execution. Community plans for major cities and surrounding areas identify long-term space needs and propose appropriate actions to address those needs. Major projects involving renovation or construction of commercial buildings must be developed in accordance with applicable community plans. In many cases it is necessary to conduct studies to support project planning or assess building conditions, some of which may take into account coordination with state and local authorities, community groups, and others who may have a stake in the development process.

Local government officials must be contacted when planning a new facility to ensure that all documents impacting the project are discussed. These documents may include master plans, current and future land-use plans, zoning maps, traffic studies, and other documents that address the availability of essential support services (e.g., fire, police, utilities, telecommunications). Helpful information includes documentation of current building conditions, maintenance concerns, site access, communication with other agencies, and other potential impacts on project scope and implementation.

<u>Action Items</u>

- Conduct all required feasibility analyses (including, but not limited, to those described above).
- Review all company directives and policies to be sure of what your company currently requires in the way of energy performance, materials usage (i.e., quality, durability, recycled content, energy saving features, impact on indoor environmental quality, daylighting, use of renewable energy sources, contracting issues, and other relevant concerns.

- Select an energy champion and give them the authority to make decisions relating to low-energy design and construction practices.
- Establish explicit energy-use targets. Factor in any additional criteria that may be specific to your company, facility location, or end use.
- Identify and list your goals for other sustainable issues, such as site planning, materials use, water use, or indoor environmental quality.

2. Budgeting Phase

Some projects may be constructed using standard designs (those completed for similar projects or off-the-shelf, prefabricated structures). Be certain that your specific low-energy goals have been accounted for.

Action Items

- Program any special requirements into your budget submission.
- Submit a budget that allows for an energy champion (as well as the meetings and other resources required to accommodate a team process), the additional studies, analyses, and verifications that will be needed and slightly higher design fees (generally 2%–4%).
- Include the requirement for an energy expert in your Request for Proposal/ Architectural & Engineering (RFP/A&E) solicitation.
- Conduct a planning meeting prior to concept development to ensure that low-energy building components and strategies will be adopted early in the planning and design stages, when these elements can be incorporated at the lowest possible cost.
- Identify the certification and testing measures required to ensure compliance with energy targets and sustainability goals.

3. Project Pre-Planning Phase

At inception, and during the early phases of a low-energy project's time line, a needs assessment is conducted. This process considers the long-term requirements of the building occupants and yields a program for the project that includes:

- User group needs and square footage requirements
- Location and site options
- Estimated costs and schedule.

It is essential that the budget established at this time be based on all factors that will influence costs, including the incorporation of low-energy design strategies.

Action Items

- Select appropriate candidate low-energy design strategies.
- Associate these strategies with the particular project phase during which they must be considered and evaluated.
- Identify the team members who will be responsible for evaluating and incorporating the strategies at each phase.
- Identify the appropriate evaluation tools to use at each phase and who will use them.
- Identify the actions to be taken by various team members at each phase and carry them out.
- Establish low-energy design as a core project goal.
- Use case studies and passive solar performance maps to help determine appropriate strategies for the specific project type at hand.
- Establish energy-use targets that surpass applicable codes and standards. In general, energy-use reductions in nonresidential buildings should be targeted at 30% or better in comparison to a standard, code-compliant building.
- Ensure that the planned building configuration takes maximum advantage of the site and climate.
- In selecting consultants, consider their level of experience and expertise in low-energy design.

Strategies to Consider During This Phase

User Energy Needs Assessment

This is a direct assessment of the energy-related needs of facility users. Whether it is in the form of an *Environmental Programming Matrix* or other, less formal, documentation, it is a fairly rigorous and thorough evaluation that considers occupancy, operating hours, and all aspects of the interior and exterior climates. The needs assessment yields more precise energy use requirements, which, in turn, helps determine the applicability of low-energy building strategies. The needs assessment is appropriate for use on all projects.

Classify users on the basis of specific needs that directly relate to specific low-energy building strategies. In addition to temperature, humidity, and general lighting standards, there should be a focus on other user needs such as the desire for exterior views and natural daylight; tolerance to moving air and temperature swings; and the type of automatic lighting control that is most appropriate for a given user.

This document may be seen as an expansion of the typical needs assessment procedure, and as such, may entail revision to standard company assessment protocols. Coming up with useful questions to ask in the needs assessment requires an understanding of the effects of various low-energy design strategies on user comfort.

Building-Appropriate Site Selection

This process involves choosing a site that fully supports the energy reduction strategies contemplated for the project. Proper siting increases the likelihood that many other low-energy building strategies can be implemented. This strategy is appropriate for all new building projects. During site selection, locate buildings that do not require extensive exterior exposure on shaded or confined urban sites. Buildings that will benefit from a greater degree of exterior exposure should be located on open sites. For many projects, the site may have been selected before the manager's involvement.

Complementary Building Uses

This process involves defining the nature of the facility and then matching the end use with complementary energy needs and minimizing the resulting wastes. The design team takes advantage of the natural symbioses and commonalties that exist between building uses that might otherwise be overlooked. This is best done when compatible projects are at similar points in their development; ideally, from the planning stages forward. At the earliest stages of project conception and site selection, consider co-locating any types of facilities where the waste products of one can be used to provide needed energy for another, or where construction-based support services can be shared.

Currently used in designing co-generation facilities, ecological industrial parks, district heating, and community-scale energy storage facilities; other applications may be identified on a case-by-case basis. Opportunities may also exist for co-locating non-polluting industrial and residential facilities. In all circumstances, action is required at the earliest stages of the project, before detailed plans for the various uses are fully developed.

4. Project Planning Phase

In close consultation with project personnel, the design consultants (e.g., architects and engineers) prepare initial and schematic design options. At this time, options for placing the proposed building on the site and massing alternatives are evaluated. Fundamental low-energy design strategies are also assessed for applicability to a specific project. Design consultants generally present their design options and analyses to project personnel for review and evaluation; this process is often repeated several times until the basic design is decided upon and approved. At the conclusion of this phase, the design should clearly indicate which low-energy design strategies have been incorporated in sufficient detail so that heating and cooling loads can be estimated and so HVAC system options can be examined.

Action Items

- Establish an interdisciplinary design team, including an energy professional, as early in the process as possible.
- Develop a preliminary layout that maximizes or minimizes solar gain. Consider atrium spaces, direct or indirect passive solar heating, earth-protected spaces, and natural and constructed shading.
- Develop landscape plans that contribute to the facility's energy performance. Consider shading options, wind breaks, and using existing site features.
- Develop a basic layout that maximizes the use of daylighting. Consider building orientation, the size and placement of windows, and top-lighting.
- Investigate using renewable power sources as part of the facility's overall power supply. Consider using solar (domestic) hot water on building types with high hot water usage and building-integrated photovoltaics (BIPV) to reduce reliance on non-renewable power.
- Conduct a preliminary energy analysis (analysis tools depend on scale of project). Use ENERGY-10 and other user-friendly tools for smaller, simpler projects (those with two or fewer zones, and roughly 50,000 square feet or less). Use DOE 2.2 and other applicable tools for larger and more complex projects.

Strategies to Consider During This Phase

The following strategies need to be assessed during the project planning phase of the time line. Their incorporation will influence the overall siting and massing of the building, as well as the basic organization of spaces.

Perimeter Circulation Space

This passive solar strategy uses circulation (corridors) and casual meeting spaces as buffers between the façade and the interior conditioned spaces. The goal is to support several low-energy building strategies that are not compatible with certain uses (e.g., direct-gain sunspaces and office space). The strategy is appropriate in buildings needing large areas for circulation, waiting, and casual meetings, such as a visitors' corridor in a hospital or casual meeting sunspaces outside laboratories or offices.

Because perimeter circulation plans generally require slightly more total floor area, it is necessary to examine user needs and evaluate the strategy in light of the overall budget. If the strategy is acceptable, look for buffer spaces that can be located along the building's exterior, particularly along the south façade. An accurate energy needs assessment is a key to the effective integration of this strategy.

