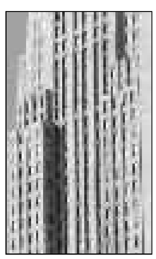
SUSTAINABLE BUILDING TECHNICAL MANUAL



Green Building Design, Construction, and Operations

Produced by Public Technology Inc. ■ US Green Building Council

Sponsored by U.S. Department of Energy ■ U.S. Environmental Protection Agency

Project Managers

Annette Osso
Business Director, Environmental Programs
Public Technology, Inc.
Project Manager

Taly Walsh
Communications Director
Public Technology, Inc.
Project Design Manager

David A. Gottfried
President
Gottfried Technology Inc.
Managing Editor

Lynn N. Simon
Gottfried Technology Inc.
Senior Editor

Editorial and Production Staff and Consultants

Mark Graef, Production Consultant
Fran Haselsteiner, Editing Consultant
Kathleen Lundy, Editing Consultant
Christopher Marshall, Production Consultant
Patrick McCarthy, Production/Research Consultant
Kristen Mosbaek, Graphic Design/Production Consultant
Shaden Tageldin, PTI Writer/Editor
Jack Werner, PTI Energy Director

Printed in the United States of America
Printed on recycled paper.

Acknowledgments

Funding for development of the Sustainable Building Technical Manual was provided to Public Technology, Inc., by the U.S. Department of Energy (DOE), with supplemental funding from the U.S. Environmental Protection Agency (EPA). The DOE and EPA principals involved with the manual's development are listed below.

DOE principals

William Becker
Director
Denver Support Office, U.S. DOE

Mary-Margaret Jenior
Senior Program Manager,
Office of Building Technologies, State and Local Programs, U.S. DOE

Louis Divone
Acting Deputy Assistant Secretary
Office of Building Technologies, State and Local Programs, U.S. DOE

EPA principals

David Scott Smith
Associate Director
Safety, Health and Environmental Management Divn.
Office of Administration, U.S. EPA

Lawrence Martin
Project Officer
Office of Research and Science Integration, U.S. EPA

Julius C. Jimeno
Director
Safety, Health and Environmental Management Divn.
Office of Administration, U.S. EPA

John C. Chamberlin
Director
Office of Administration, U.S. EPA

Public Technology, Inc. developed this manual to address the growing demand for information on the design and construction of green buildings. The manual was jointly sponsored by PTI's Urban Consortium Environmental and Energy Task Forces. The U.S. Green Building Council (USGBC) worked with PTI to develop the manual. David Gottfried of Gottfried Technology Inc., served as managing editor. An Advisory Committee of local-government and private-sector representatives assisted in developing the manual. The manual underwent a consensus review process by members of the USGBC and was peer reviewed by U.S. DOE and U.S. EPA officials.

Public Technology, Inc.

Public Technology, Inc., is the non-profit technology research and development organization of the National League of Cities, the National Association of Counties, and the International City/County Management Association. PTI's mission is to bring technology to local and state governments. Through the collective R&D work of its membership, PTI spreads the use of technology to effectively serve communities. PTI uses strong, dynamic public-private partnerships to offer to local and state government cost-saving technology services and products.

PTI is committed to a sustainable environment. Its Urban Consortium (UC) Environmental and Energy Task Forces unite cities and counties behind that goal to explore, test, and promote technologies that maintain the critical balance between healthy development and a healthy environment. Many of its members' innovative programs are highlighted in the annual PTI *SOLUTIONS* publication series.

The UC Environmental Task Force is chaired by Randy Johnson, Commissioner, Hennepin County, Minnesota. The UC Energy Task Force is chaired by Michael Lindberg, Commissioner of Public Utilities, City of Portland, Oregon.

U.S. Green Building Council

The U.S. Green Building Council (USGBC) is a balanced, nonprofit coalition of the building industry promoting the understanding, development, and accelerated implementation of green building policies, programs, technologies, standards, and design practices on a national basis. Since its formation in 1993, the council has attracted more than 100 leading national organizations to its ranks, including product manufacturers, environmental groups, building owners, utilities, state and local governments, research institutions, professional societies, and colleges and universities. USGBC has also established effective and ongoing liaisons with the White House, federal agencies, standards organizations, and organizations representing state and local governments. Issues being addressed by the council include economic analysis, full-cost accounting, green building rating systems, product certification, life-cycle analysis, environmental policies, standards development, and education of the building industry.

U.S. Department of Energy

The mission of the U.S. Department of Energy (U.S. DOE) is to assure that the nation has adequate and stable supplies of energy. The department is also committed to helping the nation discover and adopt cleaner and more sustainable energy resources and technologies—in other words, technologies that improve energy efficiency, prevent pollution, and make use of renewable resources to diversify the nation's energy mix. U.S. DOE's Office of Energy Efficiency and Renewable Energy (OEERE) operates a number of technical and financial assistance programs to improve the resource efficiency of America's buildings. Among them are Building America, which brings the diverse elements of the building industry together to practice a systems approach to building design and construction, improving cost, durability, indoor air quality, and energy efficiency. In addition, the Office encourages green building practices through its Center of Excellence for Sustainable Development, which helps communities create and implement sustainable development programs. The center will help communities adopt a comprehensive approach to planning—an approach that recognizes the links between energy, environment, economy, and community livability. Information and a "tool kit" on sustainable development is available on the Center's Internet home page, <http://www.crest.org/doe/sustainable>, or by calling (800) 357-7732.

U.S. Environmental Protection Agency

The Safety, Health and Environmental Management Division (SHEMD) of U.S. EPA is responsible for developing and implementing the agency's internal policies, programs, and infrastructure for environmental management and public and occupational safety and health. SHEMD works closely with all U.S. EPA operating units to provide management support and technical assistance. Through collaborative relationships with other federal, state, and local government agencies and organizations, business and industry, educational and research institutions, and other entities, SHEMD jointly develops products and services that have widespread public- and private-sector application. A particular emphasis is placed upon learning, information, and performance-support systems, especially those employing new technologies, to help advance the nation's objectives for a sustainable future.

Producing a manual that covers all disciplines involved in the design, construction, and operation of a building is an enormous challenge. Early in the process it was decided that this book, like a building project, would best be designed and constructed via a collaborative, integrated effort of practitioners in the field. Many individuals across the building professions provided a great deal of assistance and deserve thanks for making the manual a success.

A special thanks to Annette Osso, PTI, who provided overall project coordination and management and to David Gottfried of Gottfried Technology Inc., who managed the USGBC 's work on the manual. He developed the outline for the manual, identified authors, and worked with Lynn Simon to organized the authors' drafts and reviewers' comments to develop a cohesive document. The individual authors also deserve special thanks for working with the USGBC and PTI, contributing additional information, and reviewing material throughout the process. The Advisory Committee and additional reviewers read and commented on the manual manuscript through several review processes. PTI staff and contractors provided many hours of work to edit and produce the final document. All have worked together to provide building professionals in public and private organizations with a document that will further their green building initiatives.

A final note of thanks goes to Lou Divone, Bill Becker, and Mary-Margaret Jenior of U.S. DOE and to David Scott Smith of U.S. EPA for their support of green building initiatives in communities around the country.

Authors

Loren E. Abraham, AIA, IDSA, Environmental Research Group
Sal Agnello, Johnson Controls
Stephen P. Ashkin, Rochester Midland Corporation
Lucia Athens, University of Georgia, School of Environmental Design
Anthony Bernheim, AIA, Simon Martin – Vegue Winkelstein Moris
Clark C. Bisel, P.E., Flack & Kurtz Consulting Engineers
William Burke, AIA, University of California, Berkeley, Center for Environmental Design and Research
Nicholas T. Dines, FASLA, University of Massachusetts, Department of Landscape Architecture and Regional Planning
Bruce K. Ferguson, University of Georgia, School of Environmental Design
Daniel J. Goldberger, International Council for Local Environmental Initiatives
David A. Gottfried, Gottfried Technology Inc.
Gerard Heiber, Sigal Environmental, Inc.
Lisa Heschong, Heschong Mahone Group
Phillip Jessup, International Council for Local Environmental Initiatives
Barbara Lippiatt, National Institute of Standards and Technology
John D. Longman, Cerami & Associates
Dru Meadows, AIA, BSW International
Michael Myers, U.S. Department of Energy
William G. Reed, AIA, Hillier Group
David Rousseau, Archemy Consulting Ltd.
Kim Sorvig, University of New Mexico, School of Architecture and Planning
Dr. James A. Tshudy, Armstrong World Industries

Advisory Committee

Susan Anderson, city of Portland Energy Office
Joseph Azzarello, Herman Miller, Inc.
Kathy Bakin, American Society of Interior Designers
Larry Blackstad, Hennepin County, Minnesota
William Bobenhausen, Steven Wintor Associates
Helen English, Passive Solar Industries Council
Susan Everett, American Society of Landscape Architects
Richard Fedrizzi, Carrier Corporation
David Gottfried, Gottfried Technology Inc.
Richard Hays, city of San Diego, California
Gerard Heiber, Sigal Environmental, Inc.
Mary-Margaret Jenior, U.S. DOE
Randy Johnson, Hennepin County, Minnesota
Dimitrios Laloudakis, city of Phoenix, Arizona
Steven J. Piguet, Armstrong World Industries
William G. Reed, AIA, Hillier Group
Douglas Seiter, city of Austin, Texas
David Scott Smith, U.S. EPA
Wade Smith, Honeywell Inc.
Ross Spiegel, Constructions Specifications Institute
Alan Traugott, Flack & Kurtz Consulting Engineers
Paul Tseng, Montgomery County, Maryland
Doug Yoder, Metro-Dade County, Florida

Additional Reviewers

Loren E. Abraham, AIA, IDSA, Environmental Research Group
Anthony Bernheim, AIA, Simon Martin – Vegue Winkelstein Moris
William Burke, AIA, Architect
Nancy Carlisle, National Renewable Energy Laboratory
Anne Sprunt Crawley, U.S. DOE
Michael O'Reilly, U.S. EPA
Patricia Plympton, National Renewable Energy Laboratory
Adam Saling, San Diego, California
Dr. James A. Tshudy, Armstrong World Industries
Donald Watson, FAIA, Architect
Phil Wirdzek, U.S. EPA

Contents

Introduction

Foreword

Author
David A. Gottfried

Since the Industrial Revolution, the world has witnessed incalculable technological achievements, population growth, and corresponding increases in resource use. As we enter a new century, we are recognizing the "side effects" of our activities: pollution, landfills at capacity, toxic waste, global warming, resource and ozone depletion, and deforestation. These efforts are straining the limits of the Earth's "carrying capacity"—its ability to provide the resources required to sustain life while retaining the capacity to regenerate and remain viable.

As the world's population continues to expand, implementation of resource-efficient measures in all areas of human activity is imperative. The built environment is one clear example of the impact of human activity on resources. Buildings have a significant impact on the environment, accounting for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material and energy flows. Structures also impact areas beyond their immediate location, affecting the watersheds, air quality, and transportation patterns of communities.[1]

Within the United States, buildings represent more than 50 percent of the nation's wealth. In 1993, new construction and renovation activity amounted to approximately $800 billion, representing 13 percent of the Gross Domestic Product (GDP), and employed ten million people.[2] The resources required to create, operate, and replenish this level of infrastructure and income are enormous, and are diminishing. To remain competitive and continue to expand and produce profits in the future, the building industry knows it must address the environmental and economic consequences of its actions.

That recognition is leading to changes in the way the building industry and building owners approach the design, construction, and operation of structures. With the leadership of diverse groups in the public and private sectors, the building industry is moving toward a new value in its work: that of environmental performance.

The industry's growing sustainability ethic is based on the principles of resource efficiency, health, and productivity. Realization of these principles involves an integrated, multidisciplinary approach—one in which a building project and its components are viewed on a full life-cycle basis. This "cradle-to-cradle" approach, known as "green" or "sustainable" building, considers a building's total economic and environmental impact and performance, from material extraction and product manufacture to product transportation building design and construction, operations and maintenance, and building reuse or disposal. Ultimately, adoption of sustainable building practices will lead to a shift in the building industry, with sustainability thoroughly embedded in its practice, products, standards, codes, and regulations.

Understanding the specifics of sustainable building and determining effective sustainable practices can be confusing. Local governments and private industry often do not have the resources to perform the necessary research to assemble information on sustainable practices, assuming such information is readily available.

The S*ustainable Building Technical Manual* was written to fill that void. In its pages, noted private practitioners and local government experts extract, consolidate, and prioritize—from their own experience and expertise—the scattered and growing volume of information pertaining to sustainable buildings. The manual's primary intent is to provide public and private building industry professionals with suggested practices across the full cycle of a building project, from site planning to building design, construction, and operations.

We hope that you will find this technical manual a useful and vital resource in advancing your organization's adoption and daily practice of sustainable building principles—a necessary and important step toward recognizing the Earth's finite carrying capacity and addressing the depletion of its natural resources.

NOTES

1 David Rodman and Nicolas Lenssen, "A Building Revolution: How Ecology and Health Concerns Are Transforming Construction," *Worldwatch Paper 124* (Washington, D.C., March 1996).

2 National Science and Technology Council, Subcommittee on Construction and Buildings, *Preliminary Report* (Washington, D.C., 1993).

The Role of Local Governments

Local governments own and maintain a wide range of buildings and facilities, including administrative and office buildings, park facilities, health clinics and hospitals, fire and police stations, convention centers, wastewater treatment plants, and airports.

At their disposal are a variety of administrative, regulatory, and financing tools that can help local governments develop and operate these building resources in a sustainable manner. Local governments can create policies for municipal procurement, contract specifications, building performance, and building codes regulating community standards; enact resolutions, training and education programs, and ordinances that focus attention on sustainable development; create community boards and commissions to study local sustainable issues; and provide economic incentives for sustainable development.

Finally, many local governments have the experience and capability to create model programs and buildings, which set examples for resource-efficient guidelines and support green building programs elsewhere in their communities. Green building programs can be a first step to helping local stakeholders—policymakers, businesses, citizens, financiers, homeowners, and building owners—understand the economic and environ-

mental wisdom of adopting sustainable principles for their communities.
Many successful green building initiatives are being developed and implemented at the local level across the United States.

The city of Austin, Texas, has consistently demonstrated leadership and vision in this area. Over the last decade, the city of Austin developed its Green Builder Program to support green practices in the residential sector. More recently, it passed a resolution encouraging environmentally sound development within the residential, municipal, and commercial building sectors. Austin's ultimate goal is to be a model sustainable city.

The city of Portland, Oregon, passed an ordinance requiring the recycling of construction waste, along with a set of city-wide principles that promote a sustainable future. Metro-Dade County, Florida, is working with Habitat for Humanity and other partners to plan and develop an energy-efficient and environmentally sound low-cost housing development. Some communities, such as San Francisco, California; Seattle, Washington; San Diego, California; Hennepin County, Minnesota; and New York, New York, are developing their own green building guidelines for municipal and private buildings, or launching demonstration projects that incorporate green building principles.

Communities may also address sustainability from an overall quality-of-life perspective, as Jacksonville, Florida, did. Jacksonville, which has tracked quality indicators since 1985, involves citizens in setting targets and reports annually on progress in education, economy, public safety, health, natural environment, social environment, government, recreation, and mobility. Other communities, such as Chattanooga, Tennessee, have sought to address environmental damage in the process of redesigning their communities. In Chattanooga, more than 2,600 citizens participated in the ReVision 2000 planning process to identify specific environmental improvement goals and recommendations for future city development. Some of the cities efforts to become a model sustainable city include developing a network of greenways and eco-industrial parks, renovating and constructing new public facilities to be model green buildings, and proposing an expansion of the city's trade center to include a variety of green technologies.

Green building initiatives, as well as sustainable development activities, offer many opportunities to local governments and communities. The key to success for local governments is to take the first step toward sustainability, working initially within areas that are most likely to succeed, such as a green building project. A few possible starting points include the following:

- Examine local government policies and procurement procedures for inclusion of green building measures.
- Develop a demonstration green building project or local sustainable building design competition.
- Require that government building projects incorporate renewable energy and energy efficient systems, indoor-air-quality guidelines, and waste and water-efficiency measures.
- Survey and review other cities with green building projects, programs, and standards.
- Assemble a multidisciplinary team within the community to discuss the possibility of developing a green building program.
- Develop a green building awards program; co-sponsor the program with the local utility and local chapters of design, engineering, and property-management societies.
- Survey and publish the community's green building resources.
- Initiate a conference or series of lectures on green building issues.
- Assemble a green building resource library within an existing library or municipal office.
- Initiate a green building computer-based bulletin board or Internet site.
- Publish case studies of local green building projects or develop a green building

Overview

Sustainable Building Technical Manual: Green Building Practices for Design, Construction, and Operations is intended to meet the building industry's need for a comprehensive manual of sustainable building practices. Its goal is to provide clear, easily applied guidelines and useful practices that can be readily introduced into new construction, renovation, and building operations. The manual is designed to synthesize the large volume of available information on green buildings and direct the reader to more detailed resources for further review and reference.

The manual focuses on commercial-size building projects in both the public and private sectors. Building professionals who will find this manual a useful resource include landscape architects, planners, architects, interior designers, engineers, contractors, property managers, building owners and developers, product manufacturers, utility companies, building tenants, maintenance staff, and code officials.

Organization of the Manual

The manual is organized in seven parts, along with an Introduction and Appendix. Part I discusses the economic and environmental significance of sustainable buildings. Parts II through VI describe the sequential design, construction, and operational process for a building project, and Part VII reviews sustainable building financing issues and opportunities for local governments, as well as future green building issues and trends.

Introduction

This section contains a foreword by managing editor David Gottfried, a discussion of the role of local governments in promoting green building practices, and the manual overview.

Part I: Economics and Environment

Part I outlines the financial benefits and environmental ramifications of green building practices. It focuses on energy and water efficiency, waste reduction, construction costs, building maintenance and management savings, insurance and liability, employee health and productivity, and building value. It also reviews the local economic development potential of green building initiatives and presents a methodology for environmental life-cycle assessment and its application to green buildings.

Part II: Pre-Design Issues

This section reviews pre-design environmental issues such as design team selection, environmental guidelines, and "whole-building" design integration—the first and essential steps in creating and implementing a successful green building project.

Part III: Site Issues

Site issues chapters provide detailed information on sustainable site design, water use, and site materials. Discussed are design issues such as assessment and selection of building sites, development of landscaping that preserves natural vegetation and maintains watershed integrity, and consideration of green site materials.

Part IV: Building Design

Building design is divided into three subsections that provide information on passive solar design strategies; building systems, indoor environmental quality, and building commissioning; and building materials and specifications.

Part V: The Construction Process

Environmentally sound construction methods are outlined and the section discusses site management issues, indoor air quality, and resource efficiency as they relate to construction processes.

Part VI: Operations and Maintenance

This section reviews environmental operations and maintenance issues including indoor environmental quality, energy efficiency, resource efficiency, and renovation. Housekeeping and custodial practices that help maintain high environmental standards are also discussed.

Part VII: Issues and Trends

The first chapter in this section discusses financing options and cost issues for local governments seeking to implement green building practices. The last chapter presents green building issues such as building standards, rating systems and product certification, and green business trends such as performance contracting and product "environmental" leasing.

Appendices

The Appendices contain a comprehensive listing of information resources for local government; a glossary of terms, acronyms, and abbreviations used in this manual; and biographies of the manual's contributing writers. They also contain the PTI Advisory Committee of public and private experts, and other manual reviewers, including members of the U.S. Green Building Council and American Institute of Architects, and representatives from the U.S. Department of Energy and the U.S. Environmental Protection Agency.

Format of the Manual Chapters

Sections of this manual that discuss green building practices—Parts II through VI—are organized according to the traditional project phases of building design, construction, and operations. The chapters in each section focus on sustainable issues and green practices relevant to the specific processes that occur in each of these phases. Parts II through VI also include chapters on local government information, which provide the local government perspective on implementation issues, give examples of action taken by jurisdictions, and include lists of local options. Readers may choose to add other relevant information and resources about local green building experts, products, or regulations to these local government chapters.

Most of these chapters are organized in the following standard format:

★ SIGNIFICANCE

This section summarizes the sustainability issues relevant to the chapter's topic. It also provides background information on the subject.

☞ SUGGESTED PRACTICES AND CHECKLIST

This section suggests action-oriented, environmentally based practices that design and construction professionals may apply directly to their projects. Brief discussions accompany the practices which are presented in a checklist format.

→ RESOURCES

Resource lists accompanying chapters direct the reader to publications with additional information on the subject. These lists are not exhaustive, and are intended generally as starting points.

NOTES

The numbered citations at the end of each chapter are endnotes related to information cited in the text.

Chapter Presentation and Approach

Successful sustainable design requires an integrated approach; green building systems and operational practices are dependent on siting, solar access and light penetration, architectural design, and product specification. Green buildings must take all of these factors into consideration on a "whole-building," integrated basis. This approach is not linear; rather it is circular and multi-dimensional.

Given this level of complexity and the interrelationships between different parts of the design process, chapters cross-reference pertinent information in other chapters. Each chapter, however, can stand on its own. As a result, some of the material in a given chapter may echo information provided elsewhere. For example, topics covered in the chapter on the design of heating, ventilating and air-conditioning (HVAC) systems may be repeated, to some extent, in the chapter on operations and maintenance. The goal of this approach is to allow professionals from different fields—design, engineering, products, and operations—to use the relevant parts of this manual independently. To further this goal, we have published the manual in a notebook format, allowing easier concurrent use by several practitioners as well as additions and updates to the information contained therein.

PART I

Economics and Environment

Introduction

Sustainable development is the challenge of meeting growing human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future life and development. This concept recognizes that meeting long-term human needs will be impossible unless we also conserve the earth's natural physical, chemical, and biological systems.[1]

Sustainable development concepts, applied to the design, construction, and operation of buildings, can enhance both the economic well-being and environmental health of communities in the United States and around the world. The Union Internationale des Architects/American Institute of Architects (UIA/AIA) World Congress of Architects recognized that in its 1993 Declaration of Interdependence, which acknowledges that buildings and the built environment play a major role in the human impact on the natural environment and on the quality of life. If sustainable design principles are incorporated into building projects, benefits can include resource and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land use, transportation efficiency, and strengthened local economies and communities.

In the United States, federal agencies and the building industry, under the leadership of the National Science and Technology Council, have undertaken the development of goals for improved construction practices. These National Construction Goals promise enormous benefits for the nation, in terms of both economic prosperity and general well-being. Embracing sustainability concepts, the goals aim to reduce energy, operation, and maintenance costs; reduce building-related illnesses; increase the productivity and comfort of building occupants; reduce waste and pollution; and increase building and component durability and flexibility.[2]

Locally, public and private leaders have realized the economic and environmental benefits of green building practices and are instituting policies, developing building guidelines, and manufacturing products and systems that will achieve sustainable development goals.

This section of the manual examines the economic benefits and environmental ramifications of green buildings, and outlines a life-cycle assessment process that building professionals can use to understand the environmental and economic impact of up-front building design decisions over the full life of a property.

NOTES

1 Sustainable development definition from the Civil Engineering Research Foundation, Washington, D.C.

2 National Science and Technology Council, Committee on Civilian Industrial Technology, Subcommittee on Construction and Building, *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry* (Washington, D.C.: National Science and Technology Council, 1995).

CHAPTER 1

The Economics of Green Buildings

Author

David A. Gottfried

Few realize that construction, including new construction and building renovation, constitutes the nation's largest manufacturing activity.[1] Over 70 percent of this effort is focused on residential, commercial, industrial, and institutional buildings; the remaining 30 percent on public works. Construction contributes $800 billion to the economy, or 13 percent of the Gross Domestic Product (GDP), and provides nearly 10 million professional and trade jobs. More than 50 percent of the nation's reproducible wealth is invested in constructed facilities.[2] Because of the building industry's significant impact on the national economy, even modest changes that promote resource efficiency in building construction and operations can make major contributions to economic prosperity and environmental improvement.

Several parties—including owners, tenants, and the general public—bear the cost of building construction. The main direct cost expenditures fall within the categories of building construction, renovation, operation, and building-related infrastructure. Indirect cost expenditures stem from building-related occupant health and productivity problems as well as external costs such as air and water pollution, waste generation, and habitat destruction.

A building's "life" spans its planning; its design, construction and operation; and its ultimate reuse or demolition. Often, the entity responsible for design, construction, and initial financing of a building is different from those operating the building, meeting its operational expenses, and paying employees' salaries and benefits. However, the decisions made at the first phase of building design and construction can significantly affect the costs and efficiencies of later phases.

Viewed over a 30-year period, initial building costs account for approximately just two percent of the total, while operations and maintenance costs equal six percent, and personnel costs equal 92 percent.[3] Recent studies have shown that green building measures taken during construction or renovation can result in significant building operational savings, as well as increases in employee productivity. Therefore, building-related costs are best revealed and understood when they are analyzed over the life span of a building.

Life-cycle cost analysis—an increasingly accepted analytical method that calculates costs over the "useful" or anticipated life of an asset—reveals that low up-front expenditures, though easier to finance at building inception, can result in much higher costs over the life of a building or system. Choosing space-conditioning systems with the lowest first cost, for example, may prove to be a poor life-cycle decision, when energy operations costs over the useful years of the systems are factored into the analysis.

Because local governments often own and operate their buildings, they are in a good position to maximize environmental and economic efficiencies across all building-related cost areas through integration of green building measures. To date, however, green building measures have not been widely adopted, with the exception of energy efficient systems. Some energy-saving measures have become almost commonplace, because their economics are relatively easy to calculate, and because the utility industry has provided financial incentives and rebates that encourage their implementation.

