energydesignresources

design brief

INTEGRATED BUILDING DESIGN

Summary

Integrated building design is a process that can be used by building owners and designers to cost-effectively lower building operating costs while improving the comfort and productivity of building occupants. It is a key strategy for meeting and exceeding California's Title 24 energy code, which raises the bar of energy efficiency because it is updated every few years. To make integrated building design work, practitioners typically take these six actions when designing and constructing a building:

- They make a commitment to the integrated design process, and they back that commitment up by giving the project team members the time and resources they need to see the process through.
- They identify integrated design strategies that will reduce lifetime costs while also improving occupant comfort.
- They do whole-building analyses that treat a building and the site it sits on as a complete system, taking into account the interactions among all of the building's systems.
- They base design decisions on life-cycle economics, emphasizing the full lifetime value of proposed building improvements.
- They follow through by ensuring that the integrity of the design is maintained throughout the construction process.
- They check their work repeatedly after the project is finished in order to verify that building performance does—and continues to—live up to expectations.

The exemplary buildings produced through the integrated building design process consume less than half the energy of comparable buildings that have been conventionally designed, while providing a comfortable, healthy indoor environment.

TEAMWORK LEADS TO HIGH-PERFORMANCE BUILDINGS

CONTENTS

Integrated Design Training

The Energy Design Resources web site offers a pair of resources that present the basics of integrated building design:

- *Virtual workshops.* The workshop on Integrated Energy Design (EDR 002) presents the basic concepts and benefits of integrating energy-efficiency strategies into the design of a new building (go to www.energydesignresources.com/resource/141).

- *Integrated design training (coming soon).* This online training program provides comprehensive lessons on integrated building design, and then allows users to put their knowledge to the test through a quiz and an integrated design exercise.

Introduction

Integrated building design is a process that purposefully brings together the work of various design and engineering disciplines to produce buildings that cost less to operate; are easier to maintain; and are more attractive, comfortable, and marketable than buildings designed through the more traditional, compartmentalized approach. The benefits of integrated building design can often be achieved with little or no increase in first costs. The process aligns the all-too-often conflicting objectives of developers, financiers, architects, engineers, specialty consultants, building managers, leasing agents, building operators, owners, and tenants to yield a positive outcome for all stakeholders. For example:

- Energy-efficient buildings provide a marketing edge, making it possible for speculative developers to offer competitive lease rates.

- Life-cycle energy savings allow for an attractive return on investment for owner-builders. Improvements with a simple payback of two years can yield a return on investment of 15 percent or more.

- The benefits of energy-efficient building design can justify higher fees for architects and engineers.

- Reduced utility costs offer multiple benefits to property managers. They can, if they wish, pass some of the savings on to tenants through lower lease rates. Those lower rates, coupled with enhanced comfort from better design, can help attract and retain building tenants. The portion of the energy savings retained by the property manager will improve the building's net operating income.

- Comfortable, attractive, energy-efficient workspaces will bring benefits to tenants as well. Businesses not only incur reduced overhead costs, but they are likely to see improved employee morale and better productivity. In fact, enhanced productivity is one of the most compelling but overlooked benefits of improved building design. In a typical office building, workers' salaries are on the order of $130 per square foot per year—about 100 times the building's energy bill on a per-square-foot basis. If an extra $1 per square foot is spent on high-quality, energy-efficient design to create a more comfortable, better-lit, more-effectively cooled and ventilated space, it is likely to significantly improve worker productivity. That extra dollar would be paid back by a productivity boost of a mere 90 seconds per employee per year, and the gains are usually much higher. For example, one study of 40 buildings found that improved indoor air quality reduced the time taken for short-term sick leave by 1.6 days per employee per year.[1]

Make the Commitment

Crafting exemplary buildings requires more designer time and resources than the typical construction process allows. Developers and building owners want buildings to go up quickly, and they don't want to spend any more than they have to. As a result, designers are under enormous pressure to work quickly and to keep their plans as inexpensive as possible—which encourages them to follow established conventions. However, the traditional approach often results in buildings that are less efficient, less comfortable, and less marketable than they could have been.

The integrated design process can help to break this vicious cycle. Different parties may have different motivations for following the integrated approach: building owners may be attracted to the opportunity to keep operating costs down or to occupy a structure that expresses their commitment to sustainability, while developers of speculative buildings may see the potential for higher rents from amenities such as daylighting and improved indoor air quality. Regardless, the integrated design approach is the same. It all begins with a commitment to the process. The developer or owner must let the design team know that an energy-efficient design is desired and that a business-as-usual design will not be acceptable, that the team is expected to be innovative, and that it will have sufficient resources to create a truly energy-efficient building. Without a clear commitment, designers have little or no incentive to innovate and take risks.

There are five key elements that contribute to the success of an integrated building design project:

- A stakeholder to champion the concept
- Designation of a member of the design team as the "integrated design coordinator"
- The inclusion of a diverse set of parties on the team
- Incorporation of the requirements for an integrated building design process into the project documents
- Establishment of a fee structure that rewards the design team for the extra effort and risks of taking the integrated building design approach, based on its achieving the desired results

In combination, these techniques create a supportive working environment for building designers, helping them succeed in producing a superior building that can bring benefits to owners as well as tenants.

Find a Stakeholder to Champion the Concept

If a developer, owner, or some other stakeholder encourages innovation instead of focusing on cost and schedule alone, the integrated design project is more likely to succeed. Finding such a champion is a great goal, but it's often hard to achieve in the fast-paced and tightly budgeted building world. Today it is easier to find a champion if there's a tenant or owner that wants to make a statement, but public support has grown to the point that even developers of speculative buildings may want to build sustainable buildings as a way to attract tenants. One way to increase the chances that a champion will be found is to choose measures that resonate with the owner's or developer's mission. It's easiest to find champions for build-to-suit projects in which a site is developed according to an owner's or tenant's specifications. An owner or tenant who desires an "image building" is often willing to try new concepts and often has sufficient financial strength to provide financing guarantees. The New York Times Co.'s interest in using daylighting in its new headquarters building grew out of its desire to have the transparency of its building be a symbol of the company's openness and transparency as a news organization. Once the firm decided on an all-glass facade, the design team went all out to make the building as efficient as possible. Elements include high-performance glass, fixed exterior sunscreens, and interior motorized roller shades to control glare.[2]

As another example, the Irvine, California, North American headquarters of Ford Motor Co.'s Premier Automotive Group features a number of innovative measures, including underfloor air delivery, an earth-covered roof that will provide both insulation and water filtration, and a 200-kilowatt fuel cell (**Figure 1**).[3] The building uses 40 percent less energy than a similar structure built to ASHRAE (the American Society of Heating, Refrigeration, and Air-Conditioning Engineers) 90.1-1999 standards. Ford was willing to pay extra for the design and implementation of some of its building's features because it wanted to showcase new technologies and because it was developing a strategy for sustainable buildings. The facility was an award-winner in the Savings By Design program run by California's public utilities.[4]

Figure 1: Ford Motor Co. Premier Automotive Group's North American headquarters

Ford Motor Co.'s facility in Irvine, California, features innovative measures such as underfloor air delivery, an earth-covered roof that will provide both insulation and water filtration, and a 200-kilowatt fuel cell.