Extended Plan

By extending the plan to produce a longer, narrower footprint, you can create more exterior wall surface. In most climates, elongating the building in an east-west direction makes the most sense from the standpoint of daylighting and passive solar heating. The goal is to increase the amount of usable space that is close to an outside wall.

Building types that benefit most from exterior exposure include good candidates for daylighting and direct-gain passive solar heating. This is best accomplished early in the design process, as modifying the basic building form may occasion a slight increase in the construction budget.

Direct-Gain Passive Solar Heating

Installing south-facing glazing in an occupied space enables the collection of solar energy, which is partially stored in the walls, floors, and/or ceiling of the space, and later released. With direct-gain passive solar heating, the savings achieved in heating energy is augmented by the aesthetic and productivity-enhancing benefits of daylighting, a valuable amenity for occupants. The functioning of the space should not be compromised by direct glare from glazed openings or by local overheating.

This strategy works well in cold, clear climates. Glazing must face within 15 degrees of true (solar) south, and the affected areas must be compatible with daily temperature swings.

Some appropriate contexts for direct-gain heating include corridor spaces, eating spaces, meeting spaces that can be scheduled for use during times when the temperature is most comfortable, sleeping spaces, and recreational sunspaces. Working with the energy consultant, the designer can fine tune the amount and type of glazing with glare and temperature controls, materials in the affected space, auxiliary heating, and cooling to address local climatic changes.

Because true north and magnetic north are different, the design team will need to account for magnetic declination. For optimum effect, floor and wall finish materials with high heat-storage capacity must be exposed to direct illumination by the low winter sun. Overall, this strategy is considered central to low-energy building design.

Atrium Spaces

Atrium spaces are multi-floor open areas appropriate for circulation, lobbies, dining, or other shared space. Atriums are typically covered by a glazed roof or one that incorporates roof monitors. The goal is to configure the atrium for minimum impact on the building's energy load and this process is best applied to buildings with programmed spaces can be well-served by one or more atrium spaces. It is best to avoid configurations that produce heat losses or gains with no compensatory benefits. The atrium should bring daylight to the interior of the building while providing a "chimney" for natural ventilation during mild weather. In some cases, atriums can collect useful solar heat in cold climates— serving as a kind of transition zone, with larger temperature swings than would otherwise be appropriate in the rest of the building. The atrium's configuration should be defined at the earliest possible stages of the design process, before an undesirable or arbitrary configuration is locked in. There is no hard and fast distinction between atriums and glazed roofs over large open spaces (such as gallerias).

Induced (Stack-Effect) Ventilation

Heated air rises within a mid- or high-rise building to the top (often below a glazed roof in an atrium), where it exits through roof openings. This process induces ventilation of the adjoining spaces below. This strategy removes heat and reduces mechanical cooling and fan energy use requirements.

Spaces that are not adversely affected by increased air motion are appropriate targets for natural whole-building ventilation, which effectively conditions the space during fair weather without using air conditioning. In this strategy, it is best to incorporate air inlets, generally in the form of operable windows, at the building perimeter. For best results, use open-office space planning and avoid partitions that inhibit air movement. Consider complementing natural ventilation with controllable passive ventilators located in the upper portions of the building. Carefully coordinate the implementation of this strategy with building HVAC system and controls.

Natural ventilation works best in low-humidity climates. An atrium often serves as an ideal chimney to exhaust hot air.

Open Office Space at Perimeter

Locating private offices at interior positions leaves the perimeter open to general office space.

Open spaces at the perimeter should be programmed to allow for more extensive use of daylighting deeper into interior sections.

This strategy is best used in buildings with large areas of office space. Private, interior-located offices need compensating amenities. At minimum, install glazing that lets onto the open office space or overlooks an atrium space. This strategy is especially appropriate for buildings with limited façade glazing, such as earth-protected buildings.

This is an effective strategy that requires a strong commitment by the agency or organization to keep perimeter spaces open and not reserve them for high-ranking executives.

Landscape Shading

The use of existing or planned trees and major landscaping elements can provide beneficial shading. Trees and major landscape elements should be located to provide useful shading and reduce cooling loads. Landscape shading works best when shading west and south façades.

Study planting plans of existing site landscaping to determine whether existing trees can be retained and incorporated into the planning process. Perform shading analyses of plants in both immature and mature forms to estimate energy savings during plants' anticipated life span. Whenever possible, avoid or remove plantings that would compromise useful solar gain.

Trees and landscaping can reduce peak cooling loads through shading and can cool the ventilation air entering a building. Even during the winter, most deciduous trees and plants cast substantial shade on solar collectors (e.g., south-facing windows).

Earth-Protected Space

Partially buried, construction can moderate building temperature, save energy, and preserve open space and views above the building. The goal is to minimize heating and cooling energy use by protecting more of the building from fluctuating outdoor air temperatures.

Sites with a large natural slope in cold climates are ideal candidates for incorporating earth-protected spaces. The berm should be against walls or earth-cover roofs (in severely hot or cold climates) or combine high horizontal windows with light shelves located above earth-sheltered walls. In some cases, using "invisible" earth-protected buildings can help counter community resistance to bulky new construction.

Similar low-energy performance can also be achieved by using additional insulation.

Solar Water Heating

Solar water heating uses flat-plate solar collectors to preheat domestic hot water.

To be considered effective, this strategy should yield a significant portion (50% or more) of the domestic hot water needed for day-to-day operations. Look to building types where hot water use is high year-round, such as hospitals and laboratories. Best performance will be achieved in hot climates with high solar radiation levels.

Design an array of flat-plate solar collectors that include an absorber plate (usually metal), which heats when exposed to solar radiation. Most common among these are indirect systems that circulate a freeze-protected fluid through a closed loop and then transfer heat to potable water through a heat exchanger. Typically roof-mounted, solar collectors should face south and tilt at an angle above horizontal, approximately equal to the latitude of the project location. This configuration will provide optimum year-round performance. Provide a pipe chase to a mechanical room. The room needs to be large enough for storage tanks.

Collectors should be mounted in a location that is un-shaded by surrounding buildings or trees during the hours of 8 a.m. to 4 p.m. (at minimum) throughout the year. As is the case with many of the strategies described herein, an effective conservation program will help to minimize hot water demand and, in turn, reduce material and systemic requirements.

Building-Integrated Photovoltaic Systems

Photovoltaic (PV) arrays are now available that take the place of ordinary building elements (such as shingles and other roofing components), converting sunlight into electrical energy without moving parts, noise, or harmful emissions. The goal is to reduce the first cost of the PV array by using it in place of high-cost building elements and take into account the energy cost reductions over time. Consider deployment in sunny climates with high electrical utility charges.

Commercially available systems include thick, crystal, circular cells assembled in panels and thin-film products deposited on glass or metal substrates. At today’s prices, BIPV often provides a good payback if it replaces high-cost glazing, such as fritted glass (the arrays can even resemble fritted glass). To be cost effective, BIPV must intercept nearly a full day’s sun, so it is often most effective as a replacement for roof or atrium glazing. BIPV also works well as spandrels that are fully exposed to the sun.

Comments: One of the benefits of grid-tied BIPV systems is that power production is typically greatest (on bright, sunny days) at or near the time of the building’s peak electrical and cooling loads.

5. Preliminary Design Phase

During the previous phase of the time line, Project Planning, basic decisions were made regarding site placement, plan organization, and building size. Those determinations will now influence the basic low-energy design strategies (e.g., daylighting) that will be evaluated in detail during this phase, especially those relating to the building envelope.

Traditional building design has assigned a protective role to the walls, roofs, and floors of buildings—protection against cold, sun, rain, and unwanted intrusion. In low-energy building design, the protective role still exists, but the building envelope is also thought of as a membrane that manages or "mediates" interactions between the interior spaces and the outside environment. During schematic design, the Envelope-Related Strategies discussed below will be evaluated and integrated into the overall building design.