Obstacles to adoption of other green measures include general confusion as to what the measures entail, how to select high-environmental-performance products, and what overall economic and associated benefits can result. A perception that green building measures cost more persists despite cost-effective examples. Even simple design changes that use daylighting and natural heating and cooling potential, and can be incorporated with minimal increased up-front costs, are often misunderstood and underutilized. Too few green building demonstration projects today provide the industry with needed "how-to" information that reduces the perceived risk of "pioneering." Moreover, building owners and tenants are often aware of the connection between building-related environmental improvements and increased building economics and value, as well as increased occupant productivity.

This chapter reviews the economic opportunity and reduced liability for building projects that incorporate green building measures. The areas covered include energy efficiency, water efficiency, waste reduction, construction, building operations and maintenance, insurance and liability, occupant health and productivity, building value, and local economic development opportunities.

Energy Efficiency

Approximately 50 percent of the energy use in buildings is devoted to producing an artificial indoor climate through heating, cooling, ventilation, and lighting.[4] A typical building's energy bill constitutes approximately 25 percent of the building's total operating costs. Estimates indicate that climate-sensitive design using available technologies could cut heating and cooling energy consumption by 60 percent and lighting energy requirements by at least 50 percent in U.S. buildings.[5]

ENERGY RETROFIT

San Diego, California

In a 1995 building renovation project for the city of San Diego's Environmental Services Department, an extensive energy-efficiency retrofit package was projected to yield a four-year payback on investment. The local utility, San Diego Gas & Electric, offered incentives that covered most of the up-front cost of the energy-related improvements, thereby yielding an even earlier payback.

Thanks to efficient mechanical systems, lighting, appliances, and computer-control measures, the building is projected to achieve energy savings of approximately 60 percent over those required under California's Title 24 Energy Code. The annual energy savings are estimated at $66,000 for the 73,000-square-foot building—a savings of $0.90 per square foot, compared to typical energy costs in a similar building. DOE-2 energy-modeling software projected the building's total electricity consumption at approximately 8.4 kilowatt-hours per square foot, placing the project in the lowest five percent of all energy consumers among buildings in the city.

Returns on investment for energy-efficiency measures can be higher than rates of return on conventional and even high-yielding investments. Participants in the Green Lights program of the U.S. Environmental Protection Agency (EPA) have enjoyed annual rates of return of over 30 percent for lighting retrofits. When participants complete all program-related improvements, Green Lights could save over 65 million kilowatts of electricity, reducing the nation's electric bill by $16 billion annually.[6]

If the United States continues to retrofit its existing building stock into energy-efficient structures and upgrade building codes to require high energy efficiency in new buildings, it will be able to greatly reduce the demand for energy resources. This reduction, in turn, will lessen air pollution, contributions to global warming, and dependency on fossil fuels.

Water Efficiency

Water conservation and efficiency programs have begun to lead to substantial decreases in the use of water within buildings. Water-efficient appliances and fixtures, behavioral changes, and changes in irrigation methods can reduce consumption by up to 30 percent or more.[7] Investment in such measures can yield payback in one to three years. Some water utilities offer fixture rebates and other incentives, as well as complimentary water surveys, which can lead to even higher returns.

WATER EFFICIENCY
in a Typical 100,000 sq. ft. Office Building

Water Usage	
Number of Building Occupants	650
Water Use per Occupant per Day	20
Total Annual Building Water Use (gallons)	3,250,000
Total Annual Building Water Use (HCF*)	4,345
Water Cost	
Water Cost per HCF	$1.44
Sewer Cost per HCF	$1.93
Total (water + sewer) Cost per HCF	$3.37
Total (water + sewer) Annual Cost	$14,643
Savings	
Initial Cost of Water Measures**	$10,983
Annual Water Conservation, at 30% Reduction (HCF)	1,304
Annual Water + Sewer Savings (1,304 HCF at $3.37)	$4,394
Payback Period	2.5 years

***One hundred cubic feet (HCF) = 748 gallons**
**** Measures include efficient, low-flow appliances and fixtures as well as control sensors.**
Source: Figures based on communications with Water Department specialists in San Diego, Phoenix, and Sacramento.

Figure 1

As *Figure 1* reveals, for a typical 100,000-square-foot office building, a 30 percent reduction in water usage through the installation of efficiency measures can result in annual savings of $4,393. The payback period is 2.5 years on the installed conservation and efficiency measures. In addition to providing a 40 percent return on investment, the measures result in annual conservation of 975,000 gallons of water.

As demand on water increases with urban growth, the economic impact of water conservation and efficiency will increase proportionately. Water efficiency not only can lead to substantial water savings, as shown in the above example, it also can reduce the requirement for expansion of water treatment facilities. Non-residential water customers account for a small percentage of the total number of water customers, but use approximately 35 percent or more of the total water.[8] More information on water conservation programs and incentives can be obtained from your local water utility, or by calling WaterWiser, a national water-efficiency clearinghouse of the American Water Works Association and the U.S. Environmental Protection Agency, at 800/559-9855.

Waste Reduction

Of the 20,000 landfills located within the United States, more than 15,000 have reached capacity and closed.[9] Many more are following this pattern each year. Construction-related waste constitutes more than 25 percent of landfill content and equals total municipal garbage waste generated in the United States.[10] As a result of this volume of waste, an increasing number of landfills will not permit, or are charging extra for, the dumping of construction-related waste. In response, recycling of such debris is increasing at the job site. Materials such as gypsum, glass, carpet, aluminum, steel, brick, and disassembled building components can be reused, or, if that is not feasible, recycled.

In addition to construction-waste recycling, the building industry is beginning to achieve significant waste reductions through more building reuse and adaptation, as opposed to demolition. In past decades, the trend has been to raze a building at the end of its first life (assumed to be the "useful" life) and replace it with a new building. With ingenuity, older structures can be successfully renovated into cost-effective and efficient "new" structures. Adaptive reuse of older structures can result in financial savings to both sellers and purchasers. One example is the National Audubon Society headquarters building in New York, the product of a 1993 project that recycled a 100-year-old eight-story building. Conservation of the building's shell and floors saved approximately 300 tons of steel, 9,000 tons of masonry, and 560 tons of concrete. Audubon estimates a savings of approximately $8 million associated with restoration instead of demolition and new construction.[12]

PORTLAND TRAILBLAZERS ROSE GARDEN ARENA[11]

Portland, Oregon

One of the best examples of the savings potential for recycling of construction-related demolition debris is the Portland Trailblazers Rose Garden Arena, a new 750,000-square-foot stadium built in Portland, Oregon, in 1995. In demolishing the old stadium and an adjacent facility, the project contractor, Turner Construction Company, was able to divert successfully from the landfill the majority of the construction and demolition debris—including 1,300 tons of wood, 1,000 tons of metal, and 29 tons of cardboard—through reuse and recycling. In addition, the contractor diverted large quantities of gypsum wallboard, site-clearing debris, concrete, and asphalt. For a recycling cost of only $19,000, the contractor avoided an estimated $166,000 in landfill costs. Rebates totaling $39,000 were received from third party vendors for the metal and cardboard. The resulting net savings from the project for the full recycling effort was approximately $186,000.

Construction

Application of green building concepts can yield for savings during the construction process. Measures that are relatively easy to implement can result in savings to the contractor in the following areas:

- Lower energy costs, by monitoring usage, installing energy-efficient lamps and fixtures, and using occupancy sensors to control lighting fixtures;
- Lower water costs, by monitoring consumption and reusing stormwater and/or construction wastewater where possible;
- Lower site-clearing costs, by minimizing site disruption and movement of earth and installation of artificial systems;
- Lower landfill dumping fees and associated hauling charges, through reuse and recycling of construction and demolition debris;
- Lower materials costs, with more careful purchase and reuse of resources and materials;
- Possible earnings from sales of reusable items removed during building demolition; and
- Fewer employee health problems resulting from poor indoor air quality.

This listing suggests some possible areas for cost savings; the project team can identify other possibilities through a cooperative and integrated team approach. The contractor can also improve relations with the community and building owner by viewing them as part of the team effort to implement environmentally sound construction measures. See Part V of this manual for more detailed information and discussion of environmental construction guidelines.

Building Operations and Maintenance

The green building measures discussed in this manual can lead not only to lower building operating expenses through reduced utility and waste disposal costs, but also to lower on-going building maintenance costs, ranging from salaries to supplies. For example, in many buildings, maintenance staff collect recycled materials on each floor—or even at every employee's desk—and carry the materials down to the basement for hand sorting. Recycling chutes, a viable green alternative, allow direct discarding of materials from any floor in the building to the basement. The chute system, which ideally is installed during initial construction or renovation, can sort materials automatically, saving labor costs by eliminating the need to collect, transport, and sort recyclables. Other savings come in the form of lower waste hauling fees; reduced workers' compensation insurance premiums due to lower claims for accidents from sharp glass and cans; reduced elevator maintenance; less frequent cleaning of spills on carpets and floors; and less need for pest control.

OPERATIONS AND MAINTENANCE SAVINGS

One private waste handling company has estimated that a typical 20-floor building can realize estimated annual labor savings of $27,209 for handling recyclables with a chute system, as opposed to floor-by-floor recycling. The potential annual savings from reduced hauling is $4,800. Together, the reductions add up to a total annual savings of $32,009. The savings are offset by the installation cost of the chute system, totaling $24,000, resulting in an initial increase in net cash flow for the building owner or manager of $8,000.[13]

Environmentally friendly housekeeping products can also have financial advantages. For example, cleaning products that are purchased as concentrates and use minimal packaging not only promote waste reduction, but also can reduce product usage by 30 to 60 percent with dispensers that more accurately measure and dilute the cleaning products for optimum effectiveness.[14]

Building owners need to view the building manager and staff as vital participants in environmentally sound and cost-effective operations. Building managers, charged with the efficient operation and maintenance of multi-million-dollar assets, have experience in all areas of operations and maintenance over the life of a building. Once a building is operational, training of management and maintenance staff—including education on effective green building measures such as building energy management systems, new cleaning products, and new building codes and standards—can help them to maintain the building in a resource-efficient and economically favorable manner.

Insurance and Liability

The past decades' conventional office design, construction, and operational practices have decreased the quality of the indoor office environment, resulting in new health concerns and associated economic costs and liability. The introduction of a multitude of new contaminant pollution sources into the workplace, combined with tighter building construction, has intensified air-quality problems. For example, poor indoor air quality can result from such factors as faulty air-conditioning systems, occupant-related pollutants, construction materials that emit high levels of volatile organic compounds, and poor maintenance practices. The U.S. EPA ranks indoor air pollution among the top five environmental risks to public health. Unhealthy indoor air is found in up to 30 percent of new and renovated buildings.[15]

Sick Building Syndrome (SBS) and Building Related Illness (BRI) have become more common in the workplace, increasing building owner and employer costs due to sickness, absenteeism, and increased liability claims. It has been estimated that SBS and BRI cost roughly $60 billion each year in medical expenses and lost worker productivity in the United States.[16]

Legal actions related to Sick Building Syndrome and other building-related problems have increased. These actions against building designers, owners, or employers may be initiated by occupants who have short- or long-term problems, ranging from headaches and burning eyes to more serious ailments. Initial economic impact may come in the forms of higher health insurance premiums, increased workers' compensation claims, and decreased productivity. Expensive remediation projects and environmental cleanups may follow, and building owners may try to recover losses from the original project contractors and architects through litigation.

CASE IN LIABILITY

One liability case, settled in 1995, involved a suit between Polk County, Florida, and the insurance company of the builders of the county's eight-year-old courthouse. The court awarded the county nearly $26 million to correct design and construction flaws that resulted in a high level of mold growth and caused occupant illnesses.

In DuPage County, Illinois, the court found the county responsible for health-related complaints at its new courthouse due to improper operations and maintenance procedures. At another courthouse complex, in Martin County, Florida, a $10 million renovation to mitigate the growth of health-threatening fungi responsible for previous building evacuations has been unsuccessful.[17]

By ensuring better indoor air quality, building owners, employers, and design professionals can lower their risk of future litigation by building occupants. Professional liability insurance companies have indicated a willingness to offer design professionals lower insurance premiums for higher operating-procedure standards that lead to improved indoor air quality.[18] Some national architectural firms are attempting to rate building products according to the levels of volatile organic compounds they emit after installation, and to educate building owners and managers about healthier product choices.

Occupant Health and Productivity

The purpose of a building is not only to provide shelter for its occupants, but also to provide an environment conducive to high performance of all intended occupant activities. Recent studies have shown that buildings with good overall environmental quality, including effective ventilation, natural or proper levels of lighting, indoor air quality, and good acoustics, can increase worker productivity by six to 16 percent.[19]

An organization's most significant financial commitment is usually to its employees. Many employers spend at least as much on salary-related expenditures as they do on constructing an entire company building. In many organizations, salaries and associated benefits consume the majority of the annual operating budget.[20] For example, based on the sample calculations in *Figure 2,* a typical employer could spend $233 per square foot annually for an employee. Building construction costs generally fall below this level, often by 50 percent. In addition, annual employee salary-related expenditures, using the numbers in *Figure 2,* are approximately 130 times greater than energy costs. A productivity increase of six percent equates to savings to the employer of $14 per square foot—eight times the cost of the building's annual energy bill.

Given this information, an employer can decide to maximize the performance and efficiency of personnel resources through assessment of, and improvement to, the indoor environmental quality of its building. The following account of a recent renovation project illustrates this approach.

RENO POST OFFICE

Reno, Nevada

In the renovation of a U.S. Post Office in Reno, Nevada, the structure, a modern warehouse with high ceilings, was redesigned with a new ceiling sloped to enhance indirect lighting and improve acoustics. The original, harsh direct downlighting was replaced with softer, more efficient, and longer-lasting lamps. The total renovation cost was $300,000. The associated annual energy savings totaled $22,400, and the projected maintenance savings, $30,000, for a combined savings of $52,400, which equated to a six-year payback. What the Post Office also discovered was that the renovation measures, which resulted in better lighting and acoustics, led to a productivity increase of more than six percent. Productivity savings alone were worth $400,000 annually, returning the entire renovation cost within the first year.[21]

Both building owners and building tenant/employers can benefit in other ways by improving indoor environmental quality. For owners, these improvements can result in higher property values (see "Building Value" section below), longer tenant occupancy and lease renewals, reduced insurance and operating costs, reduced liability risks, extended equipment life, and good publicity. For tenants, benefits include reduced absenteeism and better employee morale, reduced insurance and operating costs, reduced liability risks, and community recognition.[22]

If the building owner is also the employer, an organization can offset initial construction design and systems costs with the reduction of long-term organizational and operational expenses over the building's life cycle.

PRODUCTIVITY SAVINGS

for a Typical 100,000 sq. ft. Office Building

Utility Costs	
Annual Utility Cost per Square Foot	$1.80
Total Annual Utility Cost	$180,000
Personnel Costs	
Average Employee Salary + Benefits	$35,000
Average Employee Space per Square Foot	150
Estimated Number of Building Occupants	667
Annual Average Personnel Cost per Square Foot	$233
Total Annual Building Personnel Cost	$23,345,000
Savings	
Value of 6% Productivity Increase per Square Foot	$14
Ratio of Productivity Increase to Energy Cost	8 times

Source: Example from David Gottfried, "Economics of Green Buildings," Presentation to OG&E Electric Services, October 1995.

Figure 2

Building Value

Green buildings' high efficiency and performance can result in higher property values and potentially lower lenders' credit risk. Lower operating costs associated with more efficient systems can lead to higher building net income.

In *Figure 3* the value of a 100,000-square-foot office building increases by over $1 million through implementation of green building measures. These measures, associated with energy, water, waste, and labor, result in annual operating savings of $101,400. The increased building value is calculated by using a fairly conservative building market capitalization rate—a formula used by building appraisers, brokers, and lenders to calculate a building's value—of 10 percent on the savings. As illustrated in *Figure 3,* a building's value is derived by dividing its net operating income, or savings, by the market capitalization rate.

In addition to increasing a building's net operating income or value, green building measures may allow building owners to charge higher rents or achieve higher rates of building occupancy, if tenants view green properties as more desirable. Currently, voluntary building rating programs are under development for commercial buildings in the United States (see Chapter 25, "The Future of Green Building"). As these programs are introduced into the marketplace and gain the acceptance of building owners and tenants, they could impact the value of properties. Prospective tenants will be able to rate buildings based on such measurable features as natural daylight, better indoor air quality, and lower energy, water, and waste costs. If enough buildings are rated for environmental performance, those that perform better will start to realize market advantages.

Figure 3

INCREASED VALUATION

of a Typical 100,000 sq. ft. Office Building

1. Energy Retrofit Savings (50%)	$90,000
2. Water Savings (30%)	$4,400
3. Waste + Labor Savings (e.g., chute system)	$7,000
4. Total Annual Operating Savings	$101,400
5. Market Capitalization Rate	10%
6. Increase in Building Value (divide 4 by 5)	$1,014,000

Source: Information based on discussion with CB Commercial, a commercial real estate brokerage firm.

MT. AIRY PUBLIC LIBRARY

Mt. Airy, North Carolina

Mt. Airy, North Carolina, has incorporated extensive daylighting into the passive solar design of its 13,000-square-foot public library, built in 1982. This design strategy helps to meet the town commissioners' goal of a 70 percent reduction in annual electricity consumption. The daylighting strategy admits glare-free, diffuse light to all corners of the library without damaging the books with direct illumination. It is combined with efficient lighting systems, where needed, and other features that conserve energy used for heating and cooling. Lighting energy use, usually a large portion of a library's total energy consumption, is now only one-eighth of the entire building's total energy usage. Not surprisingly, utility bills have been very low. The building's attractive design has drawn positive reactions from employees and visitors, and made the facility a town centerpiece. Visitation rates at the library are more than twice what was originally anticipated, and operating hours have been extended to accommodate users of this multipurpose cultural center.[23]

Local Economic Development Opportunities

Promotion and implementation of green building practices within a community can generate new economic development opportunities. These opportunities can take a variety of forms, including new business development to meet the demand for green products and services; resource-efficiency improvement programs that enable existing businesses to lower operating costs; development of environmentally oriented business districts; and job training related to new green businesses and products.

In Austin, Texas, the long-term existence of the city's Green Builder Program has contributed to the growth of green building trades, including, for example, companies to meet the demand for rainwater-harvesting systems and services. The city has also begun working with a non-profit organization to offer at-risk youths an opportunity to learn job skills while they build affordable green homes. On a national level, the EPA cites the potential creation of over 200,000 jobs through aggressive implementation of its Green Lights retrofit program.

In other communities, entrepreneurs have developed businesses to recycle usable building components. In Baltimore, Maryland, for example, one non-profit company redistributes over $1 million worth of building supplies a year. These materials, diverted from landfills and received as donations from construction-related businesses, are provided to non-profit organizations and low-income clients at about one-third of their retail price. A Berkeley, California, for-profit business has salvaged furniture, household goods, office equipment, and building materials for resale for over a decade. These materials are retrieved from the waste stream or donated by local residents, businesses, and construction sites. The company handles about 5,000 tons of material each year.

In Denver, Colorado, plans are underway to reuse Stapleton International Airport as a center for environmentally oriented businesses, as well as a site for training opportunities in environmental fields. San Jose, California, through its Green Industry Program, has created two Green Industry Districts, which will provide incentives such as loans and tax benefits to attract more recycled-product manufacturers and green industries. And in Portland, Oregon, the city's Businesses for an Environmentally Sustainable Tomorrow (BEST) program uses incentives and education to encourage businesses to realize the economic benefits of energy efficiency, water conservation, waste reduction or recycling, and efficient transportation practices.

Local governments facing rising building and operational costs may find that adoption of green building practices can slash public expenditures for energy, water, and waste processing. In Montgomery County, Maryland, for example, carefully crafted Energy Design Guidelines aim to reduce energy consumption in new government buildings by

40 to 50 percent, without increases in initial construction costs. These savings can help to balance budgets and offset budgetary cuts in critical areas such as education and public safety.

These examples are only a snapshot of the growing appeal of sustainable development. Local governments and businesses across the country are starting to find that green business practices, as well as the use of green building products, can result in short- and long-term economic and environmental advantages for their communities and the wider global marketplace.

NOTES

1 Civil Engineering Research Foundation. *Innovation in the U.S. Construction Industry: An Essential Component for American's Economic Prosperity and Well-being* (Washington, D.C.: Civil Engineering Research Foundation, April 28, 1994), 36.

2 National Science and Technology Council, Civilian Industrial Technology Committee, Subcommittee on Construction and Building, *Rationale and Preliminary Plan for Federal Research for Construction and Building* (Washington, D.C.: National Science and Technology Council, September 1994), 1.

3 Joseph J. Romm, *Lean and Clean Management* (Kodansha International, 1994), 94.

4 David Rodman and Nicholas Lenssen, "A Building Revolution: How Ecology and Health Concerns Are Transforming Construction," *Worldwatch Paper 124* (March 1995), 41.

5 Ibid., 39.

6 Green Lights Program literature (Washington, D.C.: U.S. EPA, December 1993).

7 Based on conversations with Richard Bennett, East Bay SMUD; Jane Ploeser, city of Phoenix; and Louis Generoso, city of San Diego (November 3, 1995).

8 American Water Works Association, *Conservation Incentive Levels and Two Pilot Programs* (Denver, Colo.: AWWA, 1995), 116

9 Al Gore, *Earth in the Balance* (Boston, Mass.: Houghton Mifflin Co., 1992), 151.

10 Rodman and Lenssen, 23.

11 Turner Construction Company case study. Information provided by Ian Campbell, Sustainability Director, 206/224-4218.

12 Audubon House, *National Audubon Society and Croxton Collaborative* (John Wiley & Sons, 1994), 134.

13 Information provided by Hi-Rise Recycling Systems, Miami, Florida 305/624-9222.

14 Rochester Midland, Product Information Sheet, Form 550-A (August 1993), 2.

15 Barbara Lippiatt and Gregory Norris, "Selecting Environmentally and Economically Balanced Building Materials" *National Institute of Standards and Technology Special Publication 888*, Second International Green Building Conference and Exposition— 1995 (Gaithersburg, Md.: NIST, 1995), 37.

16 Lippiatt and Norris, 38.

17 *Envirosense Newsletter*, 4, no. 2 (1995): 1-3.

18 Information based on telephone conversation with Brian Lynch, DPIC Insurance (November 3, 1995).

19 Romm, 102.

20 Romm, 94.

21 Romm, 92.

22 *You May Be Spending 30% of Your Life in a "Sick Building"* (New York: Healthy Properties Inc.), 2.

23 Nancy Reece, *Savings from the Sun: Passive Solar Design for Institutional Buildings* (Boulder, Colo.: American Solar Energy Society, June 1990), 3-4.

CHAPTER 2

Selecting Environmentally and Economically Balanced Building Materials

Authors
Barbara C. Lippiatt and Gregory A. Norris

Introduction

Buildings significantly alter the environment. According to Worldwatch Institute[1], building construction consumes 40 percent of the raw stone, gravel, and sand used globally each year, and 25 percent of the virgin wood. Buildings also account for 40 percent of the energy and 16 percent of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Finally, unhealthy indoor air is found in 30 percent of new and renovated buildings worldwide.

Negative environmental impacts flow from these activities. For example, raw materials extraction can lead to resource depletion and biological diversity losses. Building materials manufacture and transport consumes energy, which generates emissions linked to global warming and acid rain. Landfill problems, such as leaching of heavy metals, may arise from waste generation. All these activities can lead to air and water pollution. Unhealthy indoor air may cause increased morbidity and mortality.

Selecting environmentally preferable building materials is one way to improve a building's environmental performance. To be practical, however, environmental performance must be balanced against economic performance. Even the most environmentally conscious building designer or building materials manufacturer will ultimately want to weigh environmental benefits against economic costs. They want to identify building materials that improve environmental performance with little or no increase in cost.

The National Institute of Standards and Technology (NIST) is teamed with the U.S. Environmental Protection Agency's (EPA) National Risk Management Research Laboratory, Air Pollution Prevention Control Division, to develop by 1997 a standardized methodology and publicly available database for balancing the environmental and economic performance of building materials. EPA is developing a database of environmental performance data, and with EPA support, NIST is developing the methodology and implementing it in decision-support software for building designers and materials manufacturers. NIST is adding economic performance data to the database. The decision-support software will access the database of environmental and economic performance data. The combined software and database product will be known as BEES (Building for Environmental and Economic Sustainability).

Measuring Environmental Performance

Environmental performance is measured using an evolving, multidisciplinary tool known as life-cycle assessment (LCA). LCA is a "cradle-to-grave" systems approach for understanding the environmental consequences of technology choices. The concept is based on the belief that all stages in the life of a material generate environmental impacts and must therefore be analyzed, including raw materials extraction and processing, intermediate materials manufacture, material manufacture, installation, operation and maintenance, and ultimately recycling and waste management. An analysis that excludes any of these stages is limited because it ignores the full range of upstream and downstream impacts of stage-specific processes.

The general LCA methodology is as follows. LCA begins with goal identification and scoping (defining boundaries). What is the purpose of the LCA? What decision is the LCA meant to support? Where are environmental impact boundaries to be drawn—secondary environmental impacts, tertiary impacts? Do we include all environmental impacts, or only a pre-defined subset of impacts?

After goal identification and scoping, the four-step LCA analytic procedure begins. The inventory analysis step identifies and quantifies the environmental inputs and outputs associated with a material over its entire life cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. The impact assessment step characterizes these inputs and outputs in relation to a comprehensive set of environmental impacts. For example, the impact assessment step might relate carbon dioxide (CO_2) emissions to global warming.