Courtesy: Ford Motor Co.

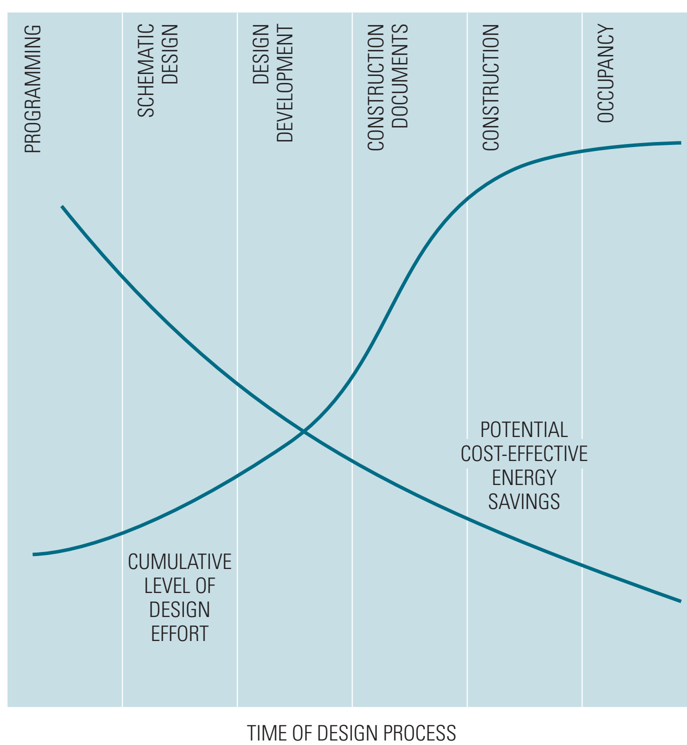
Designate an Integrated Design Coordinator

The integrated design coordinator's role is critical to the entire process of creating an energy-efficient building. Without a single individual to coordinate the overall project, this goal can often be lost among myriad competing objectives. The design coordinator focuses on the lifetime cost and benefit implications of each design decision, bringing in information on appropriate new technologies and managing communications within the design team.

Although the integrated design coordinator could be the developer, an architect, an engineer, or a contractor, it is most common to have the role filled by a specialty consultant. Regardless of who the coordinator is, it is essential to have that person involved in the design process from the earliest stages of development (**Figure 2**).

Figure 2: Energy-saving opportunities and the design sequence

The greatest energy savings can be achieved by planning for energy efficiency right from the beginning of the design process. The further along a project gets, the harder and more costly it becomes to make changes that will improve building energy use. In the later stages, the costs rise steeply, the interventions become far less effective, and the opportunity for realizing significant savings in capital costs through downsizing mechanical systems is greatly reduced.



Courtesy: Platts; data from ENSAR Group

To foster good working relationships within the design team, the coordinator needs to be an effective communicator and a good negotiator. The coordinator may occasionally be called upon to challenge the design team to innovate or to find a better solution to a given problem, so he or she must be well-versed in all facets of building design, including non-energy- as well as energy-related issues. The coordinator needs to be able to call upon independent analyses and other proofs in order to convince skeptical architects and engineers to change their approaches.

When Corporate Express planned its new headquarters building in Broomfield, Colorado, the company president made a commitment to constructing an environmentally sensitive building and providing a “humane environment” for his employees. A specialty energy consultant was hired by the owner to serve as the integrated design coordinator for the project. When the company held a design competition to select a local architectural firm, this coordinator served as a resource for each of the competing firms. This support enabled the competing firms to prepare more innovative submissions than they otherwise would have. The winning design featured extensive use of daylighting, natural views to the outdoors, and an energy-efficient indirect/direct evaporative cooling system. Throughout the development of the final design, the coordinator continued to be a key player in the overall process.

Include a Diverse Set of Parties on the Team

Including a variety of players on the design team means that a wide range of ideas can be examined. The design team for the award-winning Genzyme Building in Cambridge, Massachusetts—one of the few facilities to be awarded a Leadership in Energy and Environmental Design (LEED) Platinum designation—included architects, an environmental consultant, a lighting consultant, an interior gardens designer, a landscape architect, a structural engineer, and a construction contractor.

In the language of integrated design, that translates into inviting the contractors to the team meetings early on.

Including a wide range of participants at the design stage reduces the chances that participants will work at cross-purposes later. For example, if a building project requires special acoustical measures or shading devices, the best way to get cooperation is to hold a preconstruction conference with the contractor and all subcontractors to emphasize the special nature of some of the project's features. In the language of integrated design, that translates into inviting the contractors to the team meetings early on. Here's what can happen if that step is not taken: On one public library project, the design team had selected a variety of glazing properties to "fine-tune" the thermal and daylight transmission of windows and clerestories throughout the building, but shop drawings submitted by the window subcontractor failed to assign the correct glazing properties to the windows. That oversight was not caught until the windows were already on-site and about to be installed.

Involving the mechanical contractor on a project is also critical. Mechanical contracting fees are often set as a percentage of the mechanical construction costs. If equipment is downsized, mechanical contractors make less money while simultaneously increasing their risk by decreasing their design safety factors. Involving them early in the design process improves the chances that they'll give objective consideration to decreasing the size of mechanical equipment.[5] It can also be useful to involve local officials to get faster permitting or to facilitate any changes to laws or regulations required by innovative design options.

Incorporate the Integrated Building Design Process into Project Documents

Another way to support the integrated building design approach is to specify it in the project guidelines and standards that will be used by the design team. You can also seek certification through a recognized rating system, including some existing codes.

Participate in Savings By Design. In California, Title 24 serves as a baseline for minimum energy efficiency, and designers participating in California public utilities' Savings By Design program must beat the Title 24 requirements by at least 10 percent. By participating in the Savings By Design program, the design team ensures that the design will beat code by at least that amount.