Action Items

- As the preliminary layout is refined, ensure that access to daylight continues to be optimized. Consider perimeter access to light and views, roof monitors, skylights and clerestory windows, and light shelves.
- Develop material specifications and a building envelope configuration that maximizes energy performance. Consider window shape and placement, shading devices, differentiated façades, reflective roofing, fabric roofs, induced ventilation, nighttime cooling ventilation, and selective glazing.
- Continue energy analyses, including multiple runs of similar products (e.g., various glazings and insulation levels) to determine best project-specific options. In addition to first cost, consider durability and long-term energy performance.

Strategies to Consider During this Phase

Selective Glazing for Walls

Glass products are now available with a wide range of performance attributes that allow designers to carefully select the amount of solar gain, visible light, and heat that they allow to pass through. Solar heat is measured by the properties of shading coefficient (SC) and solar heat gain factor (SHGF). An SC of 1.0 applies to clear 1/8-inch thick glass with other glasses that admit a lesser amount of solar heat having a lower SC (e.g., 0.50 for a tinted glass that admits 50% as much solar heat as 1/8inch clear glass). The term SHGF, which is now widely used by the glazing (fenestration) industry because it takes into account a range of angles of solar incidence, is considered to be equal to a value of 0.86 times the SC. The degree of daylight, or visible light transmission, is expressed by the term *Tvis*, and the amount of heat loss is measured by the U-factor, which, expressed numerically, is the inverse of the total resistance of the glazing assembly.

Single-glazing is about R-1 for a U-factor of about 1.0. Double-glazing is about R-2 for a U-factor of about 0.50. Commercially available low-e glass typically ranges in U-factor from about 0.35 down to 0.10, depending on the type and number of coatings and the fills (e.g., argon) used in the spaces between glazing layers. Glazings should be specified with the best combination of performance characteristics for the specific application at hand.

The choice of glazing(s) is an essential consideration for all building types. Begin by incorporating glass performance characteristics (e.g., U-factor, shading coefficient) as required by the applicable codes or standards. Then, use computer analysis to investigate alternate glazings and narrow the field to those most beneficial to admitting daylight and saving energy, while still remaining within the project budget. Glazing technology has now advanced to the point that alternative glazings with very different performance characteristics can physically look very much alike. This increases the potential to use different glass types on different façades, although such an approach may be considered a maintenance headache. The best glazing selections are not merely those with the highest numerical performance levels in a given area. For example, daylighting a space with a large expanse of glass, using glazing with the highest daylight transmission may result in excessive glare. Fritted glass should be considered when glare reduction through other means is difficult to achieve.

Of the various building envelope components, glazing almost always has the most significant effect on heating, cooling, and lighting energy use. In the last 20 years, glazing technology has progressed more dramatically than perhaps any other building product or system. By using high R-factor glazing (indicating substantial resistance to heat inflow), it is often possible to eliminate perimeter baseboard heaters.

Shading Devices

Fixed or movable (manual or motorized) devices located inside or outside the glazing are used to control direct or indirect solar gain. Shading should be used to provide cost-effective, aesthetically acceptable, functionally effective solar control.

This strategy works well on south façades where overhangs provide effective shading for work space and can also serve as light shelves. Shading west façades is critical to reduce peak cooling loads. A wide range of shading devices are available, including overhangs (on south façades), fins (on east and west façades), interior blinds and shades, louvers, and special glazing (such as fritted glass). Reflective shading devices can further control solar heat gain and glare.

Devices without moving parts are generally preferable. Movable devices on the exterior are typically difficult to maintain in corrosive environments or in climates with freezing temperatures. Other building elements, such as overhanging roofs, can also serve as shading devices.

Daylighting through Windows

Using daylighting through building windows can displace artificial lighting, reduce energy costs, and is associated with improved occupant health, comfort, and productivity. The goal is to reduce lighting and cooling energy more than the increase in heating energy occasioned by reduced lighting loads. (In summer, cooling energy demand is less because the heat from artificial lighting sources is reduced. In winter, the heat that is not being produced by artificial lighting may need to be compensated for by the building's heating system).

Daylighting example. DOE Photo

Daylighting through windows is best accomplished on façades that have a generally clear view of the sky, particularly the sky at angles of 30 degrees or more above the horizon. Place much of the façade glazing high on the wall, so that daylight penetration is deeper. Consider the enhanced use of daylighting by installing light shelves on south façades. Recognize the interdependencies in glazing, light fixtures and controls, and HVAC systems. Whenever possible, electrical lighting should be considered a supplement to natural light. When the sun goes down on buildings with long hours of operation, however, efficient electrical lighting design takes on added importance.

Daylighting is a central component of the vast majority of low-energy buildings and, as such, merits significant time and attention.

Extended Daylighting through Windows—Light Shelves

A *light shelf* is a horizontal device or "shelf" that bounces direct sunlight off the ceiling and deeper into the interior spaces. Light shelves are also used to provide shading and suppress glare. Light shelves are located above vision glazing (up to and slightly above eye level), but below high glazing above. They may be positioned inside or outside (where they also provide shading), or both (this is typical). The goal is to save lighting energy, reduce glare, and provide useful shading.

In clear climates, light shelves are appropriate for integration on façades facing within about 30 degrees of true (solar) south. Light shelves should be integrated with façade design, office layout, lighting design, lighting controls, glazing, and shading devices. They tend to work best with moderately high ceilings (about 10 feet, minimum) and open planning.

Transom windows can be used to allow light from the shelves to enter interior office spaces located far from exterior walls. Maintenance may be an issue, and pigeons present a concern in some areas.

Natural Ventilation through Windows

User-controlled operation of windows provides outdoor air for ventilation and cooling, and should improve indoor air quality. A balanced approach involves taking advantage of users' desire for environmental control without interfering with efficient HVAC operation.

Particularly appropriate in building types and locations where security concerns and exterior noise or air quality is not an issue. Users must be tolerant of increased horizontal air motion. Locate windows that will serve as air inlets to face prevailing winds. During the cooling season, this strategy can be enhanced by landscaping features and projecting building features (such as fins). This strategy tends to work best in residential-type occupancies, where the user already has control over HVAC.

A well-considered control strategy (either mechanical or social) is required to prevent air conditioning from operating in a space with open windows. If such a control strategy cannot be devised or is not effective or realistic because of the building occupants, operable windows can increase building energy use.

Window Geometry

Windows should be shaped and located in a manner that minimizes glare and unwanted solar gain and maximizes useful daylight and desirable solar heating. The design team should apply functional criteria to the size, proportion, and location of windows. It is important to avoid incorporating more window area than is beneficial to the building occupants or that is needed to enhance low-energy performance.

Shape, size, and location of windows are important considerations in all projects. Make window decisions based on occupant activities and low-energy performance rather than simply for aesthetic purposes. Having said this, reduce glass area whenever possible. To minimize glare and enhance daylighting benefits, substitute horizontal strips of high windows for "punched" windows, and scattered small windows in lieu of a few large ones.

The best way to evaluate the lighting effects of window geometry and configuration is through computer analysis, using programs such as RADIANCE.

Differentiated Façades

In this strategy, the designer creates variations in the façade design in response to changes in orientation, the use of space behind the façade, and the low-energy design strategies being employed. The goal is to strive for seamless integration of energy-related design strategies with the overall aesthetic and functional design components of the project.

If each façade is to be optimized, this strategy will work on almost all projects. Select a design consultant who can work with the concept that the appearance of a building's various façades will likely differ in response to variations in their environmental loads. To that end, pursue a building style that is compatible with functionally varied façade elements.

Considered as one of the most basic and effective low-energy building strategies, using different façades is really an approach to design and style that is driven by function. Different façades do not necessarily have to be radically unique; rather, they may simply be variations on a theme. For the sake of uniformity, designers sometimes put over- hangs on all façades, even though they may only provide significant energy benefits on the south side. Such an approach can greatly compromise the basic cost-effectiveness of the strategy and should generally be avoided.