The third step, impact valuation, synthesizes the environmental impacts by combining them with stakeholder values. For example, assume there are only two environmental impacts, stratospheric ozone depletion and global warming. The impact valuation step might combine quantitative measures of ozone depletion and global warming into a single measure of overall environmental impact by normalizing the quantitative measures and weighting each impact by its relative importance. (Note that while LCA practitioners generally agree on the nature of impact valuation, not all treat it as a separate LCA step. Some include it as part of impact assessment, while others include it as part of improvement assessment.)

The improvement assessment step identifies and evaluates opportunities for making changes in the product life cycle which improve its cradle-to-grave environmental performance. Depending on the goal of the LCA, the improvement step may be omitted. For example, if the goal of the LCA is to select the most environmentally preferable from among three building materials, the improvement step is unnecessary.

NIST is applying the LCA methodology to building materials. In so doing, NIST is adding explicit guidance to the LCA impact assessment and valuation steps. The guidance consists of the following three principles:

1) Avoid false precision.

There is some uncertainty associated with the data used at each LCA step, which influences the precision of the final results. It is important to document the precision with which conclusions can be drawn about the environmental performance of building materials. For example, if at the inventory analysis step, sulfur dioxide emissions are estimated within a range of plus or minus five percent, then an overall environmental impact score cannot be derived with 100 percent certainty. The NIST methodology avoids false precision by collecting uncertainty data at each LCA step and propagating (accounting for) uncertainty throughout the LCA. The final environmental impact score will thus be bounded by an uncertainty range.

2) Address scale of impact.

The LCA impact assessment step characterizes the inventory items in relation to environmental impacts. This step will also relate the flows (to or from the environment) occurring during the life cycle of a building material to the total flows occurring at scales such as the U.S. as a whole. For example, the NIST methodology will relate the chlorofluorocarbon (CFC) emissions associated with vinyl siding's life cycle to the total CFC emissions from the U.S., and will use this information in deriving the final environmental performance score for vinyl siding.

3) Minimize assumptions and uncertainty.

Each LCA step introduces additional assumptions and uncertainty. The NIST methodology minimizes these by checking data after each LCA step to see if one building material alternative shows dominance or near dominance. Dominance is shown when one alternative performs best on all criteria.

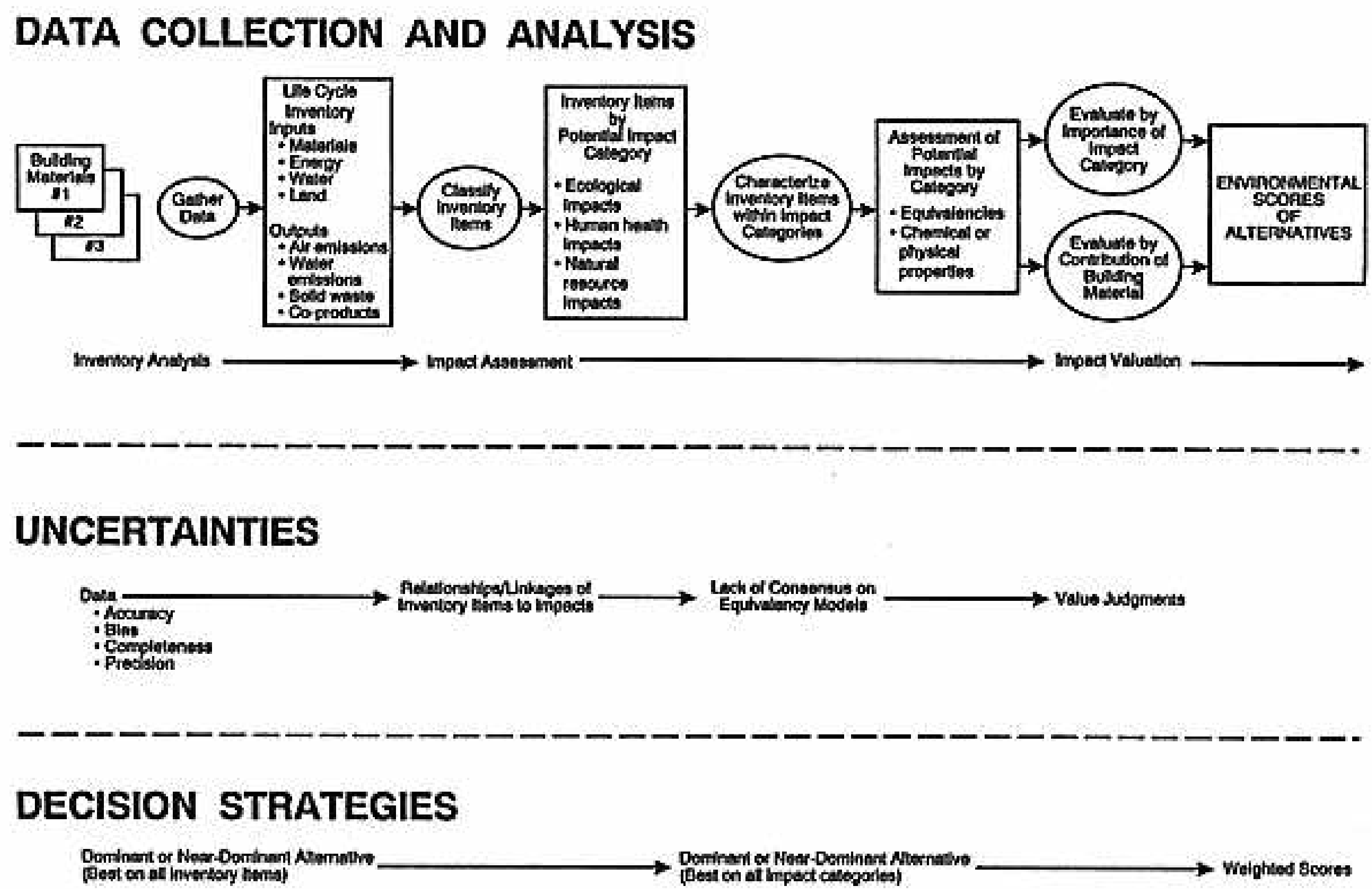
These three principles are implemented in the NIST LCA methodology for measuring the environmental performance of building materials, depicted in *Figure 1*. The goal is to assist material selection decisions by assigning relative environmental scores to a set of building material alternatives. To the extent possible, all environmental impacts will be included. The first step is inventory analysis. Environmental input and output data will be gathered for all building material alternatives on a per functional-unit basis, complete with uncertainty ranges. In the (unlikely) event that one alternative performs best or nearly best with respect to all inventory items, that alternative will be flagged as the dominant or nearly dominant alternative. Note that large uncertainty ranges do not preclude dominance as long as there is no overlap among alternatives.

The next step is impact assessment. First, inventory items are classified by impact category. Then inventory items are characterized within impact categories. For many of the impact categories, published "equivalency factors" are available to normalize the inventory items in terms of strength of contribution[2]. For example, equivalency factors have been developed for each of the major "greenhouse gases." These factors indicate the relative "global warming potential" of each greenhouse gas, taking into account the different strengths of radiative forcing as well as differences in atmospheric lifetimes[3]. The global warming potential equivalency factors will be used to convert all greenhouse gas inventory data (reported as tons of a given greenhouse gas emitted per functional unit of a particular building material—for example, tons emitted per square meter (square yard) of carpet) into "CO_2-equivalents" (reported as tons of CO_2 per functional unit). Following this conversion, all inventory data in the "global warming" impact category can be summed to arrive at a scalar total (tons of CO_2-equivalents) to allow direct numerical comparison among building materials.

Equivalency factors are subject to some uncertainty based on the strength of the underlying science. The NIST methodology will attempt to reflect the literature's assessment of this uncertainty by using intervals (ranges) rather than scalar numbers for the equivalency factors. Arithmetic operations on intervals are well-established[4] and will be used in the NIST methodology as a basic means for propagating uncertainty throughout the LCA.

For some impact categories and inventory items, equivalency factors have not been published, so there is no clear basis for normalizing and summing the inventory data within an impact category. In such instances the NIST methodology will allow the user to check for dominance or near dominance of one material alternative over the others. A flexible heuristic method will be available for assigning a summary score to the dominant and

MEASURING THE ENVIRONMENTAL PERFORMANCE OF BUILDING MATERIALS



Source: The Scientific Consulting Group, Inc.

Figure 1

non-dominant alternatives within all such impact categories, but the software will also flag these impact category results to indicate that the relative scores are not based on peer-reviewed, scientific methods for normalizing the inventory data in terms of strength of impact within the impact categories.

The third step in the LCA is impact valuation. At this step, impact assessment results will be normalized and synthesized into an overall environmental score for each material alternative. Multiattribute decision analysis (MADA) techniques are useful here[5]. MADA techniques apply to problems where the decision-maker is choosing or ranking a finite number of alternatives (building materials) which differ by two or more relevant attributes (environmental impacts). The attributes in a MADA problem will generally not all be measurable in the same units, and some may be either impractical, impossible, or too costly to measure at all (as is the case with some environmental impacts). Most MADA methods require the decision-maker to assign different levels of importance to the different attributes of the problem.

MADA techniques will be used to arrive at overall, relative environmental scores for building material alternatives. The NIST/EPA team plans to conduct workshops in 1996 to collect sets of MADA importance weights for environmental impacts from several stakeholder perspectives (e.g., policymaker, environmentalist, and building industry perspectives), with input from environmental scientists and others. The decision maker may then select that set of importance weights most appropriate for the decision at hand, and may also test the sensitivity of the environmental scores to the different stakeholder perspectives.

The LCA is complete after the impact valuation step. Impact valuation yields environmental scores, which are the goal of this LCA application, so the improvement assessment step is unnecessary.

Measuring Economic Performance

Measuring the economic performance of building materials is more straightforward than measuring environmental performance. Standardized methodologies and quantitative, published data are readily available.

The American Society for Testing and Materials (ASTM) Subcommittee E06.81 on Building Economics has published a compilation of standards for evaluating the economic performance of investments in buildings[6]. The single standard most appropriate for evaluating the economic performance of building materials for subsequent comparison with environmental performance is ASTM E 917-93, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*[7]. The life-cycle-cost (LCC) method sums over a given study period the costs of an investment. The sum is expressed in either present value or annual value terms. Alternative building materials for a given functional requirement, say flooring, can thus be compared on the basis of their LCCs to determine which is the least-cost means of providing flooring over that study period.

The LCC method includes the costs over a given study period of initial investment (less resale or salvage value), replacements, operations, maintenance and repair, and disposal. It is essential to use the same study period for each alternative whose LCCs are to be compared, even if they have different useful lives. The appropriate study period varies according to the stakeholder perspective. For example, a homeowner would select a study period based on the length of time he or she expects to live in the house, whereas a long-term owner/occupant of an office building might select a study period based on the life of the building.

It is important to distinguish between the life cycles underlying the LCA method (used to measure environmental performance), and the LCC method (used to measure economic performance). LCA uses an environmental life-cycle concept, whereas LCC uses a building life-cycle concept. These are different. The environmental life cycle of a building material begins with raw materials extraction and ends with recycling, reuse, or disposal of the material. The building life cycle of a building material begins with its installation in the building and lasts for the duration of the LCC study period, which is determined in part by the useful life of the material and in part by the time horizon of the investor. While there is overlap between these two life cycles once the material is installed in the building, it is important not to confuse the two. The reason why LCC uses a building life cycle rather than an environmental life cycle is because out-of-pocket costs to the investor are borne over this time frame. It is these costs to the investor upon which financial decisions are made.

The LCC for a building material is computed by discounting all costs occurring over the study period to the present and then summing. The discount rate converts future costs to their equivalent present values and accounts for the time value of money. Discount rate values to be used in federal projects are legislated by the Office of Management and Budget; these values apply to analyses of private-sector projects as well.

BALANCING ENVIRONMENTAL AND ECONOMIC PERFORMANCE

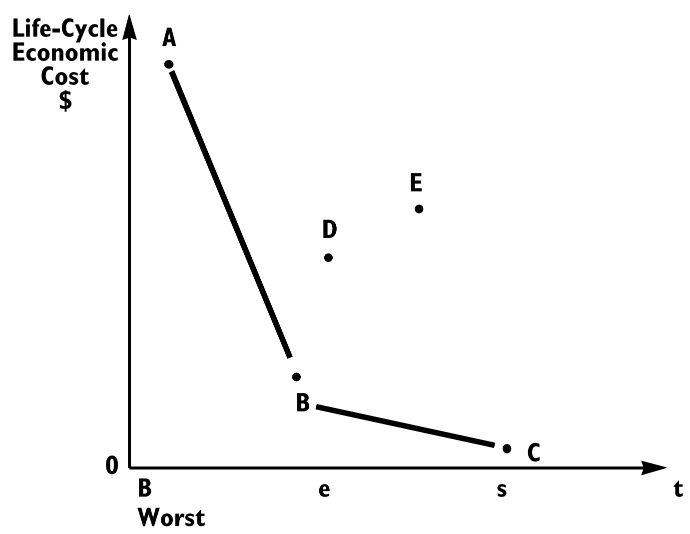


Figure 2

Balancing Environmental and Economic Performance

Figure 2 displays how environmental and economic performance are balanced. Suppose a building designer is choosing from among five alternative flooring materials and that each point in *Figure 2* represents one material's environmental/economic performance balance. The designer will first rule out Alternatives D and E because they are dominated by at least one other alternative; that is, they perform worse than another alternative (Alternative B) with respect to both the environment and economics. Of the remaining alternatives, Alternative A costs the most, but offers the best environmental performance. Alternative C offers the best economic performance and the worst environmental performance. Alternative B improves environmental performance (relative to C) at little increase in cost. The designer can now make an informed decision. He or she will select from among Alternatives A, B, and C that which best reflects the relative importance he or she gives to environmental versus economic performance.

Decision-Support Software Features

Decision-support software is being developed by NIST to implement the methodology described above for balancing the environmental and economic performance of building materials. The software will use as input the database of environmental and economic performance data. Together the software and database are known as BEES. BEES will be available over the Internet, which will offer instantaneous access to the tool as well as instant dissemination of data refinements. Data refinements are expected over time as the state of the art of environmental assessment advances, new building materials arrive on the scene, and the costs of building materials change.

BEES will accommodate different levels of user expertise. It will include built-in, "default" data so that users unfamiliar with LCA may readily make and defend building material selections. Note, however, that BEES will not include default values for the relative importance of environmental and economic performance. Rather, BEES will display, as in *Figure 2,* the environmental/economic tradeoffs offered by the decision alternatives. It will remain up to the user to select the alternative that best reflects his or her viewpoint.

The more experienced user will be able to customize the default data. For example, a materials manufacturer will be able to enter proprietary data on its products. Other data, such as relative importance weights for environmental impacts and the discount rate for LCC computation, will also be editable. These users will thus be able to do "what if" analyses to examine how changing the data affects the environmental/economic performance balance.

Finally, BEES will follow the data transparency principle of the LCA methodology by documenting data used and assumptions made at every LCA stage.

Summary

The building community is making decisions today that have environmental and economic consequences. Its decisions are plagued by incomplete and uncertain data as well as the lack of a standardized methodology for evaluating the data. The NIST/EPA team seeks to support these decisions by gathering environmental and economic performance data and by structuring and computerizing the decision-making process. The resulting BEES tool will be publicly available over the Internet.

NOTES

1 D. M. Roodman and N. Lenssen, "A Building Revolution: How Ecology and Health Concerns are Transforming Construction," *Worldwatch Paper* 124 (Washington, D.C.: Worldwatch Institute, March 1995).

2 K. A. Weitz and J. L. Warren, *Life-Cycle Impact Assessment: A Conceptual Framework, Key Issues, and Summary of Existing Methods* (Research Triangle Park, N.C.: U.S. EPA, Office of Air Quality Planning and Standards, June 1995).

3 Intergovernmental Panel on Climate Change, *Climate Change: The 1990 and 1992 IPCC Assessments* (Geneva, Switzerland: World Meteorological Organization and United Nations Environment Program, 1992).

4 R. E. Moore, *Methods and Applications of Interval Analysis* (Philadelphia: SIAM Press, 1979).

5 G. A. Norris and H. E. Marshall, *Multiattribute Decision Analysis: Recommended Method for Evaluating Buildings and Building Systems*, NISTIR 5663 (Gaithersburg, Md.: National Institute of Standards and Technology, July 1995).

6 American Society for Testing and Materials, *ASTM Standards on Building Economics*, 3d ed. (Philadelphia, 1994).

7 American Society for Testing and Materials, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, ASTM Designation E 917-93 (Philadelphia, March 1993).

ACKNOWLEDGMENTS

The environmental performance methodology described herein has benefited greatly from the input of the EPA arm of the NIST/EPA team: James White of the EPA National Risk Management Research Laboratory, and EPA contractors Joel Todd and Richard Pike of The Scientific Consulting Group, Inc., Hal Levin of Hal Levin & Associates, and Pliny Fisk of the Center for Maximum Potential Building Systems, Inc. The comments of the EPA team members and NIST reviewers Hunter Fanney, Harold Marshall, and Stephen Weber inspired many improvements.

Disclaimer: This paper originally appeared in *Second International Green Building Conference and Exposition– 1995,* NIST SP 888, A.H. Fanney, K.M. Whitter, and T.B. Cohn, eds. (Gaithersburg, MD: National Institute of Standards and Technology, 1995) 38-46. It cannot be copyrighted in the United States.

SELECTING ENVIRONMENTALLY AND ECONOMICALLY BALANCED BUILDING MATERIALS. Barbara C. Lippiatt, Economist. Gregory A. Norris, Environmental Engineer. Office of Applied Economics, Building and Fire Research Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899-0001

PART II

Pre-Design Issues

Introduction

The conventional process for a construction project involves the initial project conceptualization, followed by pre-design, design, bid, construction, and occupancy. An environmentally responsive design process adds the elements of integrated building design, design and construction team collaboration, and the development of environmental design guidelines. These new elements must be incorporated into the project from the very beginning and carried throughout the project phases to the final occupancy of the building.

Conventional buildings often fail to consider the interrelationship among building siting, design elements, energy and resource constraints, building systems, and building function. Green buildings, through an integrated design approach, take into consideration the effect these factors have on one another. Climate and building orientation, design factors such as daylighting opportunities, and building envelope and system choices, as well as economic guidelines and occupant activities, are all factors that need to be considered in an integrated approach.

A multidisciplinary design and construction team can develop a building's functional and operational design to meet environmental and financial goals. The multidisciplinary approach allows all team members—site planners, landscape architects, architects, engineers, contractors, interior designers, lighting designers, building owners, tenants, management companies, utilities, builders, and others—to share specialized expertise and coordinate their individual design efforts to achieve a well-functioning, integrated building.

Development of green building guidelines sets both general goals for the project and specific parameters for building design, products, systems, and siting. These guidelines help to shape the project as it moves through the project phases.

Chapters 3 and 4 provide information on the pre-design phase of the construction process—the critical stage that shapes the eventual design and development of a sustainable building.

CHAPTER 3

Pre-Design

Authors

Anthony Bernheim and William Reed

★ SIGNIFICANCE

An environmentally responsive design process, as outlined in *Figure 1,* follows the conventional process, with additional consideration given to sustainable design, materials, and systems. Activities which should occur in pre-design are discussed in this chapter; other parts of the manual discuss the activities that occur in the design, bid, construction, and occupancy phases of a building's development.

Because the pre-design stage is the first step in the building process, incorporating green building practices into the project at this juncture is critical. Decisions made during pre-design not only set the project direction, but also must prove cost-effective over the life of the project. Charting the course of the project at the very beginning by establishing green project goals, defining the process to achieve those goals, and developing a clear understanding of the expected results is vitally important. A clearly developed project framework guides the decision-making process throughout the project, incorporating issues related to site selection and design, the building design and its systems, the construction process, and building operations and maintenance.

Integrated building design is a cornerstone for developing sustainable buildings, which are efficiently combined systems of coordinated and environmentally sound products, systems, and design elements. Simply adding or overlaying systems will not result in optimal performance or cost savings. Rather, building designers can obtain the most effective results by designing various building systems and components as interdependent parts of the entire structure. This conceptual framework starts at the pre-design stage and is carried throughout design and construction to building completion and operation.

This integrated approach is well-illustrated in passive solar design strategies that combine siting, architectural, mechanical, and electrical features in a systemic manner that results in improved building function and increased occupant satisfaction. Incorporating increased daylighting into a building design, for example, will affect

ENVIRONMENTALLY RESPONSIVE DESIGN PROCESS

PRE-DESIGN
Develop Green Vision
Establish Project Goals and Green Design Criteria
Set Priorities
Develop Building Program
Establish Budget
Assemble Green Team
Develop Partnering Strategies
Develop Project Schedule
Review Laws and Standards
Conduct Research
Select Site

DESIGN
Schematic Design
Confirm Green Design Criteria
Develop Green Solutions
Test Green Solutions
Select Green Solutions
Check Cost

Design Development
Refine Green Solutions
Develop, Test, Select Green Systems
Check Cost

Construction Documents
Document Green Materials and Systems
Check Cost

BID
Clarify Green Solutions
Establish Cost
Sign Contract

CONSTRUCTION
Review Substitutions and Submittals for Green Products
Review Materials Test Data
Build Project
Commission the Systems
- Testing
- Operations and Maintenance Manuals
- Training

OCCUPANCY
Re-Commission the Systems
Perform Maintenance
Conduct Post-Occupancy Evaluation

Figure 1

PROJECT TEAM

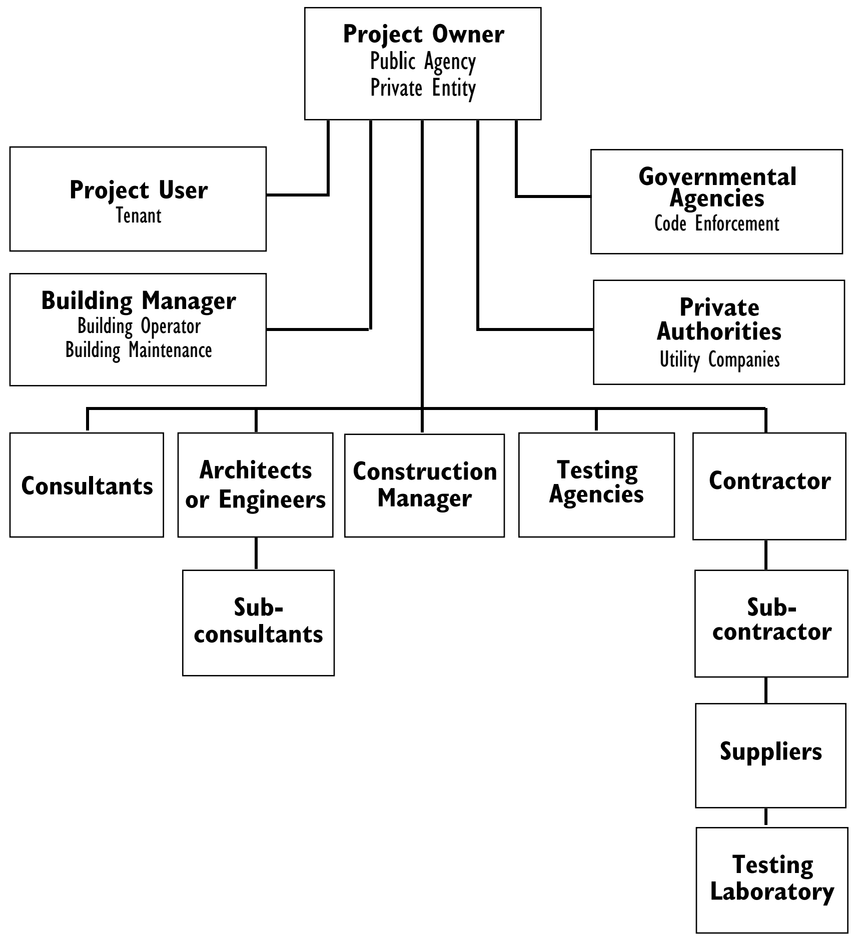


Figure 2

many other factors in the building. This strategy, which takes into account the building's orientation, as well as glazing choices and location, will permit reduction of artificial lighting. The resulting reductions in electricity use and internal heat loads will allow the downsizing of air-conditioning systems. As a result, overall energy usage and energy costs in the building are reduced, and the improved air quality and lighting conditions can result in increased productivity and health of occupants.

A team approach to design and construction is another important aspect of sustainable building that is established during the pre-design phase. This approach assures the development and implementation of an integrated building design. As illustrated in *Figure 2,* the team can comprise a wide variety of members—including the building owner, tenants, site planners, architects, engineers, contractors, local government agencies, management staff, and utility company representatives. For this approach to be successful, all parties on the design team must commit themselves to the sustainable goals of the project. Rather than working in isolation in their own areas of expertise, team members use a multidisciplinary approach in which the interrelated impacts of design, systems, and materials are recognized. Part of this process may involve education of team members to recognize the benefits of environmentally sound design or materials and to look beyond their own disciplines to conceptualize the integrated systems.

Environmental design guidelines, also an important component of green building development, direct the activities of the design team from the pre-design stage through all subsequent stages of the project. These guidelines may already exist as part of a building owner's operating policies, or may be developed for a particular construction project. If developed for a specific project, they can articulate principles that clarify the goals of the design team and rally support for the sustainable building concept from key parties such as the building owner, public officials, financiers, and the general community. The guidelines may initially state an overriding philosophy or vision, develop more defined goals in each area, and then relate specific objectives and priorities to a specific project. *Figure 3* outlines some of the green building issues—including those related to energy efficiency and renewable energy, direct and indirect environmental impact, indoor environmental quality, resource conservation and recycling, and community issues—to be considered when developing project guidelines.