Use LEED. Another approach is to use one of the recognized building rating systems, either in conjunction with code standards or as an alternative to them. LEED, sponsored by the U.S. Green Building Council (USGBC), is the most popular of these systems. The LEED rating system provides a common standard for measuring how "green"—or sustainable—a building is in terms of its design, materials, equipment, and modeled energy performance. New construction projects or major renovations can earn LEED points in six categories: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design Process. To earn LEED points, project developers register a project and later submit documentation demonstrating the fulfillment of requirements. To be certified, completed projects must earn at least 26 points out of a total of 69. Silver-rated buildings must earn at least 33 points, Gold buildings need at least 39 points, and Platinum buildings require a minimum of 52 points. In addition, architects or other members of a building design and construction team can become LEED-accredited professionals. LEED will also be the basis of a proposed new standard that is being developed by ASHRAE, the USGBC, and the Illuminating Engineering Society of North America. The proposed standard 189, "Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings," is scheduled for completion in 2007.

It is important to note that LEED is a rating system, not a "how-to" manual for sustainable design.

It is important to note that LEED is a rating system, not a "how-to" manual for sustainable design. To use LEED—or any other rating system—effectively, designers can't simply rely on checklists

It is unfair to expect designers to make the additional effort the integrated design process requires without providing additional compensation.

to guide their actions. Designers have a long tradition of employing their professional judgment to guide clients to reliable solutions that cost-effectively solve their problems. LEED offers a menu of strategies and options that have value for recommending potential solutions, but designers still need to determine which ones will be effective for any given building. In addition, the best results will occur if designers focus initially on developing plans that meet their clients' environmental and economic criteria and then add up the LEED points. This approach may not produce buildings that achieve the highest levels of LEED certification, but it will ensure that points are not added just for the sake of getting higher scores without necessarily adding value to the building under design.

Establishing Design Fees

Convincing building designers to work with innovative technologies and designs is one thing; providing them with a financial incentive to do so is another. It is unfair to expect designers to make the additional effort the integrated design process requires without providing additional compensation, particularly when investments in improved design and engineering can yield enormous benefits over the life of the building. One approach is to build the extra fees into the request for proposals for the project. The Savings By Design program offers incentives to both designers and owners for buildings that meet certain performance levels.

Another way to reward designers for excellent work while spreading the risks involved in creating integrated designs between developers and designers is with performance-based fees. In such an approach, the architects and engineers are initially compensated just as they would be for designing an ordinary building, but once the building is complete and the benefits promised by their innovative design work have been verified, they are rewarded by an additional "performance bonus." The amount of the bonus is based on some portion of the verified benefits.

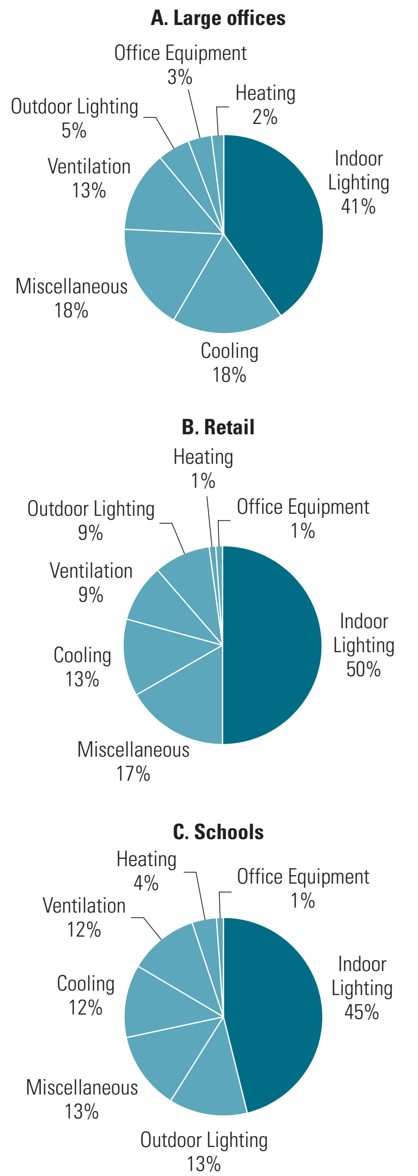
For example, the design-build firm constructing the City of Oakland's new administration building hoped to receive a substantial energy performance bonus after the building was occupied. For the team to earn the full bonus, the completed building was required to use about 25 percent less energy than if it had been built to meet only the requirements of California's Title 24 energy-efficiency standards. The contract with the design firm allowed for either a bonus or a penalty, depending on whether or not building energy use hit the target. The bonus—or penalty—was limited to $250,000, which is about 0.3 percent of the total project cost. The final project report showed that the savings, though significant, were within the deadband agreed upon by both parties and no bonus was awarded or penalty paid.

Overall, incorporating financial motivation into the City of Oakland's building contract appears to have had a positive impact on the building process. It promoted shared responsibility and encouraged contractors to meet the specifications through more innovative approaches, including installing variable-speed pumps on the chilled water system and adding perimeter daylighting controls. However, despite the reward/penalty agreement, the project's contractors were still averse to taking risks. For instance, the chillers they installed were larger than necessary and therefore not optimal for energy efficiency, despite the recommendations for smaller units in the engineering models. By installing a larger chiller, the contractor avoids the risk of the user complaining about inadequate cooling on the hottest days of the summer, but the owner also inherits higher energy bills throughout the cooling season. If that contractor had been involved in the design process from the start, he might have been more inclined to follow the recommendation for a smaller chiller, leading to savings that might have qualified for the bonus. (For more information on the Oakland project, and on performance-based design fees in general, see the EDR Design Brief "Performance-Based Compensation" at www.energydesignresources.com/resource/33.)

Overall, incorporating financial motivation into the building contract appears to have had a positive impact on the building process.

Figure 3: End-use distribution of energy use for office, retail, and school buildings in California

These charts show how various energy end uses measure up in different types of buildings. When compared to energy end use for office equipment, ventilation fans, cooling, heating, and hot water, energy used for lighting is consistently the largest part of the pie. That's why making improvements in the energy efficiency of lighting systems can significantly reduce a building's overall energy consumption.



Courtesy: Platts; data from Architectural Energy Corp.

Identify Integrated Design Strategies

Once the commitment to the integrated building design approach is made, it is up to the design team to turn that commitment into a design that meets the owner's objectives. The team begins by studying the site characteristics for applications of strategies like daylighting and natural ventilation. Then the team looks at likely energy-use characteristics of the building, so that energy design emphasis is placed where it will do the most good. **Figure 3** illustrates the energy-use characteristics of a few important building types in California. Lighting is usually the most significant end use in these buildings, so it isn't surprising that lighting offers the most potential for energy savings. In a recent study of new energy-efficient commercial buildings, lighting-system improvements represented 70 percent of the overall energy savings.