Insulation

A well-insulated building envelope reduces energy use, controls moisture, enhances comfort, and protects the energy-saving potential of passive solar design. The goal is to identify the optimum amount of building insulation to use in the walls, roof, and floor construction.

Residential building types in cold climates benefit most from large amounts of insulation. Begin by incorporating insulation levels required by code or standard, then use computer analysis to investigate optimum insulation amounts. For buildings with mass walls, use computer analysis to determine the relative advantages of placing the insulation on the inside or on the outside of the mass. Detail assemblies containing insulation to avoid thermal bridges, where conductive elements (e.g., metal studs) penetrate the insulation and short-circuit the system by conducting heat. In non-residential construction, there are many cases, particularly in hot climates, where using more insulation to enclose a sealed building will cause it to behave like a Thermos bottle—trapping heat and using even more energy.

The law of diminishing returns applies to additional levels of insulation, whereby the first increment of insulation reduces heat loss dramatically, and each additional increment provides less and less of an improvement. The quality of insulation—and how well it is installed— is very important, especially when it comes to batt insulation in walls.

Air Leakage Control

Air retarder systems are used to reduce air leakage into or out of a building. The goal is to deploy a system that reduces energy use and serves to protect the building's envelope, structure, and finishes.

Air leakage control is ad standard low-energy procedure in cold climates. Install air-impermeable components that are sealed at the joints and penetrations to create a continuous, airtight membrane around the building. Note, however, that air retarders placed on the winter/cold side of the insulation must be vapor-permeable to avoid trapping moisture within the walls.

Designers of many non-residential building types attempt to reduce air infiltration by maintaining the indoor space at a higher pressure than the outside ambient air. When an air retarder is installed, pressurization becomes easier to achieve, while at the same time, the need for pressurization becomes less critical. In masonry construction, bituminous membranes are sprayed or trowel-applied to serve as air retarders, with bitumen-based sheets typically used in curtain-wall construction. Evaluate the benefits of an air retarder not only for improved energy use, but also for reduced wall maintenance and repair costs. Also evaluate the air leakage characteristics of manufactured components such as windows, doors, and curtain walls.

Roof Monitors

Roof monitors are windows installed at roof level, typically vertical or steeply sloped. The goal is to admit useful natural light and often desirable solar heat gain during the heating season. This approach works well on many building types, particularly low buildings with one or two stories.

South-facing roof monitors should use vertical glass and be shaded by overhangs to provide daylight and useful solar heating (for many building types in many locations). By contrast, north-facing roof monitors need not be concerned with glare or the unwanted entry of direct solar rays. North-facing glazing can be inclined (tilted) somewhat to access the overhead sky better, which provides a much greater level of diffuse daylight than does the sky near the horizon. As a general rule of thumb, avoid east- and west-facing roof monitors. Also avoid horizontal glazing, which typically overheats the building, thereby dramatically increasing cooling loads. Minimize the amount of glass required to achieve desired illumination levels, and avoid narrow slots with glazing on opposite sides.

Design guidelines are available for various geometries of roof monitors and other top-lighting strategies. To fine tune monitor locations, provide quality lighting environments, and quantify resulting energy benefits, computer analysis is advised.

Scattered Skylights

This strategy involves small, individual spot-located skylights, which can be used to obtain useful daylighting. This strategy is appropriate for use in one-story buildings, such as warehouses, and especially useful in buildings where sun control is of secondary importance. Generally achieved with prefabricated elements that have flat or domed glazing, spot-located skylights should be used with care, except in cases where potential glare and direct sun penetration is of little concern within the building. Use sparingly—large numbers of separate skylights are expensive in comparison to glazed roofs.

Even when mounted above prefabricated or site-built wells, it is very difficult to entirely eliminate sun penetration when solar altitude angles are at their highest (around the summer solstice, June 21). Guidelines for spacing scattered skylights are available, and computer analysis to fine-tune sizing and spacing and quantify energy benefits is advised. Potential roof leaks are often a concern and should be addressed by proper detailing. Despite these drawbacks, scattered, spot-located skylights are widely applicable to warehouses, low-rise residential, and many other smaller buildings.

Glazed Roofs

Glazed roofs are large-area skylights typically found over atrium spaces and can provide daylighting in a manner that may increase the architectural impact of the space while providing a more direct connection between building occupants and the outside world.

Glazed roofs work well above circulation areas and other high-occupancy spaces. Consider installing a clear-span glazed roof between buildings or building sections to create a covered "street." Solar heat gain can be controlled through use of fritted glass or louvers.

Excessive cooling loads frequently accompany this design approach. When used over high spaces (such as atriums), incorporate induced ventilation strategies whenever possible. As a secondary option, mechanical cooling should be provided through a displacement ventilation approach, where only the air in the occupied zone of the space near the floor is conditioned.

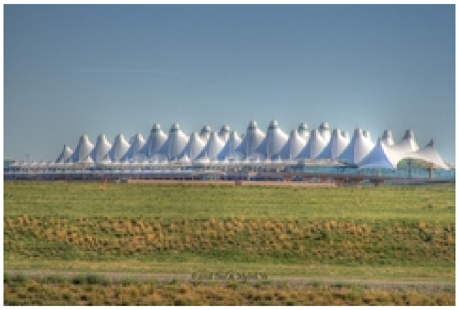
Non-Absorbing Roofing

Roofs covered by light-colored or reflective membranes are a viable passive solar strategy, as they tend to absorb less heat and can be used to reduce cooling loads.

This is a common approach for use on low buildings in hot climates. Roofing systems with light-colored or reflective top layers should be used.

Reflected light may complement other efforts aimed at daylighting "wedding cake"-type building forms. Early in the process, the designer needs to know the color of any roofing systems that will be visible to building occupants.

Fabric Roofs



Denver International Airport

These are tension roofs constructed of stretched, light-transmitting fabric—an increasingly popular architectural element. This provides a buffer from direct exposure to solar heat gains occasioned by daylighting of space.

This strategy is best applied by deploying fabric roofs over large, clear-span spaces. The overall approach must be decided early in the design process. Before committing to the design, carefully evaluate the balance between lighting, cooling, and heating loads for the specific building use and climate.

Fabric roofs are useful as temporary or permanent coverings over outdoor spaces (i.e., tents). They have been effectively used at the Denver International Airport and the San Diego Convention Center.

8. Design Development I Phase

During the earlier phases of the project, basic decisions are made that affect building massing and determine which low-energy design strategies will be implemented. During those phases, the overall thrust is to reduce the heating and cooling loads as much as possible. During design development, the design team's attention should shift to identifying efficient lighting and HVAC systems.

<u>Action Item</u>

• Continue energy analysis and the "trade-off" process.

Strategies to Consider During this Phase

Energy-Efficient Lamps and Ballasts

Identifying and using application-specific, high-efficiency lamps and ballasts to minimize the amount of electrical power required by lighting systems, while still meeting the task-specific needs of building occupants. The savings will be greatest in buildings with long hours of occupancy or in areas with high electrical utility rates.

Use T-8 (tubular, 8/8th of one inch in diameter) lamps and compatible electronic ballasts for general ambient lighting. Compact fluorescent lamps should replace incandescent or halogen lamps in downlights, as they only use about one-third the electrical power. Determine what lamp/ballast combinations work best with other strategies (i.e., daylighting, shading, lighting controls). Use light-emitting diode (LED) exit lights with an estimated life of 30 years or more to enhance building safety and all but eliminate required maintenance.

The color rendition of all fluorescent lamps has improved dramatically in recent years, to the point where they are now deemed acceptable for most applications. Compact fluorescent lamps also provide maintenance savings, as the lamps last 10 to 20 times longer than the incandescent lamps they replace.

Lighting Controls

Lighting controls automatically adjust lighting levels in response to daylight availability. Other controls automatically turn lights off in response to unoccupied space. This strategy significantly reduces lighting-based electricity demand.