These aspects of sustainable design, along with other activities that occur in the pre-design phase, including programming, budget analysis, and site selection, set the stage for successful construction of a green building.

☞ SUGGESTED PRACTICES AND CHECKLIST

Environmental Design Guidelines

❑ **Establish a vision statement that embraces sustainable principles and an integrated design approach.**
The project team, along with the client, should clearly define and articulate a vision statement that will support and enforce sustainable goals throughout the project.

❑ **Establish the project's green building goals, developed from the vision statement.**
The project goals should emanate from the needs and values of the client. The goals need not be specific, but should be broad statements of environmentally based ideas that can be further developed and integrated by the project team. They may include such issues as energy efficiency, indoor and outdoor environmental quality, waste minimization, and general princi-

TYPICAL GREEN BUILDING GUIDELINE ISSUES

■ **Energy efficiency and renewable energy**
- Building orientation to take advantage of solar access, shading, and natural lighting
- Effects of micro-climate on building
- Thermal efficiency of building envelope and fenestration
- Properly sized and efficient heating, ventilating, and air-conditioning (HVAC) system
- Alternative energy sources
- Minimization of electric loads from lighting, appliances, and equipment
- Utility incentives to offset costs

■ **Direct and indirect environmental impact**
- Integrity of site and vegetation during construction
- Use of integrated pest management
- Use of native plants for landscaping
- Minimization of disturbance to the watershed and additional non-point-source pollution
- Effect of materials choice on resource depletion and air and water pollution
- Use of indigenous building materials
- Amount of energy used to produce building materials

■ **Resource conservation and recycling**
- Use of recyclable products and those with recycled material content
- Reuse of building components, equipment, and furnishings
- Minimization of construction waste and demolition debris through reuse and recycling
- Easy access to recycling facilities for building occupants
- Minimization of sanitary waste through reuse of graywater and water-saving devices
- Use of rainwater for irrigation
- Water conservation in building operations
- Use of alternative wastewater treatment methods

■ **Indoor environmental quality**
- Volatile organic compound content of building materials
- Minimization of opportunity for microbial growth
- Adequate fresh air supply
- Chemical content and volatility of maintenance and cleaning materials
- Minimization of business-machine and occupant pollution sources
- Adequate acoustic control
- Access to daylight and public amenities

■ **Community issues**
- Access to site by mass transit and pedestrian or bicycle paths
- Attention to culture and history of community
- Climatic characteristics as they affect design of building or building materials
- Local incentives, policies, regulations that promote green design
- Infrastructure in community to handle demolition-waste recycling
- Regional availability of environmental products and expertise

Figure 3

BERKELEY UNIFIED SCHOOL DISTRICT

Berkeley, California

In 1994, the Berkeley Unified School District in Berkeley, California, enacted environmental policies that established green building goals. The school district's Materials/Indoor Air Quality Policy states:

It is the intent of the Berkeley Unified School District Facilities Program to minimize building occupants' exposure to uncomfortable and potentially harmful interior environments. This effort starts with design and construction of new and renovated facilities, and continues through the life of the facility with maintenance practices.[1]

The Energy Design Standard Policy states:

The building energy design standards policy of the Berkeley Unified School District seeks to achieve three broad goals. These are:

1) To provide a high quality indoor environment with respect to thermal comfort, lighting, and ventilation, for student, faculty, and staff.
2) To reduce energy consumption and maintenance costs of the District on an ongoing basis.
3) To improve energy conservation awareness and education of students, faculty, and staff.[2]

Both policies provide additional specific green design criteria. The Materials/Indoor Air Quality Policy deals with site layout and landscape, building materials, finishes and furnishings, building systems, and construction practices. The Energy Design Standard Policy establishes specific energy performance criteria and objectives as follows:

1) Improve district-wide energy use/square foot by 40 percent before the year 2000.
2) New and substantially renovated buildings shall exceed State Energy Code (Title 24) standards by a minimum of 35 percent.
3) Buildings which are retrofitted for energy conservation shall, as a minimum, meet the applicable provisions of the State Energy Code even where not required by law.[3]

ples of sustainability. In some instances, clients, such as governmental agencies and private organizations, may already have an environmental policy that informs and supports the project goals.

❑ **Establish green design criteria.**
The design criteria, which are more specific than the goals, should begin to clarify the most important and relevant aspects of the project. For example, they may include a certain level of improvement in energy efficiency over conventional usage, indicate a percentage of renewable energy strategies and equipment to be used in the project, stipulate requirements for sensitive site design, provide guidelines for indoor environmental quality, and indicate levels of resource conservation and recycling. In addition, they may indicate that life-cycle assessment be used to analyze the direct and indirect environmental impacts of building-material selection, and that broad community-related environmental issues, such as preservation of existing green spaces or reuse of historic structures, be addressed.

❑ **Set priorities for the project design criteria.**

– Prioritize design options based on environmental guidelines and project constraints. Priorities should flow from the vision statement, the goals, and the design criteria, and should support of the project's environmental policy. The design team, may, for example, decide that energy efficiency, indoor air quality, or several combined criteria are the main priorities for a project. Design criteria need to be prioritized in the context of the project's budget and scheduling constraints. The realities of these constraints may allow some design criteria to be included, but exclude others deemed less important by the team, or less achievable with current technology. It is also possible that the project design could be flexible enough to allow incorporation of additional criteria at a later, more practical date. Setting priorities will provide the critical direction needed by the design team in making project decisions related to design, products, and systems.
– Seek to incorporate additional green measures through this process. Prioritizing criteria also may allow the design team to justify additional green measures for the project, by using the projected financial savings of one priority, such as energy conservation, to balance the costs of other green measures. Green building materials, for example, though environmentally significant, may not have the same direct financial payback as energy savings and may have higher up front costs than conventional products. Total project costs can remain reasonable, however, if savings from the energy-efficiency measures can offset the costs of other features.

Building Program

❑ **Develop a building program detailing the project's green building requirements.**
A building program develops a clear statement of the building owner's or client's expectations for the building—and the function of the entire building and its various rooms and related structures—within the budget, schedule, and physical constraints of

the project. The building program should include both a general and a room-by-room description of the project. The project's environmental vision and goals and its design criteria and priorities should also be included in the building program. More specifically, the program should state include the criteria for energy efficiency and renewable energy, indoor air quality, materials selection, waste and demolition recycling, and any other clearly defined green requirements. In addition, the building program can take into consideration the broader community context of the building, and strive to reflect local design as influenced by cultural and climatic factors, as well as consider ease of pedestrian and mass-transit access.

Project Budget

❑ **Develop the project and building construction budget.**

Determine relevant design fees and construction costs, including those for all green building measures, for the project.

- Institute life-cycle-cost analysis for the project's green design and construction measures (see Chapter 1, "The Economics of Green Buildings," and Chapter 2, "Selecting Environmentally and Economically Balanced Building Materials").
- Seek the advice of a design professional and cost consultant with green building experience.
- Because many green and sustainable building practices are relatively new to the industry, allocate adequate contingencies for additional research and analysis of options.

Design Team Selection

❑ **Create a design and construction team that utilizes the whole-building integrated design approach.**

Select team members who are committed to the project vision. The project team should include representatives from all aspects of the building project, from site planning to construction to building operations. Team members should be willing to think beyond their own specialty and understand that the building is a system of interrelated processes and products. *Figure 2* illustrates the basic members of a project team.

❑ **Develop a Statement of Work (SOW) and a Request for Qualifications (RFQ), in preparation for hiring appropriate design professionals.**

The SOW includes the project criteria, including green building issues. The RFQ identifies the skills required for participation in the project, including green building expertise.

❑ **Select a team leader and encourage communication and integration among team members.**

The team leader's role is to integrate the design team process. The leader must have good communication skills and be well-grounded in the principles of sustainable design and construction. Additionally, the building owner, working with the team leader, can be a strong resource by supporting and emphasizing the importance of green building goals to the project.

❑ **Determine the most appropriate method for contractor selection, given the project goals.**

This includes determining the construction contract type, such as public bid, invited bid, negotiated contract, and design-build. Green building goals may be more easily achieved with negotiated contracts than with bids, as the contractor can be carefully selected and hired at an earlier stage and can be actively involved in the building design team process. Prequalification of contractor and pre-selected or invited bids are other options for achieving these results. By prequalifying contractors, the owner can select those with experience and interest in green building practices.

Whichever contract type is selected, very carefully defined specifications, including environmental procedures, need to be developed and implemented. Contract or bid documents should clarify rules for submissions and substitutions of green products and systems. (See Chapter 17, "Specifications," for further discussion.)

Partnering

❑ **Implement a partnership-oriented process for the project.**
Partnership is the best way to pursue established project goals and criteria, following the whole-building integrated design approach; to establish and maintain communication among the team members; and to resolve issues related to design changes, problems with product availability, and other issues quickly. It is also a forum to discuss new techniques and strategies for green building design and to develop new and creative solutions that benefit from the skills and knowledge of all team members. A partnering process should be in place throughout the project, starting with the design phase and continuing through the construction and pre-occupancy phases.

Project Schedule

❑ **Develop a project schedule that incorporates the additional steps of an environmentally responsive design process, illustrated in *Figure 1*.**
The schedule should be sensitive to additional research, unconventional techniques or materials, additional systems testing, pre-occupancy commissioning, or other green practices that may be used for the project in connection with its green design criteria.

Laws, Codes, and Standards

❑ **Prepare and review a list of the appropriate and applicable laws, codes, local ordinances, statutes, and industry-related standards relevant to the project.**
In addition to the typical laws and guidelines followed on most projects, some will be relevant specifically to a green building. Examples include:

- Local or state environmental quality and energy efficiency laws, such as the California Environmental Quality Act (CEQA), which requires an environmental analysis for any project that may have a significant effect on the environment.
- Standards produced by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), which address energy efficiency, indoor air quality, thermal comfort, ventilation rates, and building commissioning, and are useful when developing designs and specifications for systems and products related to space conditioning.
- Other standards, such as the American Society for Testing and Materials (ASTM) life-cycle standards and the Illuminating Engineering Society's lighting standards, and specification guidance from the Construction Specification Institute (CSI). (See Chapter 17, "Specifications," for more information on green specifications, and Chapter 25, "The Future of Green Building," for more information on standards.)

Research

❑ **Research green projects that are complete or about to be completed.**
Prepare a binder of information about these projects for reference. As appropriate, visit the projects and meet with their design teams. This exer-

cise can produce valuable information about existing green building practices and feedback on current green design and construction procedures and products. It is also a good way to educate a team, and the building owner, about green buildings prior to starting a project.

Site Selection

❑ **Evaluate project site selection, based on green criteria.**

In many projects, the site is selected prior to commencement of the design phase. Ideally, the design team should be involved in site selection and should assess the appropriateness of the site relative to green design criteria. A team may decide if the site takes maximum advantage of solar access, existing vegetation, and natural geological features, as well as analyze the site's accessibility from existing transportation corridors and its ability to meet other needs of the building owner, tenants, and visitors. (See Part III for additional site information and selection criteria.)

NOTES

1 Materials/Indoor Air Quality Standards Committee, "Materials/Indoor Air Quality Policy" (Berkeley, Calif.: Berkeley Unified School District Office of Facilities Planning, June 15, 1994).

2 Energy Design Standards Committee, "Energy Design Standards Policy" (Berkeley, Calif.: Berkeley Unified School District Office of Facilities Planning, June 15, 1994).

3 Ibid.

CHAPTER 4

Local Government Information: Pre-Design Issues

Author
Michael Myers

IMPLEMENTATION ISSUES

Local governments have the unique ability to be both owners and clients in designing the form and function of their community buildings. The pre-design phase allows local government to incorporate sustainable building criteria in its determination of where a building should be built, the function of the building, the materials used for construction, and the building's relationship to the local community.

It is during the pre-design phase that green building guidelines need to be developed and used in an integrated approach to building design. This approach encourages local governments to evaluate such factors as future energy usage, environmental impacts, water usage, site impacts, indoor air quality, waste reduction, transportation and parking, community access, operations and maintenance costs, and local economic impacts. It is also an opportunity to establish guidelines that require life-cycle costs be used to evaluate energy and water systems, as well as building products. Life-cycle cost analysis involves calculating the total costs and savings of conventional versus higher-efficiency systems or environmentally sound products.

Local governments can also require design and construction teams to have expertise in resource-efficient design and construction and to ensure that citizens and building occupants have an opportunity during the pre-design phase to contribute their ideas on building use, building design, and access to the site.

LOCAL ACTIONS

➤ The city of Austin, Texas, passed a local resolution in 1994 that requested city staff to develop sustainable building guidelines for municipal buildings, encourage voluntary private sector compliance with the city's sustainable building guidelines through education and promotional endeavors, and promote opportunities to involve at-risk youth in green building projects. The ultimate goal of the resolution is to make Austin a model sustainable city.

By December 1994, the city's Departments of Environmental and Conservation Services and Public Works developed Volume I of the *Sustainable Building Guidelines.* The guidelines are based on Austin's successful Green Builder Program for residential buildings, which received international honors at the 1992 United Nations Conference on Environment and Development.

Volume I, *Principles of Sustainable Building Design,* encourages the broad goals of energy efficiency, water conservation, and healthy structures; the use of recycled-content materials; the integration of environmental concerns, green construction, and waste-reduction practices; and procedures and guidelines for building longevity. Specifically, it aims to:

- Reduce aggregate energy use over the base line by 10 percent.
- Reduce electrical energy demand over the base case by 20 percent.
- Reduce water consumption for similar building type and site square footage by 30 percent.
- Optimally recycle or reuse construction and demolition materials generated by the project.
- Recycle 75 percent of operational waste.
- Select building materials that emphasize sustainability standards.
- Increase building longevity through durable construction elements and adaptable design.
- Achieve a healthy indoor air quality.

Volume I outlines a design process that features a team-oriented and integrated design approach. Steps in Austin's design process include: 1) development of a program-specific base line; 2) site analysis; 3) characterization of energy needs; 4) economic analysis; and 5) development of project-specific goals.

An appendix to the *Sustainable Guidelines* document includes other useful information, such as a preferred plant list for the region, materials suppliers, and resources. Volumes II and III will focus on specifying for sustainability and operations and maintenance for city facilities, respectively.

➤ In 1994, the city of Portland, Oregon, also adopted Sustainable City Principles that encourage elected officials and municipal staff to develop connections between environmental quality and economic vitality, to include long-term effects and cumulative environmental impact in decision-making, to ensure commitment to equity, to use resources efficiently and prevent additional pollution, to purchase products based on long-term environmental and operating costs, and to educate citizens and businesses about their role in implementing these principles.

Putting policy into practice, Portland developed a design services Request for Proposals (RFP) for a new municipal building. The RFP designates environmentally sensitive design and construction as priorities of the city and indicates that design and siting decisions will be based on long-term environmental impact. Areas of special focus in the RFP include recycled construction and building materials, energy efficient systems and fixtures, and water-conserving plants in the landscape. Portland also made recommendations for the composition of the design team, including specific expertise in energy-efficient design, and provided mechanisms for input from a Citizens' Task Force and city staff. These groups will meet during the design process to provide direction on siting, building design, and programs offered at the facility.

➤ The city of Santa Monica, California, is formulating a set of Sustainable Development Guidelines for construction and development projects within the city. These guidelines are intended to foster environmental responsibility without unreasonable increases in building cost or limits on construction practices. When complete, Santa Monica's guidelines should be beneficial to the environment and conducive to the future growth of the city.

➤The American Institute of Architects (AIA) has carried out a series of design charrettes in communities around the country to increase public and professional awareness of, and involvement in, environmental design projects. These intensive, short-term workshops bring together design professionals, builders, policymakers, financiers, and community organizations to explore the benefits of sustainable development practices. AIA design charrettes have examined a range of projects, including the environmentally sound development of a water aquifer; redevelopment of neighborhoods, inner-city areas, and downtown commercial areas; and reuse of a historic courthouse and a closed landfill site. The charrettes provide an opportunity to develop community support at all levels for implementation of green building practices in community projects.

LOCAL OPTIONS

- Adopt a resolution or policy to direct future building toward green practices.
- Institute life-cycle cost analysis for procurement of building systems and materials for municipal projects.
- Build local public support for green buildings by establishing a green building task force or support activities of existing local organizations.
- Hold a design charrette to focus attention on local green design efforts for public or private building projects.
- Establish a pre-design green team for municipal buildings that includes green design professionals, community members, and building occupants.
- Conduct an environmental scan of existing buildings to assess baseline energy and water usage, indoor air quality, and site characteristics, and to estimate future resource needs and costs.
- Conduct a baseline analysis of institutional issues that affect green building policy implementation—for example, procurement policies, zoning, building codes and standards, operations and maintenance policies, recycling policies, and economic policies.

➜ RESOURCES

Resources for the Local Government Information chapters are located in the Appendix.

PART III

Site Issues

Introduction

Sustainable site planning and design do not impose building design on the site. Rather, they identify the ecological characteristics of the site, determine whether it is appropriate for its proposed use, and design ways to integrate the building with the site. The intent is to lessen the environmental impact of human activity, while using natural characteristics of the site to enhance human comfort and health, and potentially provide a significant portion of the building's energy requirement. Preservation of site resources and conservation of energy and materials in construction and building operations are important results of good site design.

This section of the manual emphasizes the need to consider the regional and global effects of building and development. Far from being merely a location for construction, each site consists of interconnected living systems, all linked to the environment beyond the site's boundaries. The connected outdoor spaces—garden, plaza, greenbelt, and wilderness—also link people, both physically and socially. Keeping a building site in harmony with its surroundings is vital not only to our environment, but also to our sense of community.

The chapters in this section provide practical guidelines for developing site-integrated buildings and maintaining the ecological integrity of the site. Chapter 5, "Sustainable Site Design," covers pre-design planning: assessment of existing natural and cultural site characteristics, existing infrastructure, and building requirements. Chapter 6, "Water Issues," suggests specific methods of protecting natural watersheds, reducing water usage and pollution, and setting up systems to use gray- and blackwater. Chapter 7, "Site Materials and Equipment," discusses environmentally responsible methods of site modification. Practices discussed in Chapters 6 and 7 will be developed during the design phase and carried out during the construction and occupancy phases of a building construction project. Chapter 8 provides examples of local government initiatives related to sustainable issues.

CHAPTER 5

Sustainable Site Design

Author
Nicholas T. Dines

★ SIGNIFICANCE

This chapter focuses on green site-planning strategies and practices that specifically relate to assessing and selecting a site for uses such as office buildings and parks, institutional and research structures, retail businesses, and industrial facilities. The purpose of sustainable site planning is to integrate design and construction strategies by modifying both site and building to achieve greater human comfort and operational efficiencies. Sound site planning is prescriptive and strategic. It charts appropriate patterns of use for a site while incorporating construction methods that minimize site disruption and the expenditure of financial and building resources.

Site planning assesses a particular landscape to determine its appropriate use, then maps the areas most suitable for accommodating specific activities associated with that use. The process is based upon the premise that any landscape setting can be analyzed and studied as a series of interconnected geological, hydrological, topographic, ecological, climatological, and cultural features and systems. An ideal site plan is one in which the arrangement of roads, buildings, and associated uses is developed using site data and information from the larger macro-environment, including existing historical and cultural patterns of the community.

Selecting a building site begins the process of calculating the degree of resource use and the degree of disturbance of existing natural systems that will be required to support a building's development. The most environmentally sound development is one that disturbs as little of the existing site as possible. Therefore, sites suitable for commercial building should ideally be located within or adjacent to existing commercial environments. Building projects also require connections to mass transit, vehicular infrastructure, and utility and telecommunication networks. Sound site planning and building design should consider locating building-support services in common corridors, or siting a building to take advantage of existing service networks. This consolidation can minimize site disruption and facilitate building repair and inspection.

The use, scale, and structural systems of a building affect its particular site requirements and associated environmental impacts. Building characteristics, orientation, and placement should be considered in relation to the site so that proper drainage systems, circulation patterns, landscape design, and other site-development features can be determined.

☞ SUGGESTED PRACTICES AND CHECKLIST

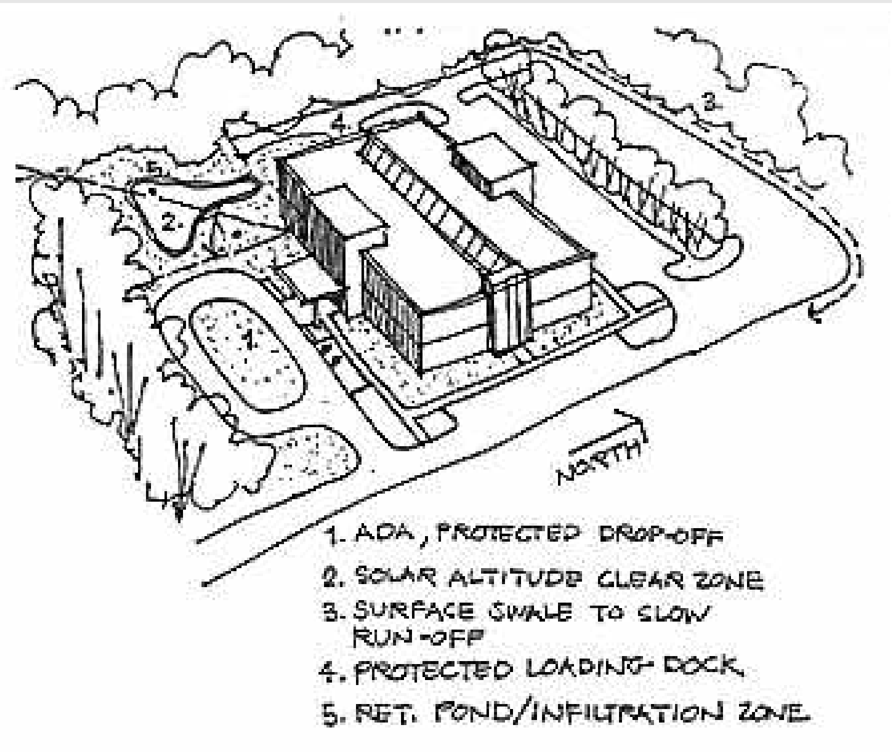
Site Analysis and Assessment

The purpose of a site analysis is to break down the site into basic parts, to isolate areas and systems requiring protection, and to identify both off-site and on-site factors that may require mitigation. Site assessment is a process that examines the data gathered and identified in the site analysis, assigns specific site factors to hierarchies of importance, and identifies, where possible, interactive relationships. For example, an analysis may identify specific soils and their properties, vegetation types and their distribution, or various slope and slope-orientation conditions to name a few site factors. An assessment applies evaluation criteria that allow the comparison of various sites' suitability for a specific use.

Sustainable design practices assess both site and building program to determine the site's capacity to support the program without degrading vital systems, or requiring extraordinary development expenditures. The result of analysis and assessment is a blueprint for the most appropriate ecological and physical fit between site, building, and the resulting cultural landscape.

Figure 1

TYPICAL TEMPERATE CLIMATE BIOCLIMATIC BUILDING AND SITE LAYOUT



Data Collection

Technical Site Data

❑ **Perform a site analysis to determine site characteristics that influence building design.**
The following site characteristics influence building design elements, including form, shape, bulk, materials, skin-to-volume ratio, structural systems, mechanical systems, access and service, solar orientation, and finished floor elevation:
- *Geographical latitude (solar altitude) and microclimate factors, such as wind loads*—Affect building layout, including solar orientation and location of entrances, windows, and loading docks *(Figure 1)*.
- *Topography and adjacent landforms*—Influence building proportions, wind loads, drainage strategies, floor elevations, and key gravity-fed sewer-line corridors *(Figure 2)*.