After the important energy end uses have been identified, design team members may propose design strategies that have the potential to reduce lifetime costs. The types of strategies proposed are limited only by the designers' experience and imagination and the budgets they are given to work with. However, the strategies do typically fall into six general categories:

- *Improving the efficiency of system components.* One way to improve the energy efficiency of buildings is to improve the efficiency of individual system components, such as lamps, ballasts, chillers, fans, pumps, and motors. Although the minimum efficiency of many of these components is set by Title 24 (see sidebar), nearly all of them are available at higher efficiencies.

- *Reducing energy waste.* Energy consumption that provides little or no amenity can usually be eliminated or reduced. For example, occupancy sensors and controls can be used to switch off lighting fixtures and HVAC services when a space is unoccupied. The U.S. Environmental Protection

Agency's Energy Star program has also identified energy-efficient personal computers, printers, monitors, copiers, and fax machines that go into a low-energy "sleep" mode when not in use, consuming 50 percent less energy than their standard-efficiency counterparts.

- *Recovering waste energy.* Buildings typically reject thermal energy via exhaust systems and air-conditioning condensers. In some cases, this thermal energy can be cost-effectively recovered. For example, in a building with a heavy cooling load, a heat exchanger placed in the exhaust and intake air streams can recover cooling energy from the exhaust air streams and use it to precool intake air; likewise, heat exchangers can be used to recover waste heat from air-conditioning systems and use it to supply hot water.

- *Changing system technology.* Rather than improving the efficiency of typical building systems, sometimes large savings can be cost-effectively achieved by switching to a different technology altogether. For example, indirect/direct evaporative cooling systems, which are much more efficient than refrigerant-based cooling systems, are well-suited to the hot, dry climate of the Southern California deserts.

- *Reducing peak demand.* Although strategies for reducing peak demand may not necessarily improve energy efficiency, they do have the potential to reduce overall energy costs. For example, thermal energy storage systems that contain ice or chilled water may help reduce chiller demand during on-peak periods. Operating standby generators during peak hours is another good strategy for reducing peak demand.

- *Generating power on-site.* Cogeneration systems, which provide both electricity and thermal energy, may be attractive for buildings with fairly constant year-round thermal energy requirements. Total system efficiency of up to 90 percent is possible, depending on the amount of thermal

California's Title 24

Title 24, which delineates California's state energy-efficiency standards, stipulates minimum efficiency requirements for newly constructed buildings.[6] However, Title 24 represents a minimum goal and, in fact, many buildings have been built that are more efficient than Title 24 requires. For example, buildings constructed in conjunction with the Savings By Design program run by California's public utilities consume energy at an average rate of about 20 percent less than if they had been built to Title 24's minimum requirements. Some of the more innovative buildings have reaped energy savings of 50 percent or more. It's also worth noting that the Title 24 standards are a moving target; California raises the bar of energy efficiency every few years.

energy recovery that is achieved.[7] Contrast that with system efficiency for a conventional power plant, which is typically around 21 percent.[8] Thermal energy from a cogeneration system can be used to meet process hot water requirements or to generate chilled water in an absorption chiller.

- *Using renewable energy systems.* Both daylighting and photovoltaic (PV) panels have received a lot of attention in California in recent years. The efficient use of daylight to supplement or eliminate electric lighting has been boosted by recent improvements in glazing systems. PV panels produce electricity during sunny periods, which generally coincide with peak demand. The cost of building-integrated PV systems is often partially offset by what is saved on the regular cladding materials that are displaced by the panels. Some of the newer PV panels can be mounted in a conventional curtain-wall glazing system, taking the place of a window or spandrel panel (**Figure 4**).

Figure 4: Building-integrated photovoltaics

These photovoltaic cells are nicely integrated into an exterior building shading device.

Courtesy: Platts

Of course, designers may mix and match any number of these strategies to create a building that minimizes lifetime costs. For example, Ford's Irvine, California, building exceeded ASHRAE standards by about 40 percent through the use of a high-efficiency glazing system, high-efficiency lighting with T5 fluorescent lamps, an underfloor air-distribution system in the office tower, increased chiller efficiency, and a fuel-cell generator.

Even the best strategies, however, have little chance for success if they require more sophisticated operation and maintenance than their operators are capable of providing. For example, thermal energy storage systems installed in several schools developed control problems that limited their ability to reduce peak demand. Investigators found that the schools were operated by custodial staff that had little time or motivation to understand or improve the operation of the systems. Designers need to consider the capabilities of building operators when selecting the optimum energy-efficiency strategies, avoiding options that would require more extensive expertise than the staff is likely to possess.

Do a Whole-Building Analysis

Whole-building analysis is an evaluative process that treats a building as a series of interacting systems instead of looking at building systems as individual components that function in isolation. The type of analysis used for evaluating systems in any given building will typically fall somewhere between these two extremes, but for an integrated building design, it is almost always necessary to take the whole-building approach.

The analysis begins with site considerations that enable effective use of daylighting and natural ventilation. Then, in virtually all applications, the best combination of energy-efficiency strategies is likely to be produced by "downstream" thinking. That is, the design team should start at the space to be conditioned and work back upstream through the distribution system (ducts, pipes, fans, and pumps) to the primary systems (chillers and boilers). The farther downstream that energy savings can be achieved, the more the benefits will be compounded upstream, because of the number of avoided losses along the way.

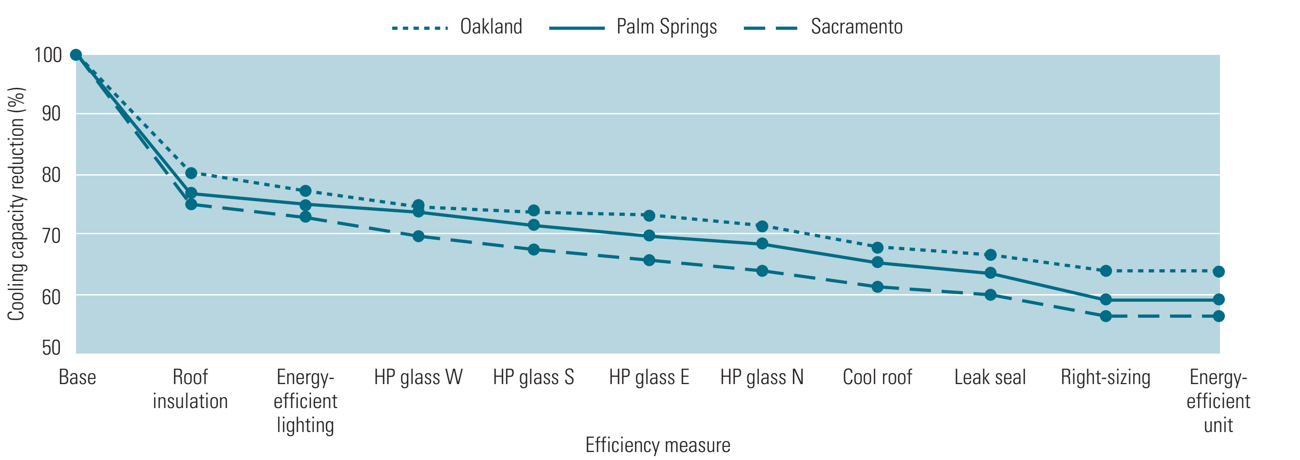
Whole-building analysis is aimed at cutting operating and capital costs by taking advantage of this compounding effect of downstream energy savings. A typical integrated design might begin with the reduction of heat loads in the occupied space through the use of energy-efficient lighting fixtures and daylighting. That may make it possible to reduce supply-air flow rates, leading to less pressure drop in the air-distribution system and allowing for smaller fans to be installed. Furthermore, as a result of all of those downstream changes, it may also be possible to specify a smaller cooling plant.