Dimming controls are used in conjunction with building designs that encourage entry of natural daylight. Occupancy sensors are best used in spaces that have intermittent occupancy, such as conference rooms and storage areas. Automatic daylight dimming controls either provide light levels in discrete steps or through continuous dimming, based on light levels sensed. Dimming systems can also be used to dim newly installed lamps when their light output is greater than it will be once they "burn in" and achieve their rated output.

Occupancy sensors are used to turn off lights and sometimes HVAC in unoccupied areas. They are made with multiple activation technologies, including those that sense body heat (infrared) as well as those that detect motion (ultrasound). Some sensors employ more than one technology as a means of eliminating false signals. Manual switching and time clocks can also be used to control certain daylight spaces.

Automatic lighting control functions are often included in a computerized energy management system that also controls the HVAC, fire safety, and security systems.

High-Efficiency Heating, Ventilation, and Cooling Equipment

This category of equipment offers operating efficiencies far greater than those afforded by systems designed to simply meet applicable codes or standards. The goal is to integrate more efficient equipment whenever it can be shown to be cost effective.

These systems are appropriate for use with large loads, long operating hours, and high energy prices (particularly for electricity). There are various types of efficient heating and cooling equipment that can readily address the specific needs and operating patterns of a given building. Many agencies require that alternate systems be subjected to a life-cycle cost analysis. If such an exercise is conducted, it should involve detailed computer analysis (such as DOE 2.2) rather than a process that simply confirms the selection of a preferred system. Ask the design team to prepare a list of performance criteria for equipment required by applicable codes and standards to be used as a basis for comparing more efficient equipment options. In some cases, the cost premium for more efficient equipment is small and can be justified by hand calculations. More often, DOE 2.2 computer analyses are required along with some form of rigorous life-cycle cost analysis. Consider using modular equipment (e.g., three small boilers instead of one large one or a dual compressor chiller) and variable-speed equipment (modulating burner or variable-speed chiller) for greater flexibility in achieving targeted reductions in energy use.

Specifying systems that are larger than necessary can be costly. The energy consultant should be careful throughout the design process to size the systems, components, and equipment appropriately. HVAC systems should also be designed to ensure healthful indoor air quality in a manner appropriate to individual spaces and the overall building type.

Exhaust Air Heat Recovery

This process involves the recovery of useful heat from the air being dispelled from a building. The goal is to transfer 50% to 70% of the heat that would otherwise be lost to the incoming air stream.

Apply this strategy in buildings with large populations or significant ventilation requirements, particularly those located in cold climates. Various types of heat exchangers are in use today, including heat wheels, plate and fin air-to-air heat exchangers, and heat pipes. Heat pipes are very simple devices that consist of a highly conductive tube filled with refrigerant which, when vaporized, transfers heat from the outgoing to the incoming air stream. Because heat exchangers obstruct the air passage of both intake and exhaust ducts, bypass dampers should be installed to facilitate operation during mild or warm weather.

Depending on the application, potential contamination of the incoming air stream may need to be monitored. For instance, recovery of heat from a combustion process is usually accompanied by a carbon monoxide sensor located in the intake.

Economizer Cycle Ventilation

Contributing to energy reduction and good indoor air quality, this strategy introduces a varying amount of ventilation air to cool the building in combination with normal air conditioning (AC). The goal is to avoid using the AC compressors or other mechanical cooling method when ambient air can provide some or all of the needed cooling.

It is best to look to buildings in cool climates where there is low relative humidity. Provide appropriate controls, along with 100% outside-air capability. Consider including enthalpy (total heat, sensible plus latent) controls to maximize benefits. This should be considered a standard low-energy HVAC procedure in all but the most humid climates.

Nighttime Cooling Ventilation

Nighttime cooling ventilation include high-volume, fan-powered ventilation of large areas during cool, dry nights. The goal is to cool the building (particularly exposed massive structural elements) with outside air as a means of saving more AC power than the sum of the power drawn by the ventilating fan, plus what is needed to overcome any excessive humidity the following day.

This strategy is appropriate for hot, dry climates where the diurnal temperature difference (between day and night) often exceeds 30°F to 35°F. This strategy relies on moving large quantities of air in an economical manner and requires a secure source of intake ventilation that can be directed into spaces to be cooled.

Large amounts of interior mass enhance the cooling effect in dry climates that consistently experience significant temperature swings. In variable climates, lower mass is desirable. However, relying on open windows for ventilation (in lieu of forced-air fan operation) may compromise security or lead to wind or water damage.

HVAC Controls

Specify controls that maintain intended design conditions, including temperature, humidity, and airflow rate in terms of cubic feet per minute (CFM) throughout the building. The proper use of controls and building automation reduces energy consumption and electrical peak demand.

In all circumstances, strive for a level of functional complexity that is compatible with the skills and capabilities of the building's operating personnel. Keep control systems as simple as possible. Avoid controls that offer little in the way of improved operations or energy savings, especially if they complicate the system and add features that require frequent maintenance or are subject to malfunction. Evaluate the use of variable-speed drives (VSD) on all large pumps and fans serving loads that only occasionally function at peak capacity. In large spaces with varying occupancies (auditoriums, large meeting rooms, cafeterias), investigate control strategies (e.g., the use of carbon dioxide monitors) that regulate the amount of outside air in accordance with actual occupancy. Consider using setback thermostats in all building types. However, avoid setting temperatures back in spaces where a large amount of exposed thermal mass will make it difficult to reestablish comfortable temperatures.

HVAC control systems can often be integrated into computerized systems that also control lighting, fire safety, and security.

9. Value Engineering (VE) Phase

<u>Action Items</u>

- Ensure that VE analysis is based on life-cycle considerations rather than solely on cutting initial construction costs.
- Incorporate energy analysis directly into the VE process.
- Be certain that energy targets for the facility are maintained during VE.
- Meet the needs of the building occupants and the intended use through design that is consistent with agency or organizational values and mission.

10. Design Development II Phase

<u>Action Items</u>

- Continue energy analysis as design is finalized to ensure that desired energy performance objectives are maintained.
- Review final working drawings, specs, and cost estimates.

11. Construction Documents Phase

Action Items

- Ensure that construction details and specifications are consistent with energy use targets and strategies.
- Be sure that mechanical system details and equipment sizing meet design targets.
- Reaffirm that lighting system details and equipment specifications are consistent with energy design intent.
- Before documents are sent out for bid, conduct a final energy design review.

12. Bid Solicitation/Contract Award Phase

Action Items

- If cutting costs is required due to high bids, advocate preserving vital energy-saving features in lieu of more easily replaceable or aesthetic components.
- Conduct additional energy analyses as necessary to ensure that intended energy performance targets are still intact.

13. Construction Phase

Action Item

- Ensure that energy features are constructed or installed as designed.

14. Turn Over to Occupants Phase

Action Item

- Verify that occupants understand the building systems and the proper use of low-energy equipment and features of the building.

Warranty Period/Commissioning Phase

Action Items

- Verify occupant comfort and understanding of building operation using a

Post Occupancy Evaluation (POE)

Action Items

- Monitor the energy performance of the facility once per quarter during the warranty period and fine-tune the system as needed.

- If feasible, develop and implement a full commissioning protocol.

What to Avoid

Some low-energy buildings fail to meet the expected energy savings because the energy-efficient technologies incorporated into the design are not correctly integrated into the building. This may be due to a lack of understanding on the part of some team members as to the relationships between the specific energy technologies needed to reduce a given building's energy use and the effective integration of these technologies into the design. Changing just one of the recommended building components changes the total environment and, thus, the effectiveness of the remaining technologies. To avoid this, it is crucial that all team members understand how each of the technologies interacts with all other building components in a given environment.

When choosing energy-saving technologies, team members should be skeptical of claims for unrealistically high levels of performance and should avoid dependence on proprietary devices. It is not advisable to have a design that relies on a particular technology for which only one product is available. In those few cases where the use of such proprietary products can be defended in the context of competitive bidding requirements, a contingency design strategy should be in place. Claims of high-level performance should be supported by objective tests and case study results.