TYPICAL BUILDING ZONES FOR SITE USE WITH REGARD TO TOPOGRAPHY, DRAINAGE, AND SOLAR ACCESS

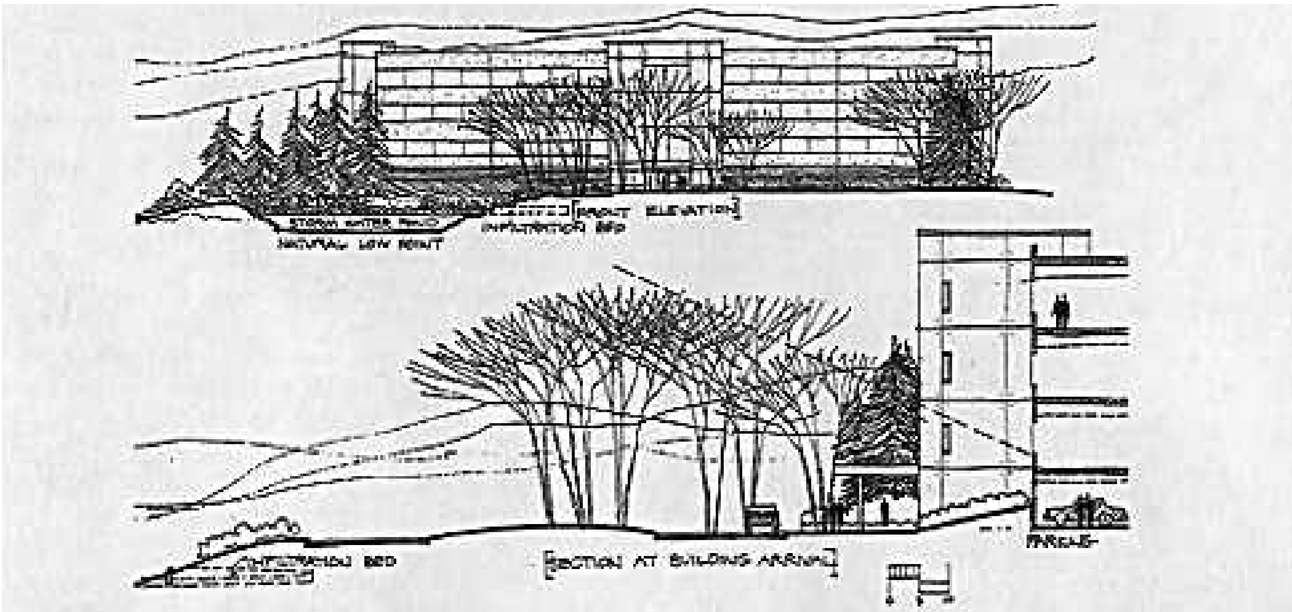


Figure 2

– *Groundwater and surface runoff characteristics*—Determine building locations as well as natural channels for diverting storm runoff and locations of runoff detention ponds *(Figure 3)*.
– *Solar access*—Determines position of building to take maximum advantage of natural solar resources for passive solar heating, daylighting, and photovoltaics.
– *Air-movement patterns, both annual and diurnal*—Particularly influence siting of multiple structures to avoid damming cold moisture-laden air, or blocking favorable cooling breezes during periods of overheating. Properly measured wind loads and pressure differentials are essential for designing interior air-handling systems or use of passive solar cooling strategies (see Chapter 11, "Renewable Energy").
– *Soil texture and its load-bearing capacity*—Determine building location on the site and the type of footing required. Identify site-grading processes by the soil's potential for erosion by wind, water, and machine disturbance.
– *Parcel shape and access*—Affect a site's capacity to accommodate a proposed development, even if its size and environmental factors are favorable. Potential access points should not burden lower-density or less compatible adjacent land use. Zoning setbacks and easements can also affect development potential *(Figure 4)*.
– *Neighboring developments and proposed future developments*—Affect proposed project and may lead to requisite design changes.

DRAINAGE AND GRADING DIAGRAM OF A TYPICAL COMMERCIAL DEVELOPMENT

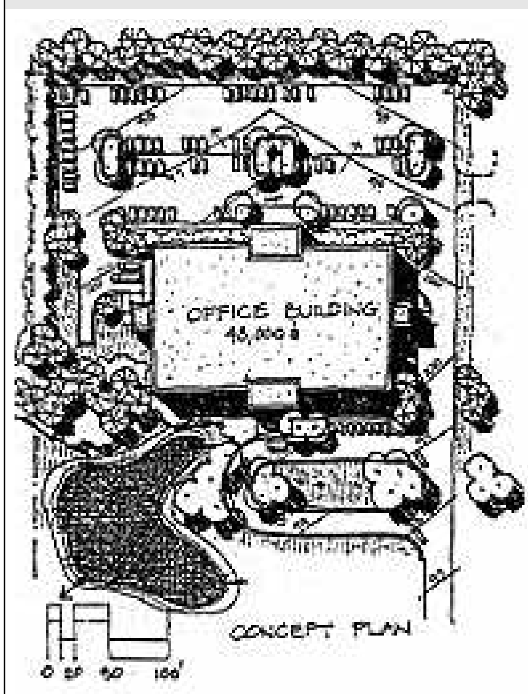


Figure 3

RELATIONSHIP OF LOT SHAPE AND SET-BACKS TO BUILDING ZONE AND SITE LAYOUT

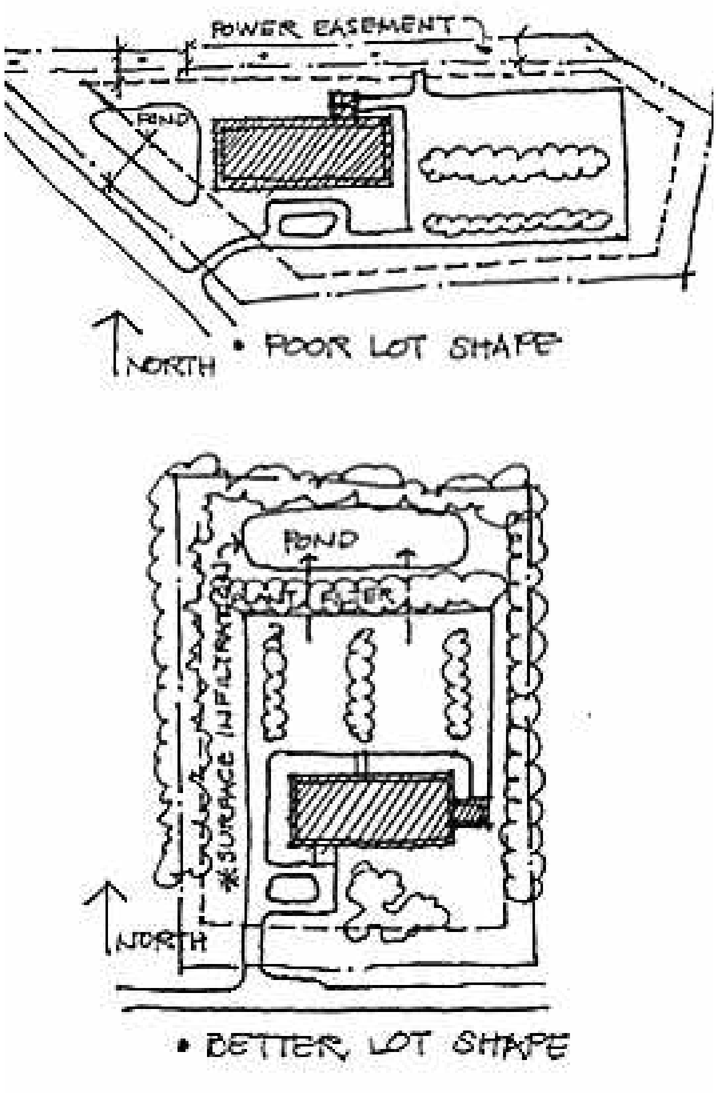


Figure 4

❑ **Analyze specific characteristics of climate zones.**
Climate zones (hot-humid, hot-arid, temperate, and cold) have specific characteristics requiring mitigation, augmentation, and exploitation (*Table 1*). Each climate zone suggests historically amenable siting and building practices.

❑ **Analyze the site's existing air quality.**
Most state and federal projects require an environmental impact statement (EIS) outlining the potential negative impacts of a proposed development and how they might be alleviated. Site planning requires two kinds of air-quality analysis regarding: (1) assessment of the existing air quality of the site to determine the presence of noxious chemicals and suspended particulates, and (2) projection of the negative consequences (if any) of the proposed development on existing air quality. In primarily commercial or industrial areas, poor air quality should be a key factor in determining site suitability and use, especially for such facilities as schools, parks, or housing for seniors. Testing should anticipate seasonal or diurnal wind patterns to make certain that the worst possible case is tested. Certified labs should perform testing to determine both chemical and particulate pollution.

❑ **Perform soil and groundwater testing.**
Perform soil tests to identify the presence of chemical residues from past agricultural activities (arsenic, pesticides, and lead); past industrial activities (dumps, heavy metals, carcinogenic compounds and minerals, and hydrocarbons); and any other possible contamination both on or in the vicinity of the subject site. Also, the possibility of water contamination, in areas where the native rock and substrata are radon-bearing deserves specific attention. These tests are crucial to determine both site feasibility and/or the construction methods required to either mitigate or remove contaminants.

❑ **Test soil suitability for backfills, slope structures, infiltration.**
The native soil should be tested to determine bearing, compactability, and infiltration rates, and, in turn, structural suitability and the best method for mechanical compaction (i.e., clay soils require non-vibrating compaction and non-erosive angles of repose for cut-and-fill slopes).

❑ **Evaluate site ecosystem for existence of wetlands and endangered species.**
In addition to wetland regulations governing vegetative-cover removal, grading, drainage alterations, building siting, and stormwater runoff mitigation, there are endangered species regulations designed to preserve specific plant and animal species. Preservation and restoration strategies require thorough economic analysis, specialized expertise, and sound baseline data gathered through both remote and on-site sensing methods.

❑ **Examine existing vegetation to inventory significant plant populations.**
This will enable the developer or owner to later specify vegetation that is susceptible to damage during construction, so that protective measures can be developed and implemented.

❑ **Map all natural hazard potentials (such as winds, floods, and mudslides).**
Historic flood data, wind-damage data, and subsidence data should be mapped along with current annual wind and precipitation data. It is important to indicate if the proposed development is within a statistically significant probability of sustaining impacts within the near future. Often, evidence of past occurrences is not visible. Subsurface investigation may yield data on surficial rock strata or uncharted previous excavations. Such evidence may require that a different site be selected, or an architectural modification be made.

❑ **Diagram existing pedestrian and vehicular movement and parking to identify patterns.**
Existing traffic and parking patterns in areas which are adjacent to or near the site may need consideration in relation to proposed building design and site circulation patterns.

❑ **Review the potential of utilizing existing local transportation resources.**
Explore the sharing of existing transportation facilities and other resources, such as parking and shuttles, with existing institutions. This can lead to greater site efficiencies.

❑ **Identify construction restraints and requirements.**
Special construction methods may be required because of local soil condition, geology, earth-moving constraints, and other site-specific factors and constraints.

Cultural and Historical Data

❑ **Review site's cultural resources for possible restoration.**
Historical sites and features can be incorporated as part of the project site, thereby increasing ties with the community and preserving the area's cultural heritage.

❑ **Review architectural style of the area for incorporation into building.**
If desirable, the architectural style that is historically predominant in an area can be reflected in the building and landscape design, enhancing community integration.

❑ **Explore use of historically compatible building types.**
There may be building types that are historically matched to the region. Consider integrating such types into building development.

Infrastructure Data

❑ **Analyze site for existing utility and transportation infrastructure and capacity.**
There may be insufficient existing infrastructure for the proposed project. The cost for required additional capacity and associated disruption to the surrounding area could make the project unfeasible. Existing infrastructure should be analyzed for integration into the building and facilities.

Data Assessment

❑ **Identify topographic and hydrological impacts of proposed design and building use.**
Measure cut-and-fill potential and assess potential for erosion, siltation, and groundwater pollution.

❑ **Develop general area takeoff and overall building footprint compatibility with site.**
For example, measure total site coverage of impermeable surfaces to determine thresholds of run-off pollution potential (i.e., over 20 percent impermeable coverage of gross site requires mitigation to clean stormwater before it enters drainage system off-site). Footprint should also maximize site efficiencies with regard to required road, utility, and service access.

❑ **Identify alternative site design concepts to minimize resource costs and disruption.** Develop several alternatives to explore optimal pattern with regard to factors such as grading and tree-clearing consequences and resulting infrastructure costs.

❑ **Review financial implications of site development, building, and projected maintenance costs.**
Total cost of the project must factor in ongoing costs associated with the site design, development, and operations, as well as hidden embodied energy costs associated with specific materials.

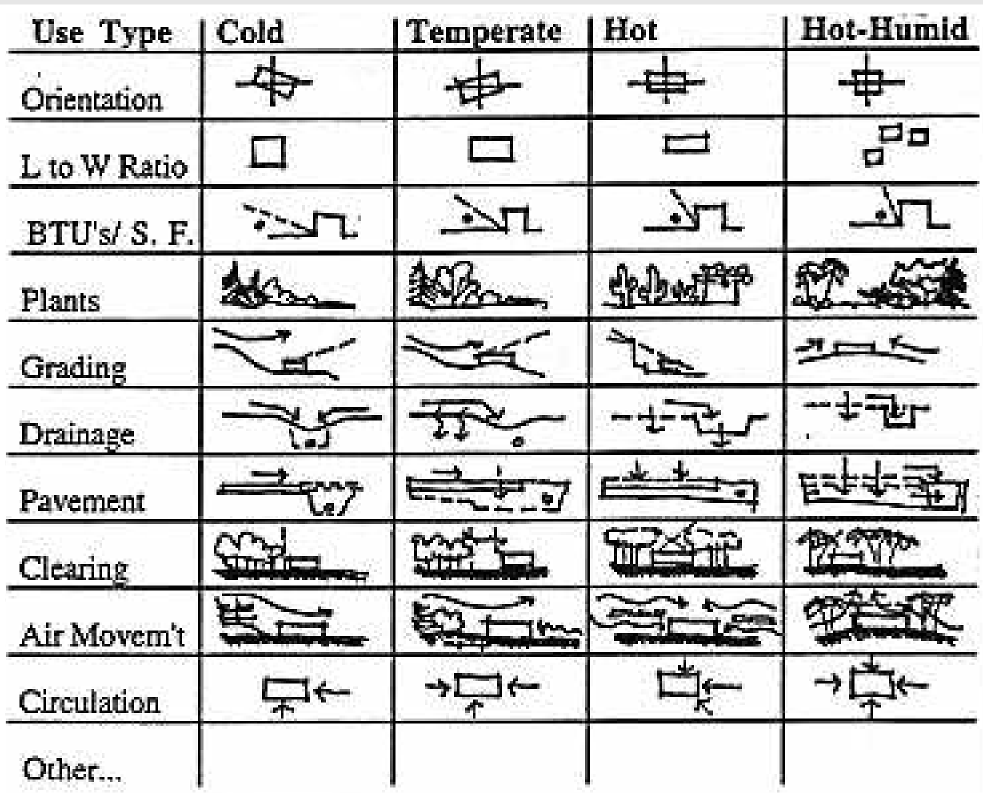
❑ **Develop matrix of use and site compatibility index.** *(Table 1).*
Each site may be assessed to reveal its development compatibility index with regard to a specific type of development. This index may reveal a pattern of incompatibilities, suggesting that either a different site be chosen or specific appropriate mitigation measures be undertaken.

Site Development and Layout

After the site has been selected on the basis of a thorough analysis and assessment, ideal diagrammatic concepts are laid out on the topographic survey with the objective of organizing all proposed built elements to achieve an efficient and effective site and development fit. The main goal of the concepts should be to minimize resource consumption during construction and after human occupation. It should be noted that during reclamation of disturbed sites, initial expenditures may be higher than normal and should be balanced by ongoing landscape management strategies. The following practices serve to guide the initial concept diagramming process.

Table 1

MATRIX OF REGIONAL BIOCLIMATIC, SITE USE, AND SITE DESIGN FACTORS



Infrastructure

Utility Corridors

❑ **Design the site plan to minimize road length, building footprint, and the actual ground area required for intended improvements.**
Such planning decreases the length of utility connections. Consult local codes regarding separation requirements for water, sewer, electrical, and gas lines.

❑ **Use gravity sewer systems wherever possible.**
Avoid pumped sewer systems because of ongoing power consumption.

❑ **Reuse chemical-waste tanks and lines.**
Existing chemical-waste tanks and lines should be inspected, protected, and reused to avoid creation of additional hazardous-materials problems.

❑ **Aggregate utility corridors when feasible.**
Where possible, common site utility corridors should be consolidated along previously disturbed areas or along new road or walk construction, both to minimize unnecessary clearing and trenching and to ensure ease of access for ongoing repairs.

Transportation

❑ **Support reduction of vehicle miles traveled (VMT) to the site.**
Where applicable, existing mass-transit infrastructure and shuttle buses should be supported, or a new line developed. Carpooling strategies should be encouraged in addition to mass-transit use. To foster the use of bicycles, showers and lockers should be considered. All of these transportation methods reduce parking and transportation costs for employees.

❑ **Use existing vehicular transportation networks to minimize the need for new infrastructure.**
This practice can increase site efficiencies associated with reduced ground coverage, parking requirements, and related costs.

❑ **Consider increased use of telecommuting strategies.**
Telecommuting and teleconferencing can reduce commute time and VMT to and from worksites. Plan for adequate telecommunications infrastructure and access in building design. (See Chapter 25, "The Future of Green Building" for further discussion).

❑ **Consolidate service, pedestrian, and automobile paths.**
To minimize pavement costs, improve efficiency, and centralize runoff, the pattern of roads, walkways, and parking should be compact. This not only is a less expensive way to build, it also helps to reduce the ratio of impermeable surfaces to the gross site area.

Building and Site Requirements

Land Features

❑ **Develop previously disturbed sites such as unused urban lots and commercial sites.**
These sites may already be affecting the environmental quality of neighboring properties, the watersheds, and other features, therefore redevelopment requires minimal disturbance of natural systems. Furthermore, redevelopment is likely to improve the immediate community, potentially create jobs, and increase land values that have been affected by the abandoned or blighted property.

❑ **Avoid stream channels, flood plains, wetlands, steep erodible slopes, and mature vegetation.**
To avoid high site-preparation costs, and to preserve important visual and ecological features, development activity should be configured to occupy "interstitial site space," or those spaces between critical resources.

Building and Site Orientation (see Figure 1)

- ❑ **Plan site clearing and planting to take advantage of solar and topographic conditions.**
  Solar orientation, sky conditions (cloudy versus clear), and topography are interrelated. A site's latitude determines the sun's altitude and associated azimuth for any given time of day, each day of the year. Site-clearing and planting strategies, which partially determine solar access, are influenced by those requirements.

- ❑ **Orient building to take advantage of solar energy for passive and active solar systems.**
  The building should be oriented to take advantage of shade and airflows for cooling in summer, and of passive solar energy for heating and wind protection in winter. If solar collectors or photovoltaic systems are proposed, orientation should allow maximum access to sunlight. (See also Part IV, Section A, "Passive Solar Design" for more information.)

- ❑ **Minimize solar shadows.**
  Landscaped areas, open spaces, parking, and septic fields should be aggregated to provide the least solar shadow for southern orientations of the building project and adjoining buildings. Calculating total site shadow can prevent the creation solar voids and cold-air-drainage dams. This is especially helpful in cold and temperate climates.

- ❑ **Minimize earthwork and clearing by aligning long buildings and parking lots with landscape contours; take up excess slope with half-basements and staggered floor levels.**

- ❑ **Provide a north-wall design that minimizes heat loss.**
  Provide entrances with airlocks, and limit glass to prevent heat loss in human-occupied areas. Large buildings in cold or temperate climates require air-handling system compensation for balancing interior building pressure in such circumstances.

- ❑ **Provide a building-entrance orientation that maximizes safety and ease of access.**
  The building should be positioned on the site so that its entrance provides maximum safety and ease of access, as well as protection from the elements.

Landscaping and Use of Natural Resources

- ❑ **Harness solar energy, airflow patterns, natural water sources, and the insulating quality of land forms for building temperature control.**
  Existing water sources and landforms can be used to create winter heat sinks in cold climates, and temperature differentials for cooling air movement in hot climates. Existing streams or other water sources can contribute to radiant cooling for the site. Color and surface orientation may be used to favorably absorb or reflect solar energy.

- ❑ **Use existing vegetation to moderate weather conditions and provide protection for native wildlife.**
  Vegetation can be used to provide shade and transpiration in the summer and wind protection in the winter. Additionally, vegetation can provide a natural connection for wildlife corridors.

- ❑ **Design access roads, landscaping, and ancillary structures to channel wind toward main buildings for cooling, or away from them to reduce heat loss.**

Public Amenities

- ❑ **Modify microclimates to maximize human comfort in the use of outdoor public amenities such as plazas, sitting areas, and rest areas.**
  Figure 5 provides examples of typical commercial buildings and associated sites.
  - Modulate sun and wind. In planning outdoor public amenities, the designer needs to consider seasonal weather patterns and climate variables such as vapor pressure in hot-humid zones, desiccating winds and diurnal extremes in hot-arid zones, and annual temperature extremes in temperate and cold zones.

– Introduce structures and plantings that provide shelter from harsh elements and highlight desirable features. Modulation of tree-canopy heights and inclusion of water fountains and other built structures can fine-tune an exterior site by accelerating or decelerating site winds, casting shadows, or cooling by evapotranspiration or evaporative cooling.

❑ **Consider sustainable site materials for public amenities.** Materials should be recycled, if possible, and have a low life-cycle cost. Albido (solar reflectance index attributed to color) should also be considered when choosing site materials (see Chapter 7, "Site Materials and Equipment").

Construction Methods

❑ **Specify sustainable site construction methods.** The construction methods employed should ensure that each step of the building process is focused on eliminating unnecessary site disruption (e.g., excessive grading, blasting, clearing) and resource degradation (e.g., stream siltation, groundwater contamination, air-quality loss). The strategies can harness features such as ventilating breezes, solar gain, and microclimates, and can mitigate unfavorable features such as cold, moist air drainage; desiccating winds; and increased stormwater runoff.

❑ **Develop sequential staging to minimize site disruption.** The building process should be strategically charted in stages to avoid unnecessary site disruption, and to achieve an orderly construction sequence from site clearing to site finish. Such a strategy reduces costs and damage to the site. It requires close coordination between all sub-contractors. (See Chapter 7, "Site Materials and Equipment," and Chapter 19, "Environmental Construction Guidelines".)

➜ RESOURCES

Architects' First Source for Products. Atlanta: 1995. A comprehensive illustrated product catalog of professional organizations that may be useful for further information and site and building products.

Groesbeck, Wesley A., and Jan Stiefel, ASLA. *The Resource Guide to Sustainable Landscapes.* Salt Lake City: Environmental Resources, Inc., 1994. A specific compilation of specification language tied to a Construction Specification Institute (CSI) format with a comprehensive listing of manufacturers specializing in environmentally friendly products, devices, and processes.

U.S. Department of the Interior, National Park Service. *Guiding Principles of Sustainable Design.* Denver: GPO, 1993. A useful general introduction to sustainable design factors affecting site planning and architecture from the perspective of those charged with stewardship of public lands. It contains useful charts and diagrams with regard to site selection, assessment, and design.

BIOCLIMATIC SITING WITHIN CONTEXT OF NORTHERN, SOUTHERN, OR EASTERN SITE ENTRANCE

Figure 5

CHAPTER 6

Water Issues

Watershed Protection

Authors
Lucia Athens and
Bruce K. Ferguson

★ SIGNIFICANCE

Every building site is in a watershed, and everything people do on a site has an impact on the watershed's condition. Sediment from soil disturbance, oil leaks, and fertilizers pollute streams; excessive runoff aggravates flooding and erosion; and deflection of rainwater from its natural paths dries out streams and wetlands in summer.

Watershed protection must occur both during and after construction. Clearing and earthmoving increase erosion by as much as 40,000 times the rate occurring in undisturbed sites.[1] Many states and regions have legal requirements for erosion and sediment control. These laws have been supplemented by national standards for stormwater discharges that regulate all non-point-source pollution—water pollution resulting from urban sources including, for example, nutrients from lawn fertilizers and hydrocarbons from highways and parking lots.

After construction, any building development is physically a mosaic of roofs, pavements, and pervious soil areas. Every impervious surface deflects rainwater away from its natural course—soil pores, native plants, and groundwater reservoirs—and into surface channels. Rainwater then concentrates into downstream floods, eroding as it goes. Carried with it are oils from cars, parking lots, maintenance yards, and storage areas; de-icing salts from roads; metals from construction and industrial materials; and herbicides, pesticides, and nutrients from overmaintained landscapes. These substances can destroy aquatic life and pollute water supplies.

In a protected watershed, soils absorb rain and make it part of the ecosystem. Pollutants are transformed as they filter through porous, humus-rich soil. Soil moisture percolates to the groundwater, which drains slowly out to streams long after the rain has fallen.

Sustainable development can solve watershed problems at the source. Its purpose is to (1) restore the infiltrating, cleansing, and storing functions of soils, plants, and groundwater by preserving natural systems; (2) restore the permeability of constructed pavements; and (3) capture and treat excess runoff by means of natural soil and biological processes. Water conservation, efficiency, and management arise from preserving, restoring, taking advantage of, and working with the site's natural systems.

☞ SUGGESTED PRACTICES AND CHECKLIST

Preservation of Soils and Drainage Ways

❑ **Emphasize preservation of mature vegetated soils and lowland areas.**
These natural systems make the watershed work by allowing rainwater and runoff to infiltrate the soil. In lowland areas, groundwater discharges into surface drainage ways, streams, and wetlands.[2] Stable vegetation around drainage ways and streams filters inflowing runoff, prevents channel erosion, and creates habitats for functioning aquatic ecosystems. Siting construction and earthwork away from drainage courses preserves vegetated buffers and protects stream quality.

❑ **Minimize pavement area.**
Minimizing pavement affords some preservation of mature native soils. Also, preserving existing vegetation generates less runoff. Good practices include:
- Concentrate and cluster development to reduce road paving.
- Double-load parking lots to share traveling and turning lanes.
- Minimize widths of road pavements.

❑ **Install silt fences to hold sediment on-site during construction.**
Silt fences should be installed before construction begins and should be maintained until construction is complete and all soil surfaces are vegetated.

❑ **Minimize use of landscape irrigation, herbicides, pesticides, and fertilizers.**
In disturbed and landscaped areas, lawn and landscape maintenance can generate a high concentration of pesticides, nutrients, and other pollutants.[3]

Porous Paving Materials

❑ **Consider use of permeable paving materials (subject to existing codes or obtained variances).**
Permeable paving materials, such as porous asphalt *(Figure 1)* or porous cement concrete, are some of the most powerful tools available for maintaining and restoring natural cycles on development sites by allowing for water infiltration close to the source. Most of the impervious portion of a typical development is in pavements for cars, not buildings for people. In the United States we are paving or repaving a half million acres per year. A variety of permeable paving materials, available since 1970, can be used for the vast majority of paved surfaces. Impervious pavements can be reserved for special situations, responding to specific on-site hazards such as swelling soils, highly plastic soils, or steep slopes (see Chapter 7, "Site Materials and Equipment").