Figure 5 illustrates the impacts of compounding upstream energy savings, showing the cascading benefits of adding measures such as extra insulation, more-efficient lighting, and high-performance glazing. The combined measures reduce the air-conditioning load by 35 to 45 percent, depending on location.

Whole-building analysis does cost more, and it takes more time than traditional rule-based methods, but the results—in terms of

Figure 5: The impact of integrated design

An integrated design strategy that called for a reduction in the amount of power consumed by lighting, the installation of high-performance glass and skylights, the use of cool roofs, and the addition of increased insulation produced significant reductions in cooling loads. These efficiency measures can pay for themselves by reducing the size, and therefore the first costs, of HVAC equipment and the associated distribution system.



Note: HP = high performance.

Source: California Energy Commission, PIER Buildings Program energy savings and occupant satisfaction—can be well worth the investment. Estimates for additional fees for whole-building design vary—in one analysis, they ranged from 0.1 percent to 0.5 percent of total building cost.[9] In California, the Savings By Design program pays designers up to $50,000 for the extra effort involved. The kinds of design errors that can result from a less-rigorous approach can be much more expensive—including higher energy costs, substantial repair costs, poor operation and maintenance, and impacts on occupant health and productivity.

Whole-building analysis requires a rigorous engineering approach to fully capture the interactions between building systems. Some of the integration issues addressed through whole-building analysis include:

- The interaction of lighting illuminance levels, glazing, and interior finishes on the visual environment;
- The impact of glazing selection and placement on the availability of daylight, glare levels, thermal comfort, and cooling loads;
- The effect that the thermal mass inherent in the building structure or interior walls can have on the magnitude and timing of peak cooling loads;
- Improved part-load operation of well-chosen equipment; and
- Benefits gained by carefully matching thermal and electrical loads relative to on-site power generation.

Taking all these issues into account typically requires sophisticated computerized design tools; it cannot be done by following simple maxims or performing back-of-the-envelope calculations.

Skycalc's calculations help designers determine the trade-offs between lighting and HVAC loads.

Lighting Design Tools

Design tools can provide a design team with competent analysis without dramatically increasing overall design effort. These tools range in complexity from simplified design guidelines to computer simulation models. Two of the more notable choices are:

- *Daylight in Buildings: A Source Book on Daylighting Systems and Components*. This book was developed by the Building Technologies Department of Lawrence Berkeley National Laboratory (LBNL). It is a comprehensive reference that describes and evaluates new and innovative technologies for using daylight in buildings. The book is the result of a coordinated international effort to enhance daylighting in nonresidential buildings by gathering the most up-to-date information available about the application and evaluation of advanced daylighting systems. It is based on work carried out by the Solar Heating and Cooling Programme of the International Energy Agency (IEA).[10] *Daylight in Buildings* may be downloaded free of charge from LBNL's web site: http://gaia.lbl.gov/iea21.

- *Skycalc*. Skycalc is a simplified spreadsheet program developed by Energy Design Resources for evaluating the daylighting performance of skylights in commercial buildings. The program accepts simplified input information (including building type, occupancy, building and skylight geometry, and skylight optical properties) and calculates the average illuminance over the space on an hourly basis for each month of the year, in each of California's 16 climate regions. The calculations help designers determine the trade-offs between lighting and HVAC loads. The tool—developed with funding from Southern California Edison, Pacific Gas and Electric, and the Northwest Energy Efficiency Alliance—comes with weather data for California and the Pacific Northwest, and there are plans to add other weather files as well. It is available for download on the Energy Design Resources web site: www.energydesignresources.com/resource/129.

There are also lighting simulation tools that calculate illuminance levels on a point-by-point level, rather than determining overall room averages. These tools are capable of handling complex room geometries and special daylighting features such as light shelves, plus a combination of electric and natural lighting sources. Computer-generated renderings of the space help a designer identify potential glare problems in the space and formulate appropriate solar control strategies.

Building energy simulation programs provide a whole-building approach to energy analysis.

Building Energy Simulation Programs

Building energy simulation programs provide a whole-building approach to energy analysis, addressing the energy-related interactions between building shell, lighting, daylighting, HVAC systems, and utility services. These tools produce sophisticated engineering models of building systems that can account for the dynamic response of the building shell and its mechanical systems to various occupancy and weather-related influences. The programs provide hour-by-hour evaluations, using typical rather than worst-case conditions to simulate the long-term performance of the building. Commonly used simulation programs include simple screening tools (such as Energy-10) as well as detailed simulation programs (such as DOE-2-based programs like eQUEST and EnergyPlus).

Energy-10 is a simplified hour-by-hour program designed for the analysis of residential and light commercial buildings. This straightforward program is intended to be used during the conceptual design phase to identify and rank energy-efficiency strategies. The types of strategies it evaluates include daylighting, HVAC controls, thermal mass, efficient lighting, passive solar heating, high-efficiency HVAC systems, and air-leakage control. Unfortunately, the HVAC system simulation is limited to packaged single-zone heating and air-conditioning systems, which limits the applicability of the program to smaller buildings. (Energy-10 is available through the Sustainable Buildings Industry Council: www.sbicouncil.org/store/e10.php.)

DOE-2-based programs are detailed hour-by-hour simulation programs designed for projecting the performance of a wide range of commercial buildings. They not only perform heating and cooling load calculations but also take into account interactions between the building shell, lighting and other internal loads, and building thermal mass. They are also capable of modeling the performance of most HVAC systems commonly found in commercial buildings, including variable-air-volume systems, multizone or dual-duct systems, water-loop heat pumps, and packaged single-zone systems. These programs can also model the performance of many other energy-efficiency strategies applicable to California. Although such programs are extremely detailed, requiring a great deal of input data, they provide users with a lot of flexibility to examine different design options and are considered to be the most rigorous building energy simulation programs commonly available.