Chapter 4
Design Considerations and Computer Modeling

This chapter explains the steps to prepare for modeling energy use.

The Base Case

A base-case design—a code-compliant building design without low-energy design features—is needed for comparison purposes in analyzing the cost and effectiveness of the low-energy design strategies identified for consideration. Considerations other than low-energy design often dictate the basic design of a building. In these instances, the base-case building is automatically created through the normal design process. To be effective, some low-energy building design technologies need to be applied during the early stages of the project, such as authorization, site selection, budgeting, and programming. In these instances, the base-case building may already include some low-energy design features.

For example, an atrium is a desirable amenity that, if incorporated early in the project, should influence decisions about site selection, building orientation on the site, and the number of buildings required to satisfy the space needs of the facility. But if the atrium is introduced after the overall building configuration is set, the parallel use of the atrium as a low-energy design component will be compromised, and it may end up being an energy liability. Similarly, in climates where a campus plan yields energy benefits, these benefits can be included among the criteria used to define the basic site plan—especially if introduced in the early project stages.

Anticipating low-energy design strategies early in the project can also influence the choice of a base case. One attraction of many low-energy building design strategies is that the occupants gain a closer connection with the outdoors environment. If this attraction is part of the design program, low-energy building design strategies may become more economical relative to the base-case design. For example, if the maximum allowable distance between any office worker and a source of natural light is lowered from the 60 feet typically accepted in a standard office buildings to 30 feet, a linear atrium between two 60-foot-wide building segments may result in a more attractive, compact, and, therefore, potentially more economical, design when compared to a 60-foot-wide base-case building.

Strategy Interactions

An important low-energy design approach involves rank-ordering a list of candidate technologies. At each step in a series of computer-driven energy simulations, candidate strategies are ranked in order of cost effectiveness relative to the base-case design. The top-ranked strategy would be the one that yields the largest energy savings for the smallest investment—the one with the shortest *simple payback*.

> A *simple payback* period is the amount of time required for the investment to pay for itself in energy savings. You can obtain an estimate of the simple payback period by dividing the total cost of the product by the yearly energy savings. For example, an energy-efficient dryer that costs $500 and saves $100 per year in energy costs has a simple payback period of 5 years.

As each strategy is applied, the payback for all subsequent candidates may change. Because there is less energy to be saved, the savings potential is often reduced. If all the strategies were independent, the remaining ones would retain their order in the ranking as each is applied in succession. In practice, however, low-energy building design strategies do interact and change their relative order in the ranking as they are applied. Presuming that the initial ranking will remain constant can lead to misjudgments about which strategies to pursue. After applying each strategy in a simulation, re-rank the remaining candidate strategies.

Another example of the interaction among building elements is in an office building where natural lighting displaces electrical energy by reducing the use of auxiliary lighting. In this case, the need for auxiliary heating increases in cold weather in response to the reduced heat contribution previously supplied by electrical lighting that is now dimmed or turned off. If this effect is not taken into account in the simulation, exaggerated estimates of energy savings will occur. Finally, it is important to remember that using one technology may preclude using certain others. For example, in buildings where heating or cooling loads have been significantly reduced, the benefits of using high-efficiency equipment to meet those loads may also be reduced and the resulting simple paybacks lengthened.

The Benefits of Multiple Use

PV cells laminated to skylight glass.

As previously noted, BIPV—integrating PV into the building envelope—can replace conventional building envelope materials and their associated costs. PV is a solid-state, semiconductor-based technology that converts light energy directly into electricity. For example, spandrel glass, skylights, or roofing materials might be replaced with architecturally equivalent PV modules that serve the dual function of building skin and power generator. By avoiding the cost of conventional materials, the incremental cost of PV is reduced and its life-cycle cost is improved. BIPV systems can either be tied to the available utility grid or they may be designed as stand-alone, off-grid systems. One of the benefits of grid-tied BIPV systems is that on-site production of power is typically greatest at or near the time of a building's peak loads. This provides energy cost savings through peak load shaving and demand-side management capabilities.

Maintenance

A well-designed, low-energy building requires less maintenance than one that relies on large mechanical systems. Unlike other technologies, well-integrated low-energy building design is much less dependent on hardware and equipment, so there is little to go wrong. The traditional building trades that use available construction materials are able to make repairs as needed. The reliability and performance record of other technologies (such as movable shading devices) should be investigated, and when deployed, moving parts should be regularly maintained. Cleaning and protecting the surface of shading devices and glazing is important and should be incorporated as part of ongoing, scheduled maintenance.

When properly implemented, low-energy building design can reduce heating and cooling loads to allow for equipment downsizes and reductions in maintenance costs. Ideally, it also yields a building that can continue to function on a basic level and remain habitable even when systems experience unexpected downtime.

Costs

Cost effectiveness is typically the primary criterion for evaluating low-energy building technologies. Energy-related design decisions should be evaluated on a life-cycle basis, rather than simply on a first-cost basis alone. It should be noted that the higher first costs of low-energy design can often be avoided or greatly minimized by anticipating and incorporating these strategies at the outset of the planning process.

Typically, a building's cost effectiveness should be measured using appropriate design and analysis tools, such as those described below. Because the costs of various energy sources vary greatly by region, specific input is required in each case.

Except for residences, utility cost data is not simply a matter of cents per kilowatt-hour of electricity, or dollars per therm of gas. Especially in larger buildings, the various fixed costs, variable costs, and capacity charges must be accurately calculated. It is sometimes appropriate to run separate simulations, with and without demand rates, to see the extent to which the savings offered by a low-energy feature is dependent on capacity rates. Small-scale co-generation may also be evaluated along with other energy sources appropriate for larger projects.

To accurately model these costs, the more sophisticated design tools (such as DOE 2.2) accept all the details of utility rate structure, whereas simpler tools rely on a simplification of the rates. It is important to realize, however, that simplified rates may mask a large capacity component and can be very misleading. It is also worth noting that when necessary energy-efficient technologies are well balanced and function in a complementary manner, they will significantly reduce energy consumption during peak load periods.

This course does not discuss utility rates, assuming that one of the final calculations made in evaluating a given technology involves using actual, project-specific utility rates to determine the anticipated savings. Team members with experience in using a given technology in a particular locality can often predict probable outcomes based on their knowledge of the interaction between the climate and utility costs. For example, measures affecting electrical consumption (such as fan energy or reduced lighting demand) will have a better payback in New England, where electricity costs are high, than in the Northwest, where lower-cost hydropower is available.

Energy savings performance contracting (ESPC) arrangements are a relatively new method of helping invest in energy-efficient building measures. ESPC is a contracting agreement that enables companies to implement energy-saving projects without making costly up-front investments. The contractor or other partner, such as a utility, owns the energy system and incurs all costs— design, installation, testing, operations, and maintenance—in exchange for a share of any energy cost savings realized.

Design and Analysis Tools

Typically, a building's cost-effectiveness needs to be measured using an appropriate design and analysis tool, such as DOE 2.0 and Energy-10.

- **DOE 2.0/DOE 2.2**: An energy analysis software program that calculates the hour-by-hour energy use of a building, given detailed information on the building's location, construction, operation, and HVAC systems.

- **ENERGY-10**: An hour-by-hour, annual simulation program designed to analyze residential and commercial buildings of less than approximately 10,000 square feet (one or two zones). Specifically conceived for use during the earliest phases of design when low-energy building strategies can be incorporated at the lowest possible cost.

Energy Savings

Energy savings will vary, depending on climate, building type, and strategies selected. In new office buildings, it is economically realistic to reduce energy costs by 30% or more below national averages if an optimum mix of low-energy design strategies is applied.

According to the Building Owners and Managers Association (BOMA), the average energy cost is $1.85 per rentable square foot. Although a 30% reduction may seem ambitious, buildings monitored by NREL's Low-Energy Building Program show energy consumption reductions as high as 75% in residential buildings and 70% in some non-residential buildings.