❑ **Use permeable vegetated surfaces for occasionally used vehicular surfaces such as overflow parking and emergency-access lanes.**
Permeable vegetated surfaces can be designed with reinforced turf and open-celled pavers, concrete or plastic grids with voids that are filled with topsoil or aggregate.[4]

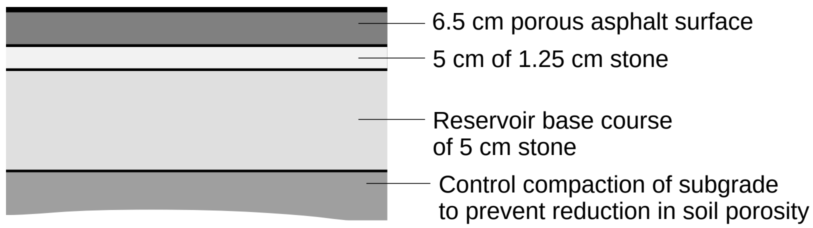
❑ **Build pedestrian surfaces, such as walkways and patios, with loose aggregate, wooden decks, or well-spaced paving stones.**[5]

Figure 1

POROUS ASPHALT

Porous asphalt has been proven in the field in hundreds of pavements of every type, from driveways to highways.[6] The distinctive porous surface layer is constructed with an "open-graded" aggregate, which leaves the voids between large particles unfilled by small particles. An open-graded stone base holds water until it infiltrates the underlying soil. Compared to impervious asphalt, porous asphalt is better-draining, has better traction and visibility in wet conditions, and produces less glare and vehicular noise.

POROUS ASPHALT SECTION



Source: Edmund Thelen and L. Fielding Howe, Porous Pavement (Philadelphia: Franklin Institute Press, 1978)

Drainage of Concentrated Runoff

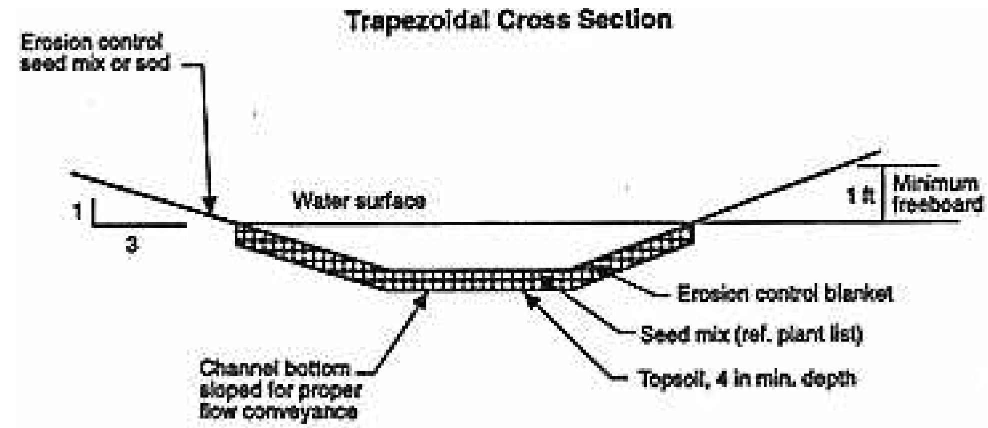
If drainage controls are implemented at the beginning of site planning, they can be integrated economically in the overall development. Detailed information on hydrologic analysis and design can be found in some of the references at the end of this chapter.

❑ **Consider disconnecting pre-existing downspouts and storm sewers from sanitary sewers.**
- Discharge downspouts into an earthern depression or gravel-filled pit for infiltration.

❑ **Moderate and treat runoff from roofs and unavoidable impervious pavements, and, to the degree possible, return it to its natural path in the soil.**
- Design every conveyance, pool, and drainage basin to match the requirements of its specific location and drainage area.
- Disperse runoff from impervious surfaces over adjacent vegatative soils with level spreaders, which change concentrated stormwater flow to sheet flow.
- Convey concentrated runoff in vegetated swales, not structural gutters or pipes. When runoff contacts vegetation and porous soil, its volume and velocity are reduced, and pollutants are filtered. Compared to closed structural systems, this open drainage system increases vegetative variety, reduces need for irrigation water, and reduces drainage velocity and erosion. In addition, it decreases downstream peak flow and runoff volume, increases infiltration, supports wildlife habitat, symbolizes interaction with nature, and requires little single-purpose maintenance *(Figure 2)*.
- Stabilize soil and reduce scouring velocity. Rock or timber checkdams, linings of sod and erosion-control fabrics, and bioengineering with quickly rooting riparian plants are effective where preexisting stream channels are unstable, or where new swales may cause erosion after grading. Swales with broad bottoms reduce velocity.
- Moderate discharge through use of constructed pools and wetlands along drainage courses. Formed by excavation of a shallow reservoir and installation of a low dam and controlled flow outlet, such pools and wetlands can temporarily store storm flows and improve water quality by allowing for settling, filtration, and biodegradation of pollutants.[7] Effective water treatment is a result of providing sufficient area for the water body and providing diverse depth zones for different plant habitats and biophysical processes.

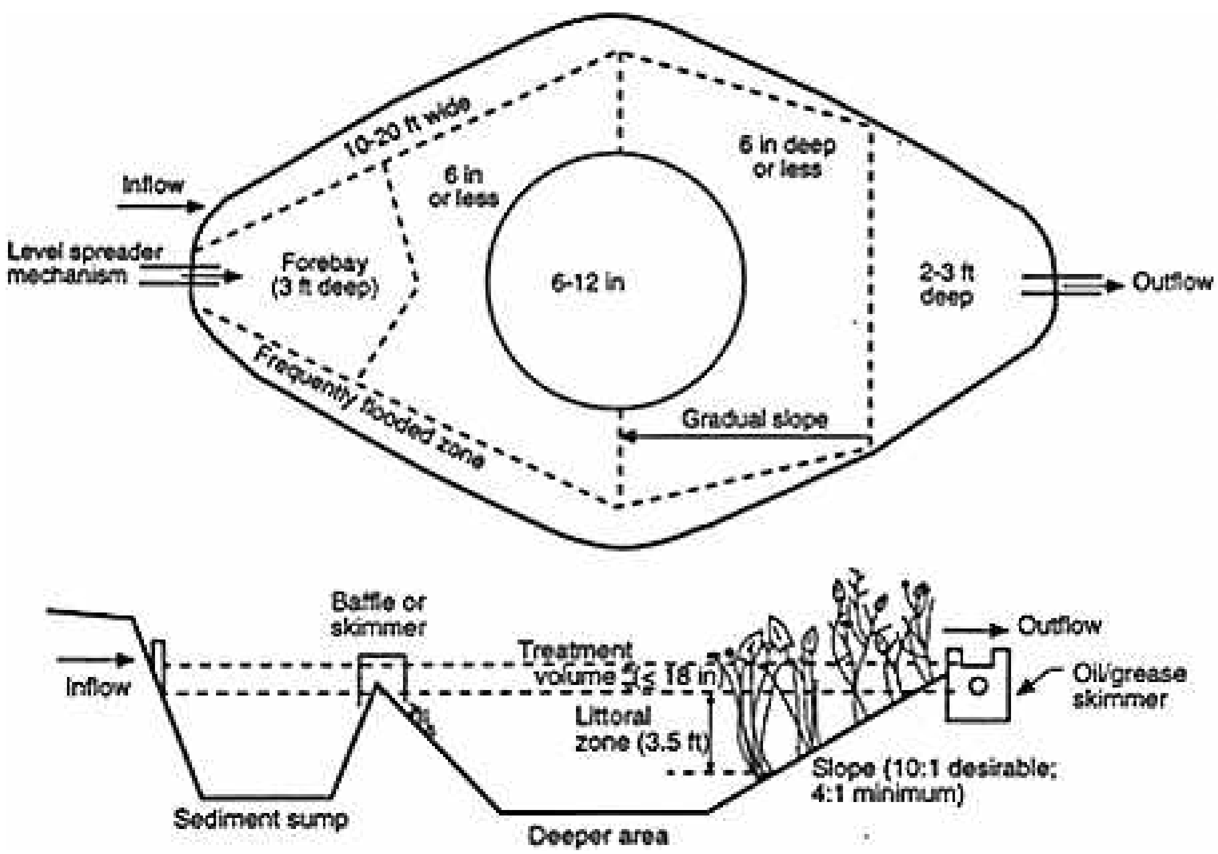
Figure 2

SAMPLE GRASS-LINED SWALE



Source: R. Horner, "Biofiltration Systems for Urban Runoff Water Quality Control" (Seattle: Washington State University, 1988), in U.S. Environmental Protection Agency, Office of Research and Development, Urban Runoff Pollution Prevention and Control Planning, EPA/625/R–93/004 (Washington, D.C.: GPO, 1993).

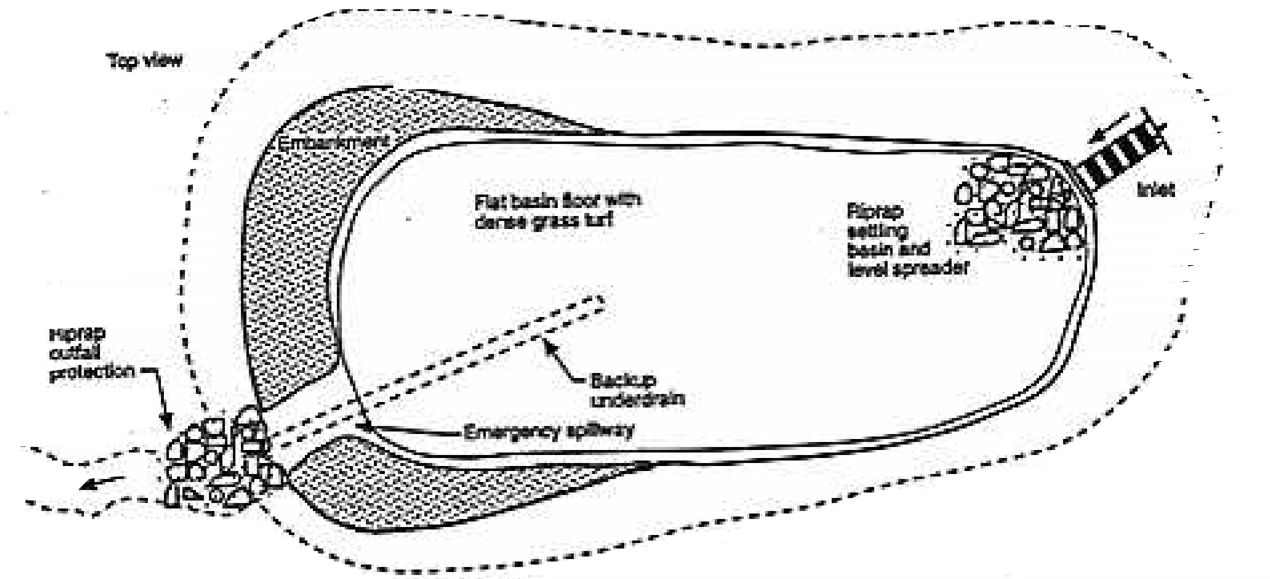
EXAMPLE SHALLOW-CONSTRUCTED WETLAND SYSTEM FOR STORMWATER TREATMENT



Source: Maryland Department of Natural Resources (1987), in U.S. Environmental Protection Agency, Office of Research and Development, Urban Runoff Pollution Prevention and Control Planning, EPA/625/R–93/004 (Washington, D.C.: GPO, 1993).

Figure 3

SAMPLE INFILTRATION BASIN



Source: U.S. Environmental Protection Agency, Office of Research and Development, Urban Runoff Pollution Prevention and Control Planning, EPA/625/R–93/004 (Washington, D.C.: GPO, 1993).

Figure 4

a. Shape water bodies with peninsulas and islands to extend flow path and treatment effectiveness.

b. Install sequences of ponds and wetlands along a site's drainage ways, beginning with miniature pools high in the drainage area to provide thorough treatment; redundancy is an asset (*Figure 3*).

c. Where driveways cross roadside swales, use the driveways as checkdams to form small wetlands.

– Use extreme caution when constructing water bodies at the lowest elevations of a site. Lowland construction of water bodies may disturb existing wetlands and riparian buffers just as any other construction would.

– Use vegetative buffer areas around parking lots. The presence of oil and sediment on parking surfaces and roadways can cause non-point-source pollution through runoff. Buffer-strip plantings around these areas can mitigate the problem.

❑ **Construct infiltration basins.**

Infiltration basins are closed depressions in the earth from which water can escape only into the soil. Infiltration is the ideal management and conservation of runoff because it filters pollutants through the soil, eliminates downstream floods and erosion, and restores natural flows to groundwater and downstream water bodies *(Figure 4)*.

– Design infiltration basins as open or closed systems. Some infiltration basins are open and vegetated; the vegetation maintains their porous soil structure. Others are constructed under the land surface with open-graded crushed stone, leaving the surface to be reclaimed for parking or other human or economic use. Their storage capacity is sometimes supplemented with perforated pipes or premanufactured chambers. Most subsurface basins should include access to the basin bottom for monitoring and maintenance. The cost of construction materials for subsurface basins is substantial, so they tend to be installed only where intense land development demands that the surface be reclaimed for double use.

– Place infiltration basins near source of runoff to be most economical and effective.

– Avoid placing basins near building foundations and on steep unstable slopes.

Water Efficiency and Conservation

★ SIGNIFICANCE

The amount of water available for use on the planet is finite, so as population grows, the available supply of water per person drops. Per capita water supplies worldwide have decreased by one-third since 1970, as the world's population has grown by 1.8 billion. Since 1980, global water use has more than tripled and is currently estimated at 4,340 cubic kilometers per year. Demand in every area of water use—urban, industrial, and agricultural—has increased, often because of mismanagement, overuse, and waste.[8] Many parts of the world are now experiencing rising water costs, seasonal shortages, and unpredictable quality and availability of supplies.

As water demands increase and municipalities must fund new water supply and treatment facilities, costs are passed on to the consumer. Many cities are using conservation rate structures in which larger users pay higher rates. Higher water use also adds to maintenance and life-cycle costs of facility operation. Efficiency and conservation in institutional, commercial, and industrial water use can result in impressive savings of both water and money—not just in water-use fees but also in sewage treatment costs, energy use, chemical use, and capacity charges and limits.

☞ SUGGESTED PRACTICES AND CHECKLIST

Water Harvesting

❑ **Collect and use "harvested" water.**

Water harvesting means collecting runoff from the soil's surface, paved surfaces, and other sources, and storing it for future use such as irrigation. Harvested water can include stormwater and irrigation runoff, water from cooling towers and heating, ventilating, and air-conditioning (HVAC) systems, and water from swales and other drainage structures directed into collection areas. After collection in a storage tank or pond, harvested runoff must be pressurized in order to be used in an irrigation system.

– Utilize gravity flow to collect runoff into harvesting areas such as storage tanks, open ponds, or detention basins.
– Direct rainfall from roofs and water from cooling towers into runoff harvesting areas.

Rainwater Harvesting

❑ **Collect and use rainwater.**

Collecting and using precipitation from a roof or other catchment area is an excellent way to take advantage of natural site resources, to reduce site runoff and the need for runoff-control devices, and to minimize the need for utility-provided water. Rainwater collection has long been utilized in arid parts of the world. Particularly in areas where populations are dispersed, rainwater collection offers a low-cost alternative to centralized piped water supply. In moist climate zones, rainwater collection is an excellent supplemental source of water.[9]

❑ **Consider quality of rainwater.**

Areas with extremely poor air quality may yield rainfall of poor quality. Rainfall in some areas is highly acidic, and therefore, undesirable for reuse. If the collection area has many overhanging tree branches, the collected rainwater will contain more debris and may appear brownish in color (caused by tannic acids drawn from plant debris). In areas with hard water, rainwater is preferable for its softness, cleaning abilities, and ability to extend the life of appliances such as water heaters and coffeemakers. The use and collection of rainwater is not federally regulated, and guidelines pertaining to its use vary by locality. If rainfall is to be used for potable or irrigation purposes, local health codes may require backflow prevention devices in order to avoid any risk of contaminating the public drinking-water supply. Check with local health-code officials for guidelines for your area.

❑ **Design an appropriate harvesting and storage system.**

The capacity of rainwater harvesting to meet water needs depends on the amount of rainfall in an area, the size of the collection area, the size of the storage area, and water needs. One inch of rainfall translates to 0.6 gallon of rainwater collected per square foot of roof area. Basic components of a rainwater-collection system include the catchment area (usually the roof), conveyance system (guttering, downspouts, piping), filtration system, storage system (cistern), and distribution system. The highest cost in most rainwater-collection systems is for water storage.

- Use appropriate roofing materials. The best roof materials for catchment are metal, clay, and concrete-based (such as tile or fiber cement). Asbestos roof materials are not suitable for potable collection because grit can enter the system. Use of asbestos roof materials may not be permitted under local building codes. Lead-containing materials such as flashing should not be used in catchment roofs.
- Install gutters and downspouts sized for the roof size and rainfall intensity. Install screening so that leaves and debris do not enter the cistern, as well as a "roof-washer" device to divert the first flush of water after a rainfall, preventing it from entering the cistern.
- Construct cistern storage. Cisterns may be constructed from a wide variety of materials. Prefabricated cisterns in steel or fiberglass are available, but tend to be quite expensive. Cisterns also may be constructed on site from concrete, ferro-cement, stone, or compressed earth. Cistern interior surfaces must, of course, be watertight. Health codes require them to be covered to prevent mosquito breeding and contamination. To prevent algae growth, which occurs with exposure to sunlight, use opaque materials only.

❑ **Filter and/or treat rainwater to use it as an irrigation source.**

Simple filtration with graded screens and paper filters can filter harvested rainwater for use in irrigation. With additional treatment, rainwater can also be potable.

Landscaping

❑ **Plant native or well-adapted species.**

In areas with low rainfall or seasonal droughts, up to 60 percent of total seasonal water usage can be attributed to irrigation. Typical urban landscapes consist of non-native or unadapted plant species, lawns, and a few trees. Non-native plants increase demands for water, especially during the growing season, thereby depleting local water supplies and driving the need for larger-capacity centralized facilities that may lie dormant during periods of low water use.

Native plants have become adapted to natural conditions of an area such as seasonal drought, pest problems, and native soils. Landscape designs that emphasize native trees, vines, shrubs, and perennials also help maintain the biological diversity of a region and preserve the character of regional landscapes.

❑ **Preserve native plant populations through careful site planning and protection of existing vegetation.**

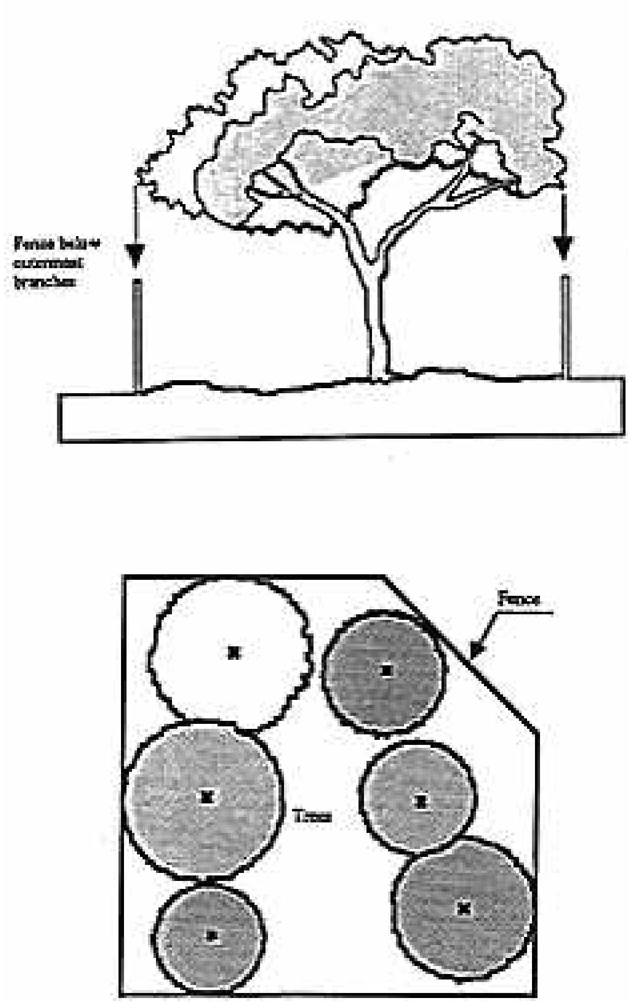
Protect trees by avoiding cut-and-fill in root zones (at a minimum, the area beneath the tree's outermost branches) and preventing heavy equipment from disturbing the area around and under them. The best way to protect existing vegetation is to fence groups of trees off *(Figure 5).*

❑ **Restore the native landscape.**
If disturbance is necessary, restore native plantings by reintroducing the same species. Habitat restoration helps to provide environments for wildlife displaced by development. Constructed landscapes that mimic ecological habitat models can decrease life-cycle maintenance costs, enhance wildlife survival, and blend edges of adjoining urban and rural areas.

❑ **Minimize use of high-maintenance lawns.**
Most turfgrasses typically require more inputs of water, maintenance, and chemicals than other types of plants. Native or drought-tolerant turf species or beds planted with shrubs, groundcover, and perennials can replace non-native lawns. In order to irrigate lawns efficiently, design them with relatively small perimeter areas and in flowing, rounded shapes. Long, skinny, or oddly shaped turf areas are difficult to negotiate with most irrigation equipment.

Figure 5

TREE PROTECTION FENCING



Source: City of Austin, Environmental and Conservation Services Department, Sustainable Building Sourcebook. (Austin: City of Austin, 1993).

❑ **Minimize use of annual plants.**
Annuals often require more irrigation than perennials, as well as higher labor and capital inputs for seasonal replanting. Perennial plantings can be designed to include a wide range of species to ensure staggered bloom cycles for long periods of color interest. Many perennials do require some additional maintenance such as seasonal pruning, which should be taken into account in maintenance plans.

❑ **Establish high and low maintenance zones.**
Group plants with similar water-use needs by determining which areas of the site should receive a higher level of care than others and, during drought periods, more irrigation. Coordinate these areas with the irrigation plan. Higher-maintenance areas should be located around major building entries and high-traffic areas. Lower-maintenance zones are low-traffic areas, buffer zones, and service areas.

Gray- and Blackwater Systems

★ SIGNIFICANCE

Worldwide industrial-sector water consumption totals 973 cubic kilometers per year.[10] Most of the wastewater flow(s) generated from this use is treated through conventional, centralized sewage treatment plants that require large inputs of capital, energy, and chemicals, and then is discharged into waterways, sometimes causing negative environmental conditions such as algae blooms.

The current capital need for new or upgraded sewage treatment plants totals over $66 billion nationally.[11] Alternative sewage systems can help minimize water-quality impacts and are often less costly to operate than conventional treatment plants. They often require less energy, less capital investment, and smaller quantities of chemicals. Alternative methods of dealing with centralized wastewater treatment include land application of reclaimed wastewater, septage lagoon systems, and composting of sewage sludge for use as a soil amendment.

Diverting or reusing wastewater before it enters the centralized wastewater stream minimizes loading of municipal water treatment plants. As an added benefit, the resulting treated effluent can be utilized on-site as an irrigation source that contains valuable plant nutrients or as part of a design feature in an attractive landscape.

Water diverted from the waste stream is either graywater or blackwater, which require different on-site handling. Graywater is wastewater generated from indoor uses such as laundries, showers, and sinks, and can be reused in toilet-flushing or irrigation to help minimize loading on any type of wastewater treatment system and reduce overall water consumption. To utilize graywater, a dual plumbing system must be installed to separate it from blackwater, which is wastewater generated from toilet-flushing. Blackwater can be treated on-site through a variety of conventional or alternative systems.

☞ SUGGESTED PRACTICES AND CHECKLIST

Indoor Water Conservation

- ❑ **Reduce overall water use.**
  Reducing overall water use reduces wastewater. Water-efficient fixtures and appliances are readily available, including toilets that are virtually waterless. Faucet bubblers, low-flow showerheads, and flow restrictors further reduce water consumption.
- ❑ **Perform a water budget analysis to project the amount and configuration of daily wastewater flows.**
  Estimate water usage and wastewater generation based on standard use patterns and the number of building occupants, then analyze the figures to determine opportunities for conservation, sources and amounts of graywater available, and other opportunities for efficiency.

Graywater Systems

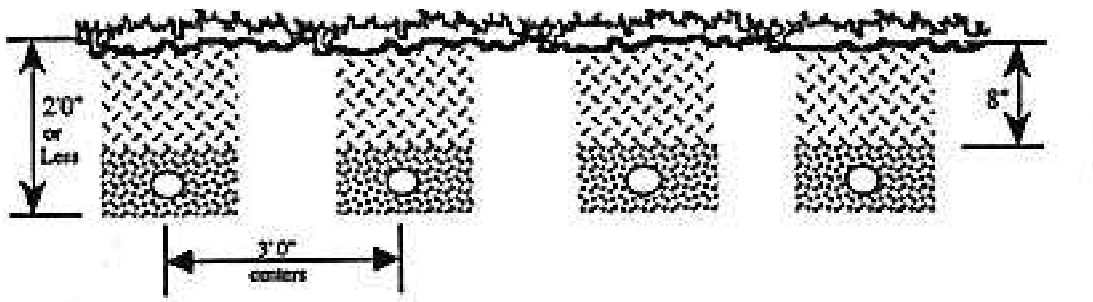
- ❑ **Separate and use graywater generated from indoor uses such as laundries, showers, and sinks.**
  Many public and commercial facilities generate relatively small amounts of graywater; other types of commercial and industrial facilities may generate large quantities. For example, a vehicle-maintenance facility that uses large quantities of water to wash trucks can realize considerable savings by recycling washwater. Therefore, volume should be considered in deciding whether it is cost-effective to treat graywater and blackwater separately.
- ❑ **Check with the local health-code department to learn about regulations governing the use of graywater.**
  Usually, irrigation with graywater is required to be subsurface, although some areas permit above-ground irrigation. Factors affecting the approval and use of graywater irrigation systems include soil depth and characteristics as well as drainage and flooding patterns. Other guidelines include setbacks for graywater irrigation lines from property or potable-water lines. Each state has individualized standards for graywater irrigation systems. Two states that have standards encouraging graywater use are Texas and California.