The very capabilities of DOE-2-based programs have hampered their widespread use as a design tool; a fairly serious amount of effort and expertise is required to use them effectively. The original program interface, which was developed in the early 1980s, used a text-based input file structure that closely resembled punch cards. There have been many improvements since then, including the development of graphical user interfaces with menu-based input screens in place of the text-style inputs. Examples of programs with these improved user interfaces include eQUEST and VisualDOE.

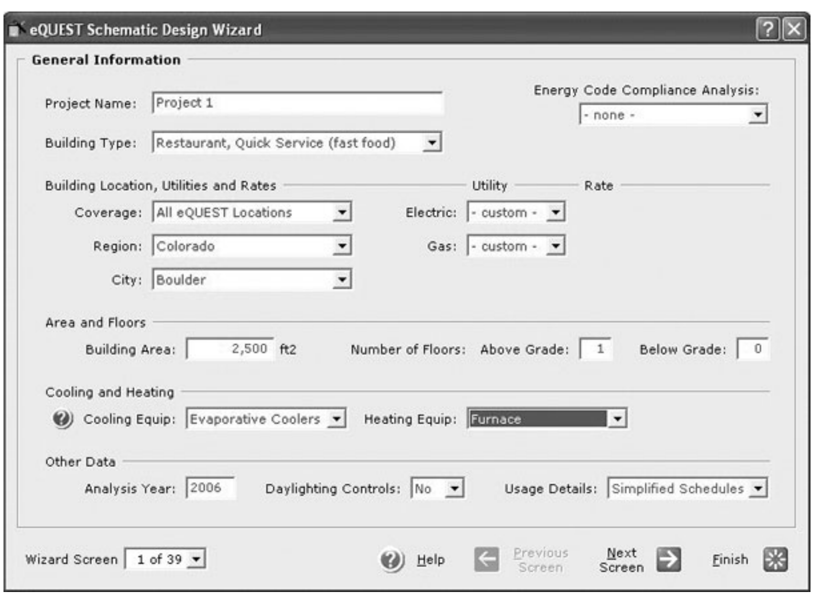
Although these improved user interfaces can reduce the time it takes to enter data into DOE-2, a high level of expertise is required to figure out what data are needed and to understand the meaning of the input language. One of the DOE-2-based simulation tools, eQUEST, developed by Energy Design Resources, features a building input “wizard” that makes this task easier by requiring a greatly reduced set of input data for describing a building. The wizard computes the remaining inputs based on the experience of simulation experts. This program can be of great help during initial design phases, when much of the detail about the proposed building is not yet known. Nonetheless, at a minimum, the user will need to enter building type, location, floor area, number of floors, cooling system type, and heating system type (**Figure 6**). Some additional details may also be entered by the user if a more accurate simulation is desired. (More information on this tool is available from Energy Design Resources in the Design Brief called "Building Simulation," available at www.energydesignresources.com/resource/21. You can download eQUEST itself from Energy Design Resources' web site: www.energydesignresources.com/resource/130.)

Base Design Decisions on Life-Cycle Economics

Life-cycle economics stands in direct contrast to the simple payback method of economic analysis, which focuses only on how quickly the initial investment can be recovered as opposed to the long-term profitability of the investment. The simple payback method typically ignores all costs and savings that occur after payback has been achieved. It does not differentiate between project alternatives that have different service lives,

Figure 6: Opening screen of the eQUEST building simulation wizard

This Energy Design Resources program can produce a complete simulation model from just the few inputs shown here.



Source: Energy Design Resources

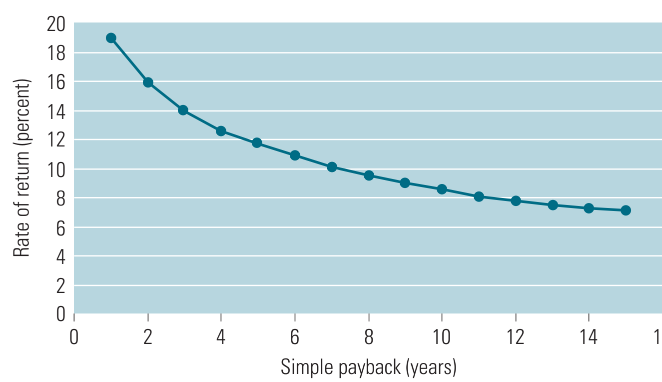
and it ignores the time-value of money when comparing a future stream of savings against the initial investment cost. A simple payback criterion of two to four years is often quoted as the decision threshold for energy-efficiency improvements, and that can grossly undervalue improvements in energy performance.

From the life-cycle economics point of view, the full range of a building's expenses must be considered over the lifetime of the building, including the costs of construction; financing; energy; operations and maintenance; periodic replacements; and even disposal of the building, equipment, or system. These costs are generally expressed in terms of net present value, making it possible to compare costs that occur at different times. Net present value accounts for the time-value of money. Taking the life-cycle economics approach, energy-efficiency investments may be attractive to investors even with simple paybacks as long as 15 years (**Figure 7**).

Design decisions based on life-cycle economics are made by comparing the life-cycle costs of various design alternatives. In

Figure 7: Rate of return versus simple payback period

Investors who limit themselves to simple payback periods of four years or less are limiting themselves to investments with a rate of return better than 12 percent. As a result, they may be depriving themselves of some attractive long-term opportunities. Even projects with simple payback periods as long as 15 years can produce a rate of return of about 7 percent.



Note: Calculations are based on a 6 percent discount rate, 15-year financing with 3 percent real interest rate, and a 15 percent tax rate.

Courtesy: Platts; data from Architectural Energy Corp.

theory, the alternative with the lowest life-cycle cost is the best option for the investor. The basic steps in a life-cycle analysis are:

1. *Gathering basic financial data.* Life-cycle economic analysis begins with the gathering of relevant financial and economic data such as utility rates, expected energy and general inflation rates, discount rates, interest rates, financing terms, and federal and state tax rates as well as setting the period of the economic analysis.

2. *Estimating annual energy costs.* Energy consumption and energy costs are calculated using a building energy simulation program.

3. *Estimating first costs.* Building construction costs are estimated from the most accurate information available.

4. *Estimating ongoing costs.* Operation and maintenance costs, replacement costs, and service life need to be included in the evaluation.

5. *Calculating life-cycle costs.* The present value of energy, construction, and ongoing costs is calculated using standard discount factors that account for the time-value of money.