Other Impacts

Better design techniques and superior technologies have largely eliminated any negative impacts associated with low-energy building design, such as overheating due to uncontrolled solar gain. The environmental benefits of low-energy building design can be significant, depending on how many energy-efficient or sustainable products are used. For example, a building that incorporates green materials, such as paints with low or no volatile organic compounds and recycled building materials, has less of an impact on natural resources than does a conventional building. HVAC systems that use non-chlorofluorocarbon (CFC) refrigerants are less harmful to the earth's ozone layer, and passive solar buildings that use significantly less energy from fossil fuels contribute less to the greenhouse gas effect than conventional buildings.

Chapter 5
Case Studies

This chapter discusses two Federal projects that have successfully implemented low-energy design concepts into their new facilities. These include the United States Courthouse Expansion in Denver, Colorado, and the National Renewable Energy Laboratory's Thermal Testing Facility, Golden, Colorado.

The United States Courthouse Expansion, Denver, Colorado

The United States Courthouse expansion in Denver, Colorado, consists of 17 new courtrooms and associated support spaces, totaling 383,000 square feet. The General Services Administration (GSA) designed this project to serve as a showcase for sustainable design and devoted considerable attention to the building's energy and environmental design features. Sustainable design strategies integrated into the building include:

- High-performance glazing system
- Daylighting complemented by energy-efficient electric lighting
- Energy-efficient HVAC systems and controls (e.g., displacement ventilation and evaporative cooling)
- Building-integrated photovoltaic system
- Recycled and low-VOC materials used throughout
- Integrated building automation system
- Low-impact landscaping
- Water-saving faucets and toilets.

Based on computer analysis using DOE 2.2, the building is expected to consume approximately 50% less energy than a minimally compliant building. As such, its annual energy costs will be reduced by almost one-half. Much of the energy savings achieved in the Denver Courthouse expansion will be the result of reduced energy demand associated with lighting, heating, and cooling.

Beyond its energy- and resource-efficient design features, the building will also provide an improved indoor environment that is expected to increase workplace performance while improving staff health, safety, and satisfaction.

In keeping with its sustainable design approach, the Denver Courthouse expansion will also reduce operations and maintenance costs and will rely, in part, on non-polluting renewable energy sources. Descriptions of the facility's specific low-energy, high-performance features follow.

High-Performance Glazing

Taking full advantage of Denver's sunny, dry climate, a high-performance, triple-glazed curtain wall system is used on the court tower to minimize HVAC heating and cooling loads, while affording dramatic views and a source of natural light for adjacent courtroom and conference spaces. A series of PV cells are integrated into the curtain wall system, providing a clean, renewable source of power.

Daylighting

The daylighting design for the Denver Courthouse expansion is based on a conscious separation of view glass from daylighting-specific glass. The system provides for maximum daylight harvesting and usage to reduce electric lighting loads during the day, as well as occupant satisfaction based on a strong sense of connection with the outdoors.

Perimeter light shelves are incorporated throughout the high-rise section of the building and are positioned at the junction between the view and the daylight glazing. The shelves diffuse daylight onto the ceiling plane and adjacent surfaces, thus minimizing contrast ratios between interior surfaces and elements viewed through the glazing. This, in turn, serves to increase visual comfort and improves the quality of the view to the outside.

Energy-Efficient Electric Lighting

The facility's artificial lighting system is designed to supplement daylight and will use a combination of direct and indirect luminaries with T-5 fluorescent lamps and dimmable electronic ballasts, together with compact fluorescent and metal halide downlights and wall washers. Illumination levels are designed to work in tandem with day-lighting and high-performance glazing systems to provide a balanced luminous environment with low energy consumption. Photocell controls will be used in conjunction with electronic fluorescent dimming ballasts to save energy in areas receiving daylight, while low-level ambient lighting enhanced by occupant-controlled task lighting will illuminate areas not served by daylighting.
Occupancy sensors will control lighting in private offices.

Displacement Ventilation

The ventilation systems that serve the courtrooms, various offices, and public corridor spaces incorporate displacement ventilation air distribution. This system features low-velocity air introduced at floor level to efficiently condition the space and remove indoor air pollutants.

Evaporative Cooling System

Much of the building's cooling and humidification loads are met using an indirect and direct evaporative cooling system, which provides a cooling effect through water evaporation. This process greatly reduces the need to run an electric-powered chiller. Denver's dry climate makes this system ideal for much of the cooling season; indeed, computer simulations show less than 100 full load hours of chiller operation per year. The system is also used to add humidity to the building during the winter to improve occupant comfort.

Variable Air Volume Systems (VAV) Using Variable-Speed Drives (VSD)

The heating and cooling needs are further addressed by a VAV air-handling system, which adjusts supply air volumes in response to the heating and cooling needs of the various zones. VSDs are installed on all fans and pumps to reduce the energy consumption of these devices during part-load operation. The main air handler incorporates four separate supply fans that can be individually staged, allowing for efficient operation of the system down to 5% of design air flow. The use of VSDs is especially important in courthouse facilities, due to their variable occupancy characteristics and occasional nighttime use.

Building Automation System

A full direct-digital-control system is used to control the HVAC and lighting systems. The system is designed to shut down the HVAC and lighting systems in unoccupied spaces and, in tandem with the VAV air handling and pumping systems, provides efficient operation under partial occupancy.

Building-Integrated Photovoltaics

PV is integrated into the southeast curtain-wall system adjacent to the public corridor areas of the tower, and a skylight is located over the security drum element in the Special Proceedings pavilion. Translucent, thin-film cells are applied to the skylight and selected panels in the curtain wall system, and additional polycrystalline PV panels are used as spandrel panels in the curtain wall system. The PV panels provide electricity during sunlight hours, reducing peak electric demand. Battery storage is not necessary, because system output is greater than building demand.

Landscaping

A variety of measures can be implemented to optimize the landscape surrounding a building. Among these, preservation of existing landscape features should be the designer's first course of action. Mature trees and vegetation are valuable resources that take many years to replace. Preserving them not only allows for their use in natural shading, it also maintains existing wildlife habitats, existing drainage patterns, and soil conditions. Tree preservation reduces the need for excavation, transportation, and relocation of soil. In addition, it reduces the need for supply and transportation of fill and landscape materials. When adding new vegetation to a site, use regionally consistent landscaping strategies, composed of locally grown, native plants.

Water Efficiency

One of the most overlooked areas in developing a whole-building design strategy is the efficient use of water resources. Water-efficiency planning is a relatively new management practice that involves analyzing cost and water usage, specifying water-saving solutions, installing water-saving measures, and verifying the savings to quantify results. A variety of water conservation technologies and techniques can be used to save water and associated energy costs, including:

- Water-efficient plumbing fixtures (e.g., ultra-low-flow toilets and urinals, waterless urinals, low-flow sinks, low-flow showerheads, and water-efficient dishwashers and washing machines)
- Reducing water use associated with irrigation and landscaping (water-efficient irrigation systems, irrigation-control systems, low-flow sprinkler heads, water-efficient scheduling practices, and xeriscaping)
- Graywater and process recycling systems that recycle or reuse water
- Reducing water use in HVAC systems.

Demand-side management methods reduce the amount of water consumed on-site at a facility and include system optimization, water conservation measures, and water reuse and recycling systems.

Other efficiency options include leak detection and repair, industrial process improvements, and changing the way fixtures and equipment are operated and maintained.

National Renewable Energy Laboratory's Thermal Testing Facility, Golden, Colorado

NREL's Thermal Testing Facility (TTF) is an open-space laboratory building comprised of high-bay laboratory areas, offices, and conference rooms. Construction of the 10,000-square-foot building was completed in 1996.