- ❑ **Install dual plumbing lines in building interiors.**
  Dual plumbing separates graywater from blackwater. Dual plumbing is not difficult to install, but is most-cost effective if done during initial construction. If dual plumbing lines are not installed initially, adding a graywater treatment system later can be quite expensive. For this reason, install dual distribution lines in new facilities if a graywater system may be incorporated in the future.
- ❑ **Utilize graywater for nonpotable purposes.**
  Recycle graywater via a dual distribution system, for such nonpotable water uses as toilet-flushing, thereby avoiding unnecessary use of high-quality potable water. Another major use of graywater is for irrigation of areas such as golf courses, ornamental landscapes, and turf areas. A separate tank, filter, and special emitters are necessary in graywater irrigation systems. Types of irrigation systems that can utilize graywater include: (1) drip irrigation with pressure dosing, which uses a pump system to "dose" the irrigation water at regulated intervals; (2) more traditional evapotranspiration systems; and (3) shallow trench systems, which utilize distribution pipes placed close enough to the surface to allow for irrigation of plant roots (*Figure 6*). In some areas, above-ground or spray irrigation is possible.

Blackwater Systems

- ❑ **When possible, treat blackwater from toilet-flushing with on-site systems.**
  - Utilize innovations such as low-pressure dosing systems in conjunction with septic tanks to overcome limitations of soil, geology, or topography.
  - Consider biological systems such as constructed wetlands. Constructed wetlands are artificial wetlands used for waste treatment. As wastewater flows through the wetland, plants and naturally occurring microbes remove waste. This technology can be used at a variety of scales, from wastewater treatment for an individual building to treatment for entire communities. Two types of systems, the surface-flow wetland, and the subsurface-flow wetland, can be utilized. Surface flow wetlands, also called wastewater lagoons, usually use a tiered system of ponds with wetland plants to treat wastewater. Subsurface-flow wetlands, also called microbial rock plant filters, are soil-less, and utilize a gravel medium to anchor plants. Wastewater flows through the gravel and is not visible at the surface. Effluent from both types of systems must be handled through irrigation or other methods.
  - Consider sand filters and aerobic tank treatment. Sand filters, a low-cost wastewater treatment technology, have been in use for many years. Aerobic tank systems offer advantages over traditional septic tanks, which do not use oxygen to treat waste.
  - Consider composting toilets. Composting toilets are a nearly waterless technology for dealing with human waste, combining the waste with organic material, such as lawn clippings, to produce a nearly odorless product that can be used as a soil amendment. Large-scale composting toilets capable of handling large numbers of users are available commercially. This type of technology is being applied at the municipal scale through a practice known as "sludge composting."
  - Consider aquaculture systems. In aquaculture systems, wastewater becomes a source of food for plants and fish. In the process, water is purified, as plants and fish ingest pollutants. This type of system requires high management, but produces food and fertilizer in return.
- ❑ **Check with the local health-code department to learn about regulations governing blackwater systems.**
  Treatment and definitions of blackwater vary—in some jurisdictions, blackwater is wastewater generated from toilet flushing; in others, it includes water from kitchen sinks or laundry facilities.

SHALLOW TRENCH SECTION VIEW



Source: City of Austin, Environmental and Conservation Services Department, Sustainable Building Sourcebook. (Austin: City of Austin, 1993).

Figure 6

Water Reclamation

❑ **Use reclaimed water for purposes such as toilet-flushing if dual distribution lines are in place.**

Reclaimed or reused water is wastewater effluent from a centralized water treatment plant that is reused in a variety of ways: for fire protection, in outdoor water features, for street cleaning, for wetlands recharge, or for industrial purposes such as cooling water, boiler-feeder water, or process water.

❑ **Check local regulations on use of reclaimed water.**

No federal regulations regarding water-reuse practices currently exist, although the EPA has published a manual on the subject (see "Resources"). Many states have adopted water-use regulations, but these vary considerably. According to a survey conducted in 1992, 18 states had adopted regulations for reclaimed water reuse, 18 states had guidelines or design standards, and 14 states had no regulations or guidelines. Most of the standards in place pertain to urban or agricultural irrigation. Regulations in some states (Arizona, California, Florida, and Texas) strongly encourage water reclamation as a conservation strategy. Regulatory guidelines for water reclamation usually pertain to reclaimed water-quality and treatment requirements, water-monitoring requirements, reliability of treatment facilities, storage requirements, irrigation application rates, groundwater monitoring, and property-line setback distances for applications. The objective of these regulations is usually to maximize resource benefits while protecting environmental and public health.[12]

❑ **Apply reclaimed effluent to land.**

This technique works best with wastewater treatment of at least 10 million gallons per day. Effluent can be distributed on golf courses, farmland, orchards, or other land. This alternative to discharging treated wastewater into streams and waterways has several benefits, including biological treatment of wastewater, recharging of groundwater, use of the water as a resource, and protection of surface-water quality. In some areas, an hydraulic irrigation-control and -release system is used, diverting effluent to a holding lagoon during wet seasons when irrigation is not needed. Permitted discharges are released from the lagoon to a waterway as necessary. The system can be fully automated and provide for flexible use.

❑ **Establish site-specific monitoring procedures.**

When using reclaimed water for irrigation or land application, monitor to control overwatering and detect buildup of nitrogen, phosphorus, potassium, calcium, iron, and sodium.

➜ RESOURCES

WATERSHED PROTECTION

Bormann, F. Herbert; Diana Balmori; and Gordon Geballe. *Redesigning the American Lawn: A Search for Environmental Harmony*. New Haven, Conn.: Yale University Press, 1993. A concise outline of the energy and environmental costs of conventional planting design and some alternatives to it.

Ferguson, Bruce K. *Stormwater Infiltration*. Boca Raton, Fla.: CRC Press, 1994. A thorough and easily readable reference on the single most sustainable approach to watershed protection, covering both broad concepts and technical details.

Ferguson, Bruce K., and Thomas N. Debo. *On-Site Stormwater Management: Applications for Landscape and Engineering*. 2nd ed. New York: Van Nostrand Reinhold, 1990. A graphic and easily readable introduction to hydrologic concepts and applications for practitioners in design and environmental fields.

Schueler, Thomas R. *Design of Stormwater Wetland Systems*. Washington, D.C.: Metropolitan Washington Council of Governments, 1992. A thorough and well-organized outline of planning-level choices in stormwater wetland design and their implications for performance, cost, and environment.

Welsch, D. *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources*. Technical Publication NA-PR-07-91. Radnor, Pa.: U.S. Forest Service, 1991. Concise and graphic summary of the ecological importance of riparian vegetation and how to preserve it in development.

LANDSCAPE ISSUES

Bennett, Richard, and Michael Hazinski. *Water Efficient Landscape Guidelines*. Denver: American Water Works Association, 1993. This practical guide covers development of local landscape standards, reclaimed-water use, and water budgeting.

Elleson, Connie; Thomas Stephens; and Doug Welsh. *Xeriscape Gardening: Water Conservation for the American Landscape*. New York: Macmillan, 1992. Brings a national perspective to the use of Xeriscape™ landscape principles, applications, and projects.

Groesbeck, Wesley A., and Jan Striefel, ASLA. *The Resource Guide to Sustainable Landscapes*. Salt Lake City: Environmental Resources, Inc., 1994. A handbook that uses the master specification format to organize information on landscape materials selection and practices.

Mollison, Bill. *Permaculture: A Designer's Manual*. Tyalgum, Australia: Tagari Press, 1988. An innovative text that provides information on permanent and edible forms of landscapes based on ecological principles.

Robinette, Gary. *Water Conservation in Landscape Design and Management*. New York: Van Nostrand Reinhold, 1984. Provides practical tips on how to integrate water conservation principles into landscape design.

RAINWATER HARVESTING

State of California Department of Water Resources. *Captured Rainfall*. Sacramento, Calif.: State of California, May 1981. An information-packed report that includes calculation techniques and practical considerations for the selection and use of a rainwater-collection system.

Pacey, Arnold, and Adrian Cullis. *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas*. London: Intermediate Technology Publications, 1986. One of the few books out on rainwater collection. It covers technical aspects, design criteria, and design for farming and drinking-water systems.

U.S. Department of Agriculture. *Handbook of Water Harvesting*. Handbook #600. Washington, D.C.: U.S. Superintendent of Documents, 1983. Booklet provides a good source of information and technical data.

GRAY- AND BLACKWATER SYSTEMS

Burks, Bennette; and Mary Minnis. *On-Site Wastewater Treatment Systems*. Madison, Conn.: Hogarth House Ltd., 1994. Introductory text for engineers, policymakers, and citizens. This book covers on-site wastewater treatment history, process design theory, soil science, installation, operation, and land use.

WATER RECLAMATION AND REUSE

Brittain, Richard G.; K. James DeCook; and Kenneth E. Foster. *Water Harvesting and Reuse: Designing an Urban Residential Demonstration*. Tucson: University of Arizona, College of Agriculture, Office of Arid Lands Studies, 1984.

Small Flows Clearinghouse. *Municipal Wastewater Reuse: Selected Readings on Water Reuse*. Morgantown, W.Va.: National Small Flows Clearinghouse, 1991. A bound collection of current articles and case studies on a variety of water-reuse projects and issues.

U.S. Environmental Protection Agency. *Guidelines for Water Reuse*. EPA/625/R-92/004. Washington, D.C.: GPO, 1992. Technical manual on water-reuse issues and applications, including regulatory guidelines and funding alternatives.

EXAMPLES OF REGIONAL GUIDELINES AND STANDARDS

Association of Bay Area Governments. *Manual for Erosion and Sediment Control Measures*. Oakland: Association of Bay Area Governments, 1995.

Birch, Peter B.; Helen E. Pressley; and Patrick D. Hartigan, eds. and comps. *Stormwater Management Manual for the Puget Sound Basin (The Technical Manual)*. Olympia: State of Washington Department of Ecology, 1992.

Goettemoeller, Robert L., and David P. Hanselmann. *Ohio Stormwater Control Guidebook*. Columbus: Ohio Department of Natural Resources, Division of Soil and Water Districts, 1980.

Livingston, Eric H., and Ellen McCarron. *Stormwater Management: A Guide for Floridians*. Tallahassee: Florida Department of Environmental Regulation, Stormwater/Non-Point Source Management, n.d.

Morton, William B. *Reducing the Impacts of Stormwater Runoff from New Development*. Albany: New York State Department of Environmental Conservation, Bureau of Water Quality Management, 1992.

Virginia Department of Conservation and Historic Resources. *Virginia Erosion and Sediment Control Handbook*. Richmond: Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, 1992.

NOTES

1 Harold P. Guy, *Sediment Problems in Urban Areas*, Circular 601-E (Washington, D.C.: U.S. Geological Survey, 1970).

2 Bruce K. Ferguson, "Landscape Hydrology; A Component of Landscape Ecology," *Journal of Environmental Systems* 21, no. 3 (1992): 193–205.

3 Herbert F. Bormann, Diana Balmori, and Gordon Geballe, *Redesigning the American Lawn: A Search for Environmental Harmony* (New Haven: Yale University Press, 1993) 19.

4 James B. Beard and Samuel I. Sifers, "Stabilization and Enhancement of Sand-Modified Root Zones for High Traffic Sports Turfs with Mesh Enhancements," *Texas Agricultural Experiment Station Bulletin* no. B-1710 (College Station: Texas A&M University, 1993); David Nichols, "Comparing Porous Pavers," *Landscape Architecture* 85, no. 5 (1995): 26-27; and Robert J. Southerland, "Concrete Grid Paver Construction," *Landscape Architecture* (March/April 1984): 97.

5 Bruce K. Ferguson, *Stormwater Infiltration*, (Boca Raton, Fla.: CRC Press, 1994) 52–5.

6 Bruce K. Ferguson, *Stormwater Infiltration*; and Kim Sorvig, "Porous Paving," *Landscape Architecture* 83, no. 2 (1993): 25.

7 Thomas R. Schueler, *Design of Stormwater Wetland Systems* (Washington, D.C.: Metropolitan Washington Council of Governments, 1992).

8 Sandra Postel, "Facing Water Scarcity," *State of the World 1993*, ed. Linda Starke (New York: Worldwatch Institute, 1993), 22, 23.

9 Arnold Pacey and Adrian Cullis, *Rainwater Harvesting* (London: Intermediate Technology Publications, 1986), 2–5.

10 Arsen Darnay, ed., *Statistical Record of the Environment* (Detroit: Gale Research, 1992), 575.

11 Ibid., 666.

12 Jeffrey Payne, and Camp, Dresser & McKee, "Summary of Water Reuse Regulations and Guidelines in the United States" (Anaheim, Calif.: The Water Environment Federation 66th Annual Conference, October 3-7, 1993).

CHAPTER 7

Site Materials and Equipment

Author
Kim Sorvig

Outdoor construction and site modification rely on diverse materials: living plants and soils, raw materials, and manufactured items. The careful selection of site materials is an essential part of environmentally conscious design. Selection variables to be considered include toxicity in manufacture and use; energy consumption in extraction, manufacture, or transport; potential to intensify heat, glare, runoff, wind, or other climatic factors; and, in the case of plant materials, invasiveness, water consumption, and disease susceptibility.

Material performance depends upon bio-regional characteristics: a plant or paving stone suitable in Miami is unlikely to perform well in Anchorage or Albuquerque. Likewise, material selection must be specific to the proposed uses of the site: native grasses or porous asphalt may be ideal for low-traffic locations, but not for heavily used public spaces. Specialized site knowledge is essential to making good choices, and early integration of regionally appropriate, ecologically based principles can significantly enhance project success.

Soils and Soil Amendments

★ SIGNIFICANCE

Soil is an irreplaceable living resource that, once removed or killed, can take decades (in some regions millennia) to re-form.[1] While soil serves many mechanical purposes for construction, regarding it as inert invites problems—from mudslides and cracked foundations to unhealthy landscape plantings. For these reasons, soil characteristics must be respected during design, and the soil itself protected during and after construction. Sustainable development avoids building on prime agricultural soils, and requires that on each site enough undamaged, fertile soil remain after construction to support plant and wildlife diversity, infiltrate precipitation, and filter pollutants that cannot be controlled at their sources.

Soil fertility not only supports plant life but also disperses and filters water, and neutralizes or binds many air and water pollutants. The source of all these benefits is the topsoil, a gossamer-thin blanket over the earth; its depth is a millionth or less of the earth's radius (0.5 inch to 48 inches is typical of most North American soils).[2] Topsoil consists of two parts: a mineral element (sand, silt, and clay in varying proportions, weathered from subsoil) and organic materials (decaying plant and animal remains known as humus). These organic materials are digested and churned by micro- and macroscopic soil organisms whose health is essential to fertile soil.

Soils vary in water-holding ability, nutrient content, pH and salinity, and humus content. They may also be contaminated or, in rare cases, naturally toxic. Each aspect can dramatically affect plant, animal, and human life on the site, as well as construction projects.

Soil's mechanical properties affect what can be built on a site. Depth and strength of bedrock affects structures, excavations, and costs. Percolation affects septic systems and flooding. Erodible soils are vulnerable to foot or vehicle traffic and to changes in vegetative cover. Erosion can damage a watershed's ability to distribute and retain water, contribute to flooding, and contaminate water sources. Performance and review of site-specific soil analysis reveal how these factors affect a building project.

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Involve a qualified site-design professional on the design team early in the project.**

❑ **Obtain and evaluate the chemical and physical characteristics of site soils.**
A general picture of soil characteristics is available for most U.S. counties from the U.S. Soil Conservation Service's *Soil Survey*, and is essential for early planning and design work. Before proceeding with detailed design, contract with a reputable soil-testing laboratory. Be sure the service includes a written evaluation of soil suitability for the proposed use, and recommendations for soil remediation and amendment. Use soil analysis to rule out contamination before the site is purchased.

❑ **Amend the soil in planting areas according to professional advice.**
Involve a qualified site-design professional on the team early in the project. Develop a plan to leave as much of the native soil undisturbed as possible. Amendments may include sand or gravel for improved drainage, lime or other pH modifiers, organic manures, and chemicals to improve nutrient availability. Humus is used to increase water-holding capacity, as are proprietary superabsorbent materials. In some cases, amendment may involve specific plowing or irrigation activities—for example, to break a hard-pan or to leach out excessive salts.

❑ **Protect the soil during construction.**
Soil compacted or contaminated by construction activity may become lifeless.

- Design for minimal grading. Where grading is unavoidable, carefully remove and stockpile existing topsoil, replacing it after rough grading. Depending on soil-test findings, the top four to six inches of soil are usually stockpiled.
- Plan construction sequences that minimize heavy-equipment movement over the soil; restrict all equipment, including private vehicles, generators, etc., to areas that will be paved or built over.
- If soil compaction is unavoidable (as with a construction-access road) remediate by tillage and amendments before completing work.

(See Chapter 19, "Environmental Construction Guidelines.")

❑ **Carefully design for grading and excavation.**
In siting facilities, work with the existing topography to save both construction and maintenance costs. Avoid disrupting existing drainage patterns; equalize cut-and-fill; and in general minimize grade changes where possible. Grading for stormwater control

should direct water to planted areas to minimize irrigation needs. Steep sites may benefit from terracing and retaining walls.

❑ **Follow all applicable erosion-control regulations.**
During construction, any exposed soil is susceptible to erosion and contributes to sedimentation downstream. Most jurisdictions require erosion and sedimentation protection.

❑ **Stabilize soil during and after construction.**
Commonly used temporary controls include filtration barriers (straw-bale dams, filter-fabric fences), soil tackifiers, jute netting, hydroseeding with quick-sprouting plants like annual rye-grass, or mulch. More permanent soil stabilization may be required: use geo-textiles (fabrics designed to filter soil from water); soil “cells” separated with masonry, wood, or fabric; and crib- or retaining walls.

❑ **Use bio-engineering.**
One of the most effective, and certainly the most ecological, of soil-stabilization methods is bio-engineering, which weaves live woody cuttings into a living retaining structure that mimics the soil-retention capabilities of matted roots.[3] The flexibility of such live structures protects them from wash-out problems common with rigid constructions.

❑ **Schedule soil-maintenance tasks.**
A site-specific schedule of soil-maintenance tasks, in parallel with planting-maintenance tasks, should be developed.

Plant Materials and Management

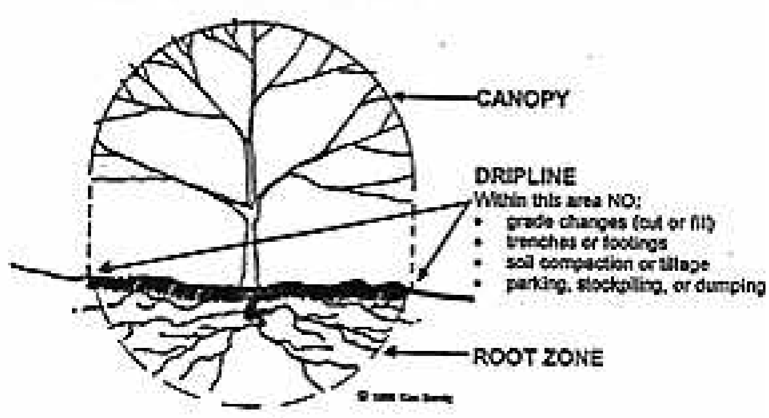
★ SIGNIFICANCE

Without plants, life on earth would cease. Plants provide oxygen; purify air; buffer climatic conditions; and modify shade, sun, wind, temperature, run off, and humidity. Landscape planting can also separate incompatible activities, allowing better use of space. Most cultures treat well-planned, healthy landscapes as important assets; this can add significant resale value to buildings.[4]

Site design and planting affect ecosystem diversity. The average garden contains only a few plant species, less diverse than most native plant communities. Landscapes planted with predominantly non-native species and maintained with pesticides tend to reduce overall diversity and increase water use, thus damaging native ecosystems. Habitat destruction, to which non-native planting can contribute, causes nearly half of all species extinctions.[5] Sustainable development strives to maintain native habitat, and avoids fragmenting it or replacing it with less diverse vegetation.

Figure 1

THE DRIPLINE: A RULE OF THUMB TO PROTECT EXISTING TREES FROM ROOT DAMAGE



☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Include an ecologically knowledgeable landscape architect as an integral member of the design team.**

❑ **Preserve existing vegetation, especially native plants.**

– Design to avoid sprawl, which destroys native plant communities.
– Use greenbelts and protected wetlands to create a continuous web of native habitats (also serving as bikeways and trails) through which animals can migrate safely. Many communities have greenbelt groups and ordinances, both valuable sources of advice and guidance.
– Decrease parking, paving, and lawns to the minimum that will actually be used.
– Make every space serve several functions; where possible, make the landscapes of public or institutional buildings available to the local community, rather than fencing them off.
– Avoid "replacing" healthy mature trees with small nursery stock.

❑ **Protect existing plants during construction** *(Figure 1).*
Delineate and fence the "dripline" (area directly under the canopy) of all trees. Prohibit parking, stockpiling, heavy-equipment movement, or excessive foot traffic in fenced plant-protection zones within driplines; enforce with a liquidated-damages clause.

❑ **Design new plantings as diverse communities of species well-adapted to the site.**
Use primarily native species: they usually require less maintenance and less water than exotics after establishment (one or more seasons). Do not, however, expect "no-maintenance" landscapes. Reserve exotics for accents. Avoid use of any plant that is invasive: such species overrun native ecosystems. Avoid monocultures (plants of all one species or age), and use plants which attract desirable wildlife.

❑ **Follow Xeriscape™ principles.**
A trademarked term referring to water-efficient choices in planting and irrigation design. The seven basic Xeriscape™ principles for conserving water and protecting the environment are: planning and design, use of well-adapted plants, soil and climate analysis, practical, reduced turf areas, use of mulches, appropriate maintenance, and efficient irrigation by grouping plants with similar water needs. Coordinate plantings with water harvesting systems.[6]

❑ **Use plants to mitigate climate conditions.**
Deciduous plants, when correctly located, provide shade in summer and admit sun when their leaves fall for winter, a natural technique for passive solar design. Evergreen trees can provide year-round sun and wind protection (see Chapter 11, "Renewable Energy"). Windbreak plantings diminish wind within a distance three times their height. To decrease noise significantly, a wide (200-foot) band of plantings is required.

❑ **Use a reputable nursery or contractor to supply and install plants.**
Do not accept wild-dug plants, which may be endangered, and whose removal impoverishes other landscapes. Specify plants grown in the same U.S. Department of Agriculture (USDA) Hardiness Zone as the site, preferably within a 200-mile radius. Seed or seedlings may be cost-effective for mass planting, and tend to develop good hardiness. The planting contract should require the contractor to plant during the correct season (which varies by species), and to maintain all plantings through at least one full growing season after planting, with a warranty to replace any plant that dies within that time.

❑ **Employ integrated pest management (IPM) against insects and weeds.**
IPM uses biological controls as a first defense; if such non-toxic controls fail, carefully timed and targeted pesticides are used. Biological controls include parasitic insects, which destroy pests; pheromone (sex-scent) traps; natural pesticides like pyrethrum; and companion-planting. Artificial pesticides should be chemically targeted to a nar-

row range of pest species, and should be chemically non-persistent in soil, air, or water. They must also be *physically* targeted, using accurate, low-volume applicators to avoid drift and oversaturation. Workers must be trained in proper application.

❑ **Use mulching, alternative mowing, and composting to maintain plant health.**
Organic mulch around plantings conserves water and maintains favorable soil temperatures. Mulch may be purchased; cleared or trimmed vegetation can be chipped economically for mulch using a rented chipper. Mulching mowers leave fine clippings on lawns as mulch. Any form of mulch eventually breaks down and recycles its nutrient content. Composting plant debris in piles or bins hastens this breakdown; the compost is then used as soil amendment. Many municipalities maintain composting services. Compost maintains soil fertility better than chemical fertilizer, and helps landscape plants resist pests and diseases without pesticides.

❑ **Compile and follow a seasonal maintenance task list.**
Regular maintenance is essential to a healthy landscape that fulfills the design vision as it grows. The schedule should specify times for pruning, watering, fertilizing, and pest inspection.

Paving Materials

★ SIGNIFICANCE

Thousands of acres of land are paved annually in this country, although much of the paved area is under used: streets deserted except at rush hour, church parking lots barren during the work week, and city-hall spaces vacant on weekends. Underutilized paved surfaces waste materials, energy, and financial resources and eliminate natural habitat for plants and animals.

To create stable surfaces for human activities, most traditional paving excludes water from the soil. This impermeability results in increased run off, erosion, flooding, and loss of soil fertility. Pavement retains heat, contributing significantly to urban “heat sinks” and increased HVAC energy use. It also can cause uncomfortable glare and create harsh, alienating environments.