6. *Comparing life-cycle costs.* The life-cycle costs of each alternative are calculated and compared. The alternative with the lowest life-cycle cost is the best economic option for the investor. Computerized tools can make these tasks easier. The Building Life Cycle Cost program from the National Institute for Standards and Technology is often used in federal projects.[11] Energy Design Resources offers eVALUator, another financial analysis tool that simplifies life-cycle cost calculations.

The eVALUator program accepts as inputs the traditional life-cycle economic parameters described above as well as other input parameters of interest to owners, developers, and financiers: salary costs, productivity improvement rates, time-on-market capitalization rate, average lease rate, and average occupancy. It generates a year-by-year cash-flow analysis in addition to traditional life-cycle economic parameters such as net present value of life-cycle savings and internal rate of return. The program includes useful features such as the ability to consider differing perspectives (building developer versus a real estate management company, for instance) and the ability to consider the effects of an energy-efficiency measure on occupant productivity.[12]

Follow Through

Once the building design is completed, construction management companies, general contractors, and subcontractors take the project through to completion. Energy-saving features that were designed into the building can sometimes be placed at risk due to actions taken during the bidding and construction phases. Decisions about value-engineering processes, change orders, and product substitutions may be made on the basis of reducing first costs or staying on schedule, with little or no consideration of the implications of such design changes for the overall performance and life-cycle economics of the building. Poor workmanship or inadequate commissioning can weaken or nullify the best intentions of a design team. However, if the parties that carry out these next phases of the work are made part of the integrated design team from the start, there is less chance that they will compromise the design intent. In addition, **Table 1**, page 25, shows steps that can be taken at each phase of the project to ensure that the integrity of the design is maintained.

The entire design team shares responsibility for seeing that the integrated design intent is properly maintained during construction. However, the architect's on-site construction representative and the integrated building design coordinator have a responsibility to work closely with the general contractor and

Table 1: Integrated design from start to finish

Carrying out a successful integrated building design project requires attention to detail during every phase of the design and construction process.

Project phase	Action items
Team formation	Select a broad team representing all interested parties and all phases of the project
Preliminary design	Assess site for daylighting, solar, and natural ventilation opportunities
	Define energy problems and opportunities
	Identify possible solutions
	Perform preliminary economic analysis
Design development	Perform detailed lighting and daylighting studies
	Integrate load-reduction measures into mechanical design
	Coordinate architectural, lighting, and interior designs
	Simulate energy performance
	Refine economic analysis
	Prepare commissioning plan
Construction documents	Review building plans and specifications
	Review equipment selections
	Review construction details
	Finalize performance and economic analyses
Construction	Review change orders and product substitutions to maintain the integrity of the design
	Inspect quality of materials and correctness of installations
Commissioning and occupancy	Develop commissioning plan and involve commissioning agent early in the process
	Verify energy savings
	Solicit feedback from occupants
	Continue to monitor and tune performance throughout the life of the building

Courtesy: Platts; data from Architectural Energy Corp.

specialty subcontractors to preserve the energy-saving features of the project. Here's what can happen if various parties are not integrated into the design team: In a utility office building, a series of interior light shelves were designed to provide shading and enhanced daylighting for an open-office portion of the building. Cost overruns resulted in the light shelves being eliminated, which caused glare and poor interior lighting. Complaints eventually resulted in the light shelves being installed as designed, much to the relief of the occupants.

Commissioning is an essential part of the integrated building design process that needs to be addressed in the early stages of design.

In another example, during the design of one large corporate office building, a series of plant zones were specified at the client's request to provide shading, moisture, visual relief, and ambience. During construction, the client decided to change the use of the space and put offices where the plant zones were to have been located. The glazing properties in these zones had been selected for plant growth, not for human comfort. Consequently, glare and higher solar gains made for unpleasant offices, and post-occupancy changes had to be made to the glazing.

Check Your Work

One way of ensuring that a building is well-designed and that the integrity of the design is preserved through the construction process is to routinely check the work of both the design team and the construction crew. Checking the results of the project ensures that the owners get what they paid for, that the occupants will be happy with the space, and that the performance of the building will meet the design team's expectations. No matter how experienced the design team is, lessons learned from one project can improve the next, in addition to providing solid evidence of the benefits of energy-efficient design. Procedures that are useful for testing the completed building include commissioning, continuous commissioning, measurement and verification, and post-occupancy evaluations.

Commissioning. Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs. It is an essential part of the integrated building design process that needs to be addressed in the early stages of design. While the bulk of commissioning tasks occur during the construction and acceptance phases, the quality assurance process that commissioning represents starts with documentation of the owner's requirements and design intent. In fact, the commissioning agent may be included in design meetings right from the start. On one effective integrated design project, the commissioning agent was involved when project criteria were first developed and will stay involved, to a lesser degree, through the life of the building, to check performance and correct problems as necessary.[13] Several commissioning resources are available on the Energy Design Resources web site, including:

- EDR Design Brief, "Building Commissioning": This Brief describes the role of the commissioning agent throughout the whole process, from design through completion. It is available online at www.energydesignresources.com/resource/17.

- EDR Design Guidelines—Commissioning Guidelines: These Guidelines include an introduction to commissioning and a comprehensive guide for design professionals. They are available online at www.energydesignresources.com/resource/37.

- Cx Assistant: Commissioning Assistant is a web-based tool that provides project-specific building commissioning information to design teams. It enables the user to evaluate probable commissioning costs, to identify an appropriate commissioning scope, and to access sample commissioning specifications related to the construction project. Cx Assistant is available online at www.energydesignresources.com/resource/176.

Continuous commissioning. Also known as retrocommissioning, continuous commissioning is the same systematic process as commissioning, but applied to existing buildings to ensure that their systems can be operated and maintained according to the owner's needs. Studies have found that continuous commissioning can help building managers cut energy bills by 5 to 25 percent, even if the buildings have already incorporated the latest energy-saving technologies. An integrated

Studies have found that continuous commissioning can help building managers cut energy bills by 5 to 25 percent.

design team can plan for this type of activity early on by specifying an energy management system that can provide alarms when systems are not performing as expected.

Measurement and verification. Although commissioning ensures that building equipment and systems perform according to design intent, it does not verify whether the energy savings predicted during the design phase have actually been achieved. This is where performance measurement and verification come in. Monitoring may be done for a variety of reasons, but the two leading ones are:

Predicting and verifying the energy savings from innovative energy-efficient design can be a complex and expensive process.

- *Educational or marketing purposes.* Measurement makes it possible to verify that the energy savings are real and the strategies followed in the project were justified. The knowledge gained can then be applied to future projects. Documented proof of energy savings on past projects can help convince new potential clients that the return on energy-efficient design is well worth the extra cost in the planning and construction phases.