Performance monitoring has been underway since occupancy. Although the TTF was designed to serve as a laboratory, the technologies discussed in this case study are appropriate to a wide range of commercial buildings, offices, warehouses, and institutional facilities. Sustainable design strategies integrated into the building include:

- Passive solar features
- Efficient electric lighting
- Daylighting features
- Occupancy sensors
- Efficient HVAC design
- Energy management system with direct digital control.

The TTF's design team included an architect, mechanical engineer, electrical engineer, structural engineer, building-owner facilities staff, and an energy consultant. From the outset, the team focused on optimizing the interactions among the building's various systems, taking into account the influence of building occupants, their daily activities, and climatic conditions in the surrounding area. Energy-related design decisions were based in part on the results of computer simulations. The building's owner and eventual occupants determined necessary building criteria at the outset of the design phase. The type of spaces required included flexible generic laboratory space, assorted open-area support offices, a conference room, washrooms, and a kitchenette area.

Once the building's use was established, the design team and NREL research engineers set a building energy cost reduction goal of 70%, and a strategic design and construction plan was developed to serve as a "road map" to guide the process. The plan included integrating passive solar features, low building load coefficient, efficient electric lighting, daylighting features, occupancy sensors, efficient HVAC design, and an energy management system.

Initial base-case results showed that electrical lighting loads accounted for a large portion of the energy use—roughly 73%, not including plug loads. Cooling loads were next, at 15% of the building's total energy consumption. Based on this information, the NREL research staff believed that internal heat gains could be minimized by reducing the electric lighting load and by minimizing unwanted solar gains. This was accomplished by integrating daylighting and efficient artificial lighting strategies, specifying high-performance windows, and by engineering the dimensions of overhangs. By minimizing the cooling load, the design team was also able to downsize the HVAC system in comparison to what would have been required in the base-case scenario.

Computer modeling indicated that the largest energy savings could be achieved by reducing the electric lighting load. Reducing plug loads had a similar effect, but plug loads are not related to the building envelope design. Reducing infiltration, controlling ventilation and unwanted solar gains, and improving the building's opaque envelope all produced similar energy-saving results. In addition, the facility's interior was arranged to free up additional floor area. By moving the mechanical room from the exterior east wall to a location above the central core, an additional 800 square feet of laboratory floor space was created without a concomitant increase in energy use. The TTF's final low-energy design achieved its energy reduction goal by applied energy-efficient design strategies as described below.

Passive Solar Design

To take advantage of Colorado's sunny climate, the TTF integrates many passive solar features, including appropriate siting and building orientation. The design also incorporates a small amount of thermal mass in the slab floor and north wall of the building, and the north wall also acts as a retaining wall for a mesa, providing the thermal benefits of earth berming. Among the facility's most important features, however, are the proper selection, orientation, and placement of windows and clerestories.

The building was carefully engineered to provide passive solar gain in the winter months, while minimizing this gain during the summer. The final design incorporates 88% of its total fenestration as a single row of view glass and two rows of clerestories along the southern façade. An additional 8% of view glass is divided equally between the east and west façades, while the remaining 4% is positioned on the north wall. South-facing clerestory windows were designed with a high SC of 0.76 (SHGC of 0.68), while all others have a lower SC of 0.51 (SHGC of 0.45). The higher SCs allow more solar gain to enter the building. In addition, all windows have a low-e coating, which prevents the transmission of most non-visible spectrum light and unwanted solar gain. The careful design and placement of overhangs rounds out the picture by blocking direct solar radiation during the summer when sun angles are high, while allowing direct solar radiation in winter, when sun angles are much lower.

Overall, the TTF's envelope and its passive solar features were designed to heat the building during the day and into the evening hours, such that the only heat load on the building will take place during the morning hours. Bear in mind that the glazing configurations and other passive solar strategies described above are very much site- and application-specific and will not necessarily apply to different building types in other locales.

Thermal Envelope

The TTF's floor is constructed of a 6-inch concrete slab with 4-foot perimeter insulation. The north wall is constructed of an 8-inch concrete slab with 2 inches of rigid polystyrene, while the east, west, and south walls use 6-inch steel studs with batt insulation positioned between the studs. Expanded polystyrene is placed over the entire exterior surface, which is finished with Exterior Insulation and Finish System (EIFS) stucco. The roof is constructed using metal decking atop steel supports with a 3-inch polyisocianurate covering. The thermal insulation positioned on the wall exterior creates an energy sink within the building, which dampens the building's natural temperature swings. For example, during cold winter nights, when outdoor temperatures drop well below freezing, the TTF's indoor temperature drops by only 10F.

Lighting

The TTF is illuminated by a dynamic combination of electric lighting and daylighting, depending on real-time occupancy status and daylight luminance values. A stair-stepped design is integral to the daylighting plan; daylight enters the building through a row of view glass and two additional rows of clerestories lining the south façades of the open office areas, mid-bays, and high-bays, respectively. Additional windows exist along the east, west, and north walls to balance incoming daylight. Again, all windows are engineered to take full advantage of day-lighting opportunities.

A sensor that measures illumination levels controls the building's supplemental electric lighting system, and the building's energy management system (EMS) uses this information to control electric lighting status, depending on the amount of natural light available in each lighting zone. In terms of lighting systems, the facility uses T-8 and compact fluorescent lighting, 72% of which provides supplemental lighting to day lit zones, while the remaining 28% provides primary lighting to the building's central core. The EMS-integrated occupancy control protocol uses passive infrared and ultrasonic occupancy sensors to disengage lighting when not required. Together, these features have significantly reduced the building's (lighting-based) electrical use as well as its cooling load, while heating loads increased only slightly during the winter months.

Heating, Ventilation, and Air Conditioning

Because the TTF minimizes HVAC requirements, a smaller, more efficient, and less expensive HVAC system was installed. Actually, the TTF uses two separate HVAC systems: a VAV air handling unit (AHU) to serve the main building, and a packaged single-zone AHU to serve the conference room. The VAV unit relies on direct and indirect evaporative cooling as its primary cooling source, supplemented by ceiling fans, which help reduce the temperature stratification that is common in spaces with large ceiling heights.

The TTF's efficient HVAC design limited the total amount of ductwork throughout the building, which, in turn, reduces material costs during construction, as well as maintenance thereafter. All duct-work is insulated and located indoors to reduce losses to the outside environment and bordering zones.

Energy Management System

The TTF uses a digital building control system for most mechanical building operations. This EMS allows for easy monitoring, tuning, and diagnosis, helping to keep the building operating as designed. The EMS operates each of the HVAC units and the electrical lighting system and also collects diagnostic and performance data. Two tankless heat-on-demand water heaters provide the facility with domestic hot water: one serving the kitchen and the other dedicated to the washrooms. Both units are natural gas-fired and provide 80% thermal efficiency.

Summary

Since the beginning of time, people have designed shelter for the local climate, taking advantage of natural daylight and prevailing winds. Today, these same principles apply to low-energy building design but are combined with what we have learned about energy conservation; advanced materials, products, and mechanical systems; renewable energy; and energy performance design tools. When designed in tandem, technology, such as energy-efficient lighting, occupancy sensors, and daylighting strategies, can reduce a building's energy load and improve occupant comfort.

Energy managers can be assured that a climate-responsive design will yield long-term energy savings regardless of fluctuations in energy prices and will serve as the basis for durable, comfortable, environmentally sound buildings. Advances in other key technologies will further transform the building industry. New design and analysis tools have greatly improved the designer's ability to predict building energy performance, while giving energy managers better control over operations and maintenance costs. As these tools continue to be refined and their use becomes more commonplace, low-energy building design will emerge as the only logical approach to new construction and renovation.

The technologies, systems, and design strategies discussed in this course are helping to ensure a bright future for low-energy buildings and at the same time making them more comfortable and attractive than their conventional counterparts. When starting a project, remember that an accurate assessment of low-energy design features and technologies comes from a clear understanding—not just of how the many components of a building work—but of how they work together. This often begins with awareness that the current, highly fragmented building process is not producing the best results, and that a new view of the building as a system of interdependent components is required.

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