- *Contractual necessity.* Verifying the delivery of energy savings promised in a performance contract is often a condition of the contract. The monitoring and measurement of energy savings reduces the risk for the owner and motivates the design and construction team to do the best possible job. In addition, performance-based fees for an engineer or architect may be based on quantified energy savings.

Predicting and verifying the energy savings from innovative energy-efficient design can be a complex and expensive process. Variables such as weather, occupancy patterns, and remodeling can seriously affect actual savings. In 1996, the U.S. Department of Energy released a document entitled “North American Energy Measurement and Verification Protocol,” which provides guidelines for the process of verifying savings from energy-efficient building design. This document, which garnered considerable interest from other countries, was revised, updated, and re-released in 1997 as the “International Performance Measurement and Verification Protocol,” and then revised again in 2001. The organization introduced another useful document, “Concepts and Options for Determining Energy Savings in New Construction,” in 2003. (These reports and documents can be downloaded from the International Performance Measurement and Verification Protocol web site at www.ipmvp.org.)

Evaluating a building after occupancy provides invaluable feedback that can help designers improve the quality and performance of future buildings.

The biggest challenge to measurement and verification for new buildings is establishing baseline energy use. How would a particular building have performed without the energy-efficiency upgrades? For new commercial construction projects, the job of creating valid comparisons is often best accomplished through the use of computer simulation models. First, a model is developed that represents the building as it is built. That model is then modified so it represents the building as it would have been built had the designer’s goal been to simply meet minimum efficiency codes and standards. Short-term metering carried out after commissioning and full occupancy may be used to check the predictions of the model.

Post-occupancy evaluations. Although evaluating a building after occupancy provides invaluable feedback that can help designers improve the quality and performance of future buildings, that type of analysis is rarely included in the architectural design process. As a consequence, little is learned about how the building is actually performing, how satisfied the occupants are with their spaces, or what preventive actions are needed to ensure proper operation of building systems in the future.

A variety of qualitative and quantitative methods are available for evaluating building performance and occupant satisfaction. Researchers can send or hand out questionnaires, monitor environmental conditions that would affect comfort and indoor air quality, or track indices related to productivity, such as employee absenteeism or the use of sick leave.

For More Information

Building Energy Simulation User News

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This publication includes articles relating to the DOE-2, PowerDOE, and BLAST programs. A list of simulation program suppliers, developers of add-on programs for generating input files or viewing program outputs, and simulation practitioners in California is included. *Building Energy Simulation User News* is available free of charge from the Simulation Research Group at Lawrence Berkeley National Laboratory.

High Performance Buildings Research Initiative

National Renewable Energy Laboratory (NREL)

U.S. Department of Energy

web www.nrel.gov/buildings/highperformance

The High Performance Buildings Research Initiative works to improve buildings by designing structures and developing computer tools to integrate passive solar energy, energy efficiency, and renewable energy technology. NREL's web site offers background information, case histories, and research results.

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LBNL has particular expertise in windows and daylighting research, lighting system research, and building energy simulation research. Technical reports can be ordered from the publications department or downloaded from the Internet. A variety of software tools that can be used for energy-efficient building design are also available for downloading.

Office of Energy Efficiency and Renewable Energy (EERE)
The U.S. Department of Energy
web www.eere.energy.gov and www.eere.energy.gov/buildings

The EERE manages the federal research and development activities for energy efficiency and renewable energy technologies. Its web site has links to research and development sites throughout the federal government. The EERE offers a Building Technologies Program that works to improve the energy efficiency of buildings through innovative new technologies and better building practices. Research efforts cover energy-efficient components and equipment, materials, and whole-building optimization. Regulatory activities cover building codes, equipment standards, and guidelines for efficient energy use.

Savings By Design
web www.savingsbydesign.com

The Savings By Design program offers services and incentives to help architects and building owners raise energy performance to a top priority. The program is funded by California utility customers and administered by Pacific Gas and Electric Co., San Diego Gas & Electric, Southern California Edison, the Southern California Gas Co., and the Sacramento Municipal Utility District (SMUD).

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The USGBC is a center for debate and action on environmental issues facing the building industry. The mission of the USGBC is to accelerate the adoption of green building practices, technologies, policies, and standards. The LEED Green Building Rating System, developed by the USGBC, is an independent rating system for assessing the energy efficiency and sustainability of commercial buildings.

Notes

1 William Fisk, Lawrence Berkeley National Laboratory (LBNL), "Economic Benefits of Improved IAQ, Health, and Productivity in Sustainable Buildings," White House Summit on Sustainable Buildings, Washington, DC (January 24, 2006).

2 Steve Selkowitz (March 10, 2005), Head, Buildings Technology Department, LBNL, Berkeley, CA, 510-486-5064, seselkowitz@lbl.gov.

3 Savings By Design, "Savings By Design Award Winners Integrate Energy Efficiency with Outstanding Design," from www.savingsbydesign.com/awards-2003/index.html (accessed February 28, 2006).

4 U.S. Green Buildings Council, "Premier Automotive Group North American Headquarters: Ford Motor Company, Irvine, California," from www.usgbc.org/FileHandling/show_general_file.asp?DocumentID=386 (accessed February 1, 2006).

5 Ira Krepchin, "Integrated Building Design: Can Teamwork Lead to High-Performance, Cost-Effective Buildings?" *E SOURCE Report, ER-00-15* (September 2000).

6 California Energy Commission, "2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings" (September 2004, effective October 2005), Sacramento, CA, 916-654-5200, www.energy.ca.gov/title24.

7 ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers), "Cogeneration Systems and Engine and Turbine Drives," Systems and Equipment Handbook, Chapter 6 (1996), Atlanta, GA, 404-636-8400, www.ashrae.org.

8 Bill Howe et al., *E SOURCE Drivepower Technology Atlas* (Boulder: Platts, 1999), Chapter 1.

9 Amory Lovins, "Energy-Efficient Buildings: Institutional Barriers and Opportunities," *E SOURCE Strategic Issues Paper II* (1992).

10 International Energy Agency, "Performance Evaluation of Daylighting Systems," Task 21, Energy Conservation in Buildings & Community Systems, Programme Annex 29, Subtask A.

11 Building Life Cycle Cost software and manuals explaining the principles of life-cycle costing methods may be downloaded free from www.eere.energy.gov/femp/information/download_blcc.cfm#blcc5.

12 To learn more about eVALUator, go to www.energydesignresources.com/resource/131.

13 Ira Krepchin [5].

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Co., San Diego Gas and Electric, Southern California Edison, and Southern California Gas, under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our web site at www.energydesignresources.com.

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