Zoning laws in some communities limit the creation of new impermeable surfaces. A variety of permeable paving surfaces, as well as non-pavement soil-stabilization methods, can partially overcome the disadvantages of “conventional” paving.

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Limit paved areas to the strict minimum for their intended purpose.**
For example, parking spaces based on the nine- by 18-foot standard save nearly 20 percent more land area than ten- by 20-foot spaces. Many zoning ordinances overcalculate parking “needs.” In such cases, seek a variance and consult recent federal laws, like the Intermodal Surface Transportation Efficiency Act (ISTEA), that strike a more reasonable balance between private cars and transportation alternatives. The Act provides funding for state and metropolitan transportation planners to integrate car, bus, train, bicycle, and pedestrian modes of transport, thus reducing dependence on private cars.[7]

- ❑ **Carefully distinguish between light-vehicular, heavy-vehicular, and pedestrian paving.**
  In landscape design, vehicular-strength paving is often used by default even for sidewalks; this unnecessarily eliminates beautiful alternative materials, and wastes materials and money, since many paving materials are non-renewable and energy-intensive, and should not be wasted.
- ❑ **Use water-permeable or "porous" paving.**
  Porous asphalt and concrete are made with aggregates carefully sorted to eliminate "fines" (small particles). Removing fines opens voids that allow drainage, yet porous paving retains most of the strength of conventional paving. Porous paving is suited to parking and lightly used roads; in high-traffic areas, combine it with conventional paving.[8]
  Other permeable systems include block-lattices, which permit drainage but give stability (grass grows in the lattice spaces, while the blocks support vehicles). Lattices are best used for occasional access (fire lanes, overflow parking); constant traffic may kill the grass, as may harsh climates. Some permeability can also be achieved by setting traditional stone or masonry pavers on sand instead of on concrete.
- ❑ **Design paving to serve dual purposes.**
  Porous paving is often constructed over a gravel reservoir sized to hold stormwater volume, thus combining parking and a retention basin within a single area. Such space saving is both economically and environmentally sound.
- ❑ **Design to minimize runoff.**
  Curbed pavement edges concentrate runoff, which increases potential for erosion and flooding. Where possible, porous gutters and curbless designs spread run off more usefully. In general, runoff should be infiltrated as close as possible to its source; flow concentrated over long distances picks up speed and erosive power, and disrupts the distribution patterns of natural precipitation. Infiltration at the source is also more cost-effective (see also Chapter 6, "Water Issues").
- ❑ **For light-duty roads and paths, stabilize *without* pavement.**
  Correctly installed, crushed stone or brick is a stable, porous surface. Proprietary chemical additives can bond soil particles for stability. Geotextile webs and strips are used, much like the straw in traditional adobe, to increase soil strength without affecting its drainage or growing characteristics. Such surfaces are slightly flexible, which minimizes cracking and decreases maintenance costs.
- ❑ **Locate pavement where solar heat gain is desirable.**
  Texture, type, and color of pavement can reduce or concentrate heat or glare if coordinated with prevailing climate conditions. Coordinate paving design with plantings and shade structures to avoid glare and unwanted heat gain. These factors are particularly important in hot and cold environments.[9]

Materials for Site Construction and Furnishings

★ SIGNIFICANCE

Careful selection of site construction materials can reduce energy consumption and waste, increasing human comfort without excessive environmental costs. Inappropriate selection of materials can cause resource depletion and environmental contamination, either at the site or at the source of the material. Many environmental effects of resource use are indirect. Only a few common site materials are directly toxic to soils or plants;

others, not themselves toxic, require toxic processes in their manufacture. Site material extraction (like logging or mining) can also have environmental consequences by increasing erosion and contaminating water bodies.

Site materials face severe conditions, such as exposure to water, freezing, and ultraviolet rays.[10] When site materials fail, resources are wasted and soil or water may be contaminated. Materials must also be physically and psychologically comfortable for outdoor use: for example, metal seating is uncomfortable except in moderate temperatures.

No single rule or practice can guarantee materials that are both environmentally appropriate and suitable to their construction purpose. Materials should be compared not only against other materials, but against the baseline of a "no-build" option. Consider each material's "embodied energy," the known amount of energy expended in its extraction, transportation, production, recycling, and disposal. Selecting products manufactured locally can reduce embodied energy by decreasing transportation. Also important is the product's life cycle. Life-cycle cost (LCC) analysis takes into account purchase, operation, maintenance, replacement, and disposal costs over the expected service life of the product, thus revealing cost/benefits more clearly than conventional cost analysis.[11] Life-cycle assessment (LCA) is a related analysis method that helps compare the environmental consequences of material choices. (See the American Society for Testing and Materials (ASTM) Standards E 917-93 and E-50.06 (Draft); and Chapter 2, "Selecting Environmentally and Economically Balanced Building Materials," for more information on LCC and LCA.)

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Reduce material use, reuse, and recycle—in that order of priority.**
- Reduce material requirements through effective site layout. For example, re-routing a walkway or rotating a building can eliminate a costly retaining wall and site grading. Structures designed and sited without careful regard to site-specific conditions create structural, maintenance, and ecological problems.
- Specify reused materials where possible. With the exception of railroad timbers, reuse is rare in landscape materials. In some regions, used brick is a popular commodity, and other durable items like flagstones are reused.
- Specify recycled-content materials for site use, based on life-cycle performance requirements. Wood substitutes made of recycled plastic are now available as lumber and in site furniture. Concrete and asphalt can also be recycled.

❑ **Use new materials thoughtfully; consume the minimum for the purpose; avoid waste.**
Support manufacturers whose product literature includes environmental data. Consider renewability (can the material be *grown* or naturally replenished?), sustainable production (will resources be used up too fast?), and recyclability. For example, wood is renewable and recyclable, but production of some timber species is not sustainable at current rates of consumption. Several natural ecological timber organizations provide useful information about these issues.

❑ **Perform an environmental-impact and cost analysis of all materials based on life-cycle principles.**
(See Chapter 2, "Selecting Environmentally and Economically Balanced Building Materials," and Chapter 17, "Specifications.")

Irrigation Equipment

★ SIGNIFICANCE

In dry regions of the United States, landscape irrigation can constitute half a city's water usage; up to half of that is wasted.[12] Facing such statistics, municipalities are enforcing water-efficiency laws and strictly monitoring commercial landscape irrigation.

Automatic irrigation systems can save water when compared to hand-watering or flood irrigation. However, by definition, any form of irrigation involves addition of surface water beyond what is naturally found on-site. The baseline for evaluating irrigation strategies should be natural precipitation and practices that rely on it. Even efficient irrigation should not be *assumed* to be environmentally responsible without comparison against this baseline.

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Base irrigation design on Xeriscape™ principles.**
See "Plant Materials and Management" section of this chapter concerning this approach to water-efficient irrigation and planting design.[13] Always coordinate design of planting and irrigation system.

❑ **Employ water-harvesting techniques.**
Using processed city water for irrigation is wasteful, since plants do not require potable water, and are often vulnerable to chlorine. For landscape purposes, use cisterns or ponds to collect run off from roofs and pavement. Check dams trap runoff in pockets to support plants, as do swales. Diversion of water along key contour lines, or "keylines," efficiently spreads runoff along topographic planes for gradual release[14] (see Chapter 6, "Water Issues").

❑ **Use graywater in irrigation.**
Graywater plumbing (separated from sewage pipes, either by retrofit or in new construction) can save money and reduce water consumption (see Chapter 6, "Water Issues").

❑ **Install drip irrigation systems.**
Drip irrigation systems direct water accurately onto the base of each plant. Drip systems may use less than half the water of conventional systems, which lose water to evaporation and soak areas of soil that may not need water. Uniform drip watering often produces faster, healthier plant growth. Surface drip systems usually use "spaghetti tubing" while underground systems use "leaky" pipe (permeable-walled pipe specific to underground drip irrigation).

❑ **Increase efficiency of irrigation with controllers and sensors.**
Timers and computers provide measured amounts of water at regular intervals. Sensors override the timer in response to rainy or windy conditions, reducing waste. Such controls and the electrical valves they operate require power, either from a transformer or, in some systems, solar electricity.[15]

❑ **Be sure design and layout of the irrigation system are site-specific.**
Topography, structures, and drainage affect the direction, height, and coverage of spray-heads. The site's lowest sprinkler often leaks wastefully after the system is turned off, as water further uphill drains to the low point. Overspray can result either from bad design or from wind. Drip systems avoid these problems, but share the problem of pressure drop: the farther water flows through a pipe, the lower its pressure.

❑ **Maintain irrigation systems regularly for efficiency.**
Poor maintenance causes significant water losses and undermines the value of irrigation systems. Periodically adjust sprinkler output by testing actual performance with a rain-gauge. Inspect for vandalism, accidental damage, and sinkage; reset sprinkler heads flush with the ground. Regularly inspect for leakage. Drain the system for winter, and flush it when reactivating. Recent systems are self-cleaning; older ones may require flushing to remove sediment.

Outdoor Lighting and Electrical Systems

★ SIGNIFICANCE

Lighting consumes about one-fifth of all U.S. electricity; of this, existing efficiency measures could save an estimated 90 percent. Site lighting, one of the fastest-growing sectors of the lighting industry, can be carefully designed to avoid waste. The environmental and social costs of this type of lighting must be carefully weighed against its benefits.

"Light pollution" can disrupt biological cycles in plants and animals, including humans. Glare increases hazards by blinding people and making areas outside the light even less visible. Jurisdictions like Tucson, Arizona, with astronomical observatories and other specialized facilities, have legislated against light pollution, which often hinders effective stargazing by over-illuminating the night sky.

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Light the minimum area for the minimum time.**
Limit all-night illumination to areas with actual all-night use or extreme security concerns—simple timers or photocells can be used to turn lights on and off at seasonally appropriate times. For security lighting, motion-sensors can spotlight intruders without beaming constant glaring lights.
- Use cut-off fixtures, shades, or highly focused low-voltage lamps to avoid spillover. Linear "tube lights" and fiber-optics can light the way for pedestrians without illuminating a whole area.
- Question the "brighter is better" myth, especially for security and advertisement.
- Some local ordinances encourage excessive lighting; seek waivers or revisions.

❑ **Clearly identify the actual purpose of lighting to determine minimum acceptable levels.**
Hazard lighting is usually focused on the hazard, bright enough to warn, identify, and allow judgment of distance. Area lighting, seldom as bright or focused, allows a user to choose a safe route.[16] Follow manufacturer's guidance on light distribution and intensity.

❑ **Use energy-efficient lamps and ballasts.**
The most efficient new lamps produce *ten times* as many lumens per watt of power as a conventional incandescent bulb. Most newer bulbs are designed to fit old fixtures; some require a conversion kit. Operating-cost savings (including deferred bulb replacement, labor, and equipment rental for inefficient, hard-to-reach parking-lot lamps) quickly recover the cost of re-lamping. New fixtures are often miniaturized, allowing design flexibility.

❑ **Use low-voltage lighting.**
Increased efficiency has made 12-volt or 24-volt lighting effective and popular for site lighting.[17] Lower-voltage fixtures are safer and often less expensive to install than typical 120-volt options. They can decrease power and energy usage.

❑ **Use renewable energy sources for lighting and other outdoor power.**

Photovoltaic (PV) power is generally cost-effective if a site is over 200 yards from the utility grid, and is an attractive alternative to power lines running through a site.[18] PV power is low-maintenance and very reliable. Its design *must* be specific to both the region and the site. It is possible to incorporate PV panels attractively into architectural elements like windows and roofs. Photovoltaic power requires storage batteries for nighttime lighting. Manufacturers offer solar path-lights, streetlights, and security lights. Extremely bright all-night lighting is difficult to achieve with PV power; however, as noted above, it is desirable to avoid such lighting strategies. Solar electricity is also ideal for running pumps, including irrigation systems. Solar-powered water purification and even solar lawn-mowers are becoming available, and deserve consideration.[19] For daytime uses, batteries are not usually needed, except where long cloudy periods are common (see Chapter 11, "Renewable Energy").

→ RESOURCES

SOILS

Brady, Nyle C. *The Nature and Properties of Soils*. 8th ed. New York: Macmillan, 1974. Classic text on the make-up, fertility, and mechanics of soils.

Carter, Vernon Gill, and Tom Dale. *Topsoil and Civilization*. Rev. ed. Norman, Okla.: University of Oklahoma Press, 1974. Sobering account of human dependence on soil.

Davidson, Donald A. *Soils and Land Use Planning*. New York: Longman, 1980. How soil characteristics can make or break zoning and development policies.

Olson, Gerald W. *Field Guide to Soils and the Environment: Applications of Soil Survey*. New York: Chapman and Hall, 1984. Unlocking the wealth of information found in USCS *Soil Surveys*.

Schiechtl, Hugo. *BioEngineering for Land Reclamation and Conservation*. Edmonton: University of Alberta Press, 1980. Detailed techniques of soil stabilization and protection using live plant structures.

U.S. Soil Surveys map soils by county and give information on engineering and ecological characteristics of site-specific soils. Contact the U.S. Soil Conservation Service, P.O. Box 2890, Washington, DC 20013, 202/447-4543 (Canada: 306/695-2284).

PLANT MATERIALS

Regional native-landscaping books are essential for ecologically appropriate planting design. If a garden design book does not state which geographic region it covers, assume that it focuses on the Eastern Deciduous Forest region. It is also likely to include many British horticultural imports without noting that these are non-native.

Cornell University. Bailey Hortorium. *Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada*. New York: Macmillan, 1976. Standard reference on plants cultivated in the U.S., including origin. Third or later editions recommended.

Druse, Ken. *The Natural Garden*. New York: Potter, 1989. How to design minimal-maintenance gardens with native plants.

Harker, Donald, et. al. *Landscape Restoration Handbook*. Boca Raton, Fla.: Lewis, 1993. Region-by-region reference (continental U.S.) listing best plants for restoring damaged ecosystems; maps and plant-category tables aid selection.

Hightshoe, Gary L. *Native Trees, Shrubs, and Vines for America: A Planting Design Manual for Environmental Designers*. New York: Van Nostrand Reinhold, 1988. Each native species illustrated; its growing needs, natural range, and landscape value charted.

Smyser, Carol A. *Nature's Design: A Practical Guide to Natural Landscaping*. Emmaus, Penn.: Rodale, 1982. Includes regional plant lists and a brief introduction to biological pest controls, plus excellent design methodology.

PAVING MATERIALS

Jacobs, Allan B. *Great Streets*. Cambridge, Mass.: MIT Press, 1993. Illustrated examples of successful streetscapes.

Paine, Jon E., ed. *Pervious Pavement Manual*. Orlando, Fla.: Florida Concrete and Products Association. Construction manual for porous concrete. Contact the Florida Concrete and Products Association, 649 Vassar St., Orlando, Fla. 32804, 800/342-0800.

Sorvig, Kim. "Porous Paving" *Landscape Architecture*, February 1993; and "The Path Less Traveled," *Landscape Architecture*, December 1994. Washington, D.C.: American Society of Landscape Architects. Porous asphalt and concrete, soil-cement, stabilized soil, and crushed traditional pavements are discussed.

Untermann, Richard K. *Accommodating the Pedestrian: Adapting Towns and Neighborhoods for Walking and Bicycling*. New York: Van Nostrand Reinhold, 1984. Strategies for existing developments or new ones to become less car-centered and more people-friendly.

U.S. Department of Energy. Lawrence Berkeley National Laboratories. *Cooling Our Communities*. U.S. Government Printing Office Document no. 055-000-00371-8. Paving and planting strategies to avoid heat build-up.

Vance, Mary A. *Garden Walls, Walks and Steps: A Bibliography*. Monticello, Ill.: Vance Bibliographies, 1986. Source-listing of information on paving and outdoor construction from many authors.

SITE CONSTRUCTION MATERIALS

American Society for Testing and Materials. Standard E 917-93. *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*. Philadelphia, Penn.: ASTM, March 1993.

American Society for Testing and Materials. Subcommittee on Green Buildings. *Standard Practice for Green Buildings*. Standard E-50.06, draft document, 1993. Contact ASTM, 100 Barr Harbor Drive W., Conshohocken, PA 19428, 610/832-9500.

Fisk, Pliny. *Bioregions & Biotechnologies* and *Sustainable Design Compendium*. Austin, Tex.: Center for Maximum Potential Building Systems, n.d. How to use native resources to produce ecologically intelligent development. Contact the Center for Maximum Potential Building Systems, 8604 F.M. 969, Austin, TX 78724, 512/928-4786.

Landphair, Harlow C., and Fred Klatt. *Landscape Architecture Construction*. New York: Elsevier, 1978. Standard reference on hardscape techniques.

Robinette, Gary O. *Landscape Architectural Site Construction Details*. Reston, Va.: Center for Landscape Architectural Education and Research, 1976; distributed by Environmental Design Press. Illustrated with construction detail drawings.

Sorvig, Kim. "Brave New Landscape." *Landscape Architecture*, July 1992. Washington, D.C.: American Society of Landscape Architects. Emerging and experimental materials in landscape construction. *Landscape Architecture*'s "Technique & Practice" column runs monthly updates on materials.

IRRIGATION EQUIPMENT

Ellefson, Connie; Tom Stephens; and Doug Welsh. *Xeriscape Gardening: Water Conservation for the American Landscape*. New York: Macmillan, 1992. Detailed instructions on irrigation and planting design; low-water plant-lists for all U.S. regions.

Gates, Jane Potter. *Drip, Trickle and Surge Irrigation*. Beltsville, Md.: National Agricultural Library, updated periodically since 1992. Review of irrigation technology and products.

Mollison, Bill. *Permaculture: A Designer's Manual*. Tyalgum, Australia: Tagari, 1988. Sourcebook of sustainable living techniques; includes many water-harvesting methods.

Sorvig, Kim. "Sun on the Water." *Landscape Architecture*, September 1994. Washington, D.C.: American Society of Landscape Architects. Solar-powered landscape irrigation.

Watkins, James A. *Turf Irrigation Manual: The Complete Guide to Turf and Landscape Sprinkler Systems*. Dallas, Tex.: Telsco Industries, 1987. Discusses irrigation hardware. Most irrigation manufacturers also offer detailed design manuals.

OUTDOOR LIGHTING AND ELECTRICITY

Moyers, Janet Lennox. *The Landscape Lighting Book*. New York: Wiley, 1992. Complete treatment of design, equipment, installation, and maintenance of outdoor lighting.

Post, Hal, and Vernon Risser. *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices*, Albuquerque: Sandia National Laboratories, 1988. Complete manual for planning and installing solar-electric power for any purpose.

Schaeffer, John, ed. *Alternative Energy Sourcebook: A Comprehensible Guide to Energy Sensible Technologies*. Ukiah, Calif.: Real Goods Trading Corporation, updated annually. Catalog with detailed technical explanations; items can be purchased through Real Goods.

Sorvig, Kim. "Low-Voltage Lighting," "New Light on the Landscape," "Transformations of Light," *Landscape Architecture,* January 1994; August 1993; and February 1994. Washington, D.C.: American Society of Landscape Architects. Reviews of current lighting for landscape use, including fiber optics and other unusual equipment.

NOTES

1 Nyle C. Brady, *The Nature and Properties of Soils*, 8th ed. (New York: Macmillan, 1974), 309.

2 Ibid., 9–10.

3 Hugo Schiechtl, *BioEngineering for Land Reclamation and Conservation* (Edmonton: University of Alberta Press, 1980), 37–139. This comprehensive source should be read thoroughly by anyone interested in bioengineering.

4 Lloyd W. Bookout, *Value by Design: Landscape, Site Planning, and Amenities* (Washington, D.C.: Urban Land Institute, 1994), 1–125. Detailed study of the value-added aspects of site design.

5 Daniel Chiras, *Environmental Science* (Redwood City, Calif.: Benjamin/Cummings, 1994).

6 Connie Ellefson, Tom Stephens, and Doug Welsh, *Xeriscape Gardening: Water Conservation for the American Landscape* (New York: Macmillan, 1992), esp. 3–130.

7 See Architectural Graphic Standards or similar reference works for national standards, and use minimum sizing possible, unless barred by local code. For information on ISTEA (Federal Law PL 102–240 enacted 1991) call your state Department of Transportation or the American Society of Landscape Architects Government Affairs Office, (202) 686–8351.

8 Kim Sorvig, "Porous Paving," *Landscape Architecture*, February 1993.

9 US Department of Energy. Lawrence Livermore Labs, "Cooling Our Communities," US Government Printing Office Document #055–000–00371–8 (Washington, D.C.: GPO, n.d.).

10 For discussion and examples, see Janet Lennox Moyer, *The Landscape Lighting Book* (New York: Wiley, 1992). Chapter 7 concerns corrosion of materials in contact with soil and weather; Moyer notes that several manufacturers experienced serious losses by merely adapting indoor fixtures for outdoor use (interview with the author, Albuquerque, 1994).

11 See Post and Risser, *Stand Alone Photovoltaic Systems* (listed in Resources) for clear examples of life-cycle costing, with worksheets.

12 Ellefson, Stephens, and Welsh, 3.

13 Ibid., 9. Principles of design and irrigation, and regional plant lists, are included.

14 Bill Mollison, *Permaculture: A Designer's Manual* (Tyalgum, Australia: Tagari, 1988), 155–170, 336–358.

15 Kim Sorvig, "Sun on the Water," *Landscape Architecture*, September 1994.

16 Jot. D. Carpenter, ed., *Handbook of Landscape Construction* (Washington, D.C.: Landscape Architecture Foundation, 1976), 191–200. Includes table of desirable illumination levels for various functions.

17 Kim Sorvig, "Low-Voltage Lighting," *Landscape Architecture*, January 1994.

18 Hal Post, and Vernon Risser, *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices* (Albuquerque: Sandia National Laboratories, 1988), 2, 7–86. Excellent detailed discussion, in clear language, of all aspects of photovoltaic use.

19 For information, consulting services, and supply of these and other alternative-power systems, see John Schaeffer, ed., *Alternative Energy Sourcebook: A Comprehensible Guide to Energy Sensible Technologies* (Ukiah, Calif.: Real Goods Trading Corporation, updated annually).

CHAPTER 8

Local Government Information: Site Issues

Sustainable Site Design

Author
Michael Myers

IMPLEMENTATION ISSUES

Environmentally sound site selection and design are evolving processes that integrate local needs with the existing natural environment and pre-existing infrastructure. Designers of local government projects should be especially aware of such issues as access to the site by public transportation, impact of development on the surrounding community, and inclusion of public amenities, such as recreational green space.

Fortunately, local governments are well-positioned to address these issues. They can influence the direction of development, for example, by promoting the redevelopment of urban areas, including abandoned industrial properties (or brownfields). This development strategy takes advantage of existing infrastructure, including sewers, roads, mass transit, and utility corridors; encourages environmental cleanups; and brings jobs to under-employed communities. It also reduces urban sprawl, which contributes to eroding urban tax bases, regional air-quality problems, and the destruction of farmland and natural resources. Local governments can encourage such reuse of existing or abandoned properties and develop green building strategies to promote revitalization of existing urban communities by working with state and federal agencies to revise zoning regulations and provide financial assistance and incentives to development initiatives.

Local governments can also consider and implement development options that utilize telecommunications technology to reduce transportation needs. Telecommuting, including the establishment of telecommuting centers, is being tested in communities across the United States. In addition, the redevelopment of older urban centers can be enhanced by the addition of telecommunications capacity in existing buildings.

As local governments consider site selection for and design of municipal, commercial, and residential structures, they also need to consider disaster resistant planning. Choices that keep in mind possible long-term weather trends can help jurisdictions avoid costly post-disaster relief and rebuilding measures. (See also Chapter 25, "The Future of Green Building.")

LOCAL ACTIONS

➤ The Stapleton Redevelopment Project, approved in March 1995 by the Denver, Colorado, Planning Board, is developing a mixed-use plan for the 4,700-acre site of the city's former international airport. The project is based on sustainable principles. It strives not only to integrate urban development, transportation, natural systems, and wildlife habitat, but also to create a balanced mix of uses and densities—including parks, housing, and businesses—for efficient, accessible, and diverse neighborhoods and communities.

The city's planning team is using a geographic information system (GIS) to assemble data on climate, water resources, land use, transportation, infrastructure, and community energy resources. This information will be used with the computer-based PLACES methodology to model present and future development options. Denver will be able to predict the impact and cost of development and design resource-efficient sites before any new structures are built.

The Stapleton Redevelopment Project also plans to reuse the airport terminal itself, turning the building into a site for new green businesses, as well as a center for established companies focusing on national and international business opportunities in the environmental and technology fields. Finally, the project will tap nearby community and academic resources to sponsor sustainable educational and training opportunities at the airport-terminal site.

➤ The Pennsylvania-based Slippery Rock Foundation, with a grant from the Howard Heinz Endowment, has developed *Guidelines for Sustainable Development* that provide design, construction, and operations suggestions. The guidelines provide basic green site-development recommendations, for example, the reuse of existing structures and already disturbed areas, evaluation of site resources, minimization of paving and impervious surfaces, and analysis of the future impact of a site within the broader context of community.

➤ The town of Carrboro, North Carolina, has instituted an architectural process that allows flexibility in site design and development. Carrboro's Arcardia neighborhood, for example, is in the process of developing 33 lots on 16 acres that have narrower-than-usual streets and homes built to satisfy passive solar guidelines. The homes feature radiant-heated floors and some photovoltaic hot-water systems; their landscape design reflects attention to water conservation and use of native plants.

➤ The city of Austin, Texas, *Sustainable Building Guidelines* encourage habitat preservation and site restoration, landscape designs that provide passive solar cooling, and the addition of plants and fountains to municipal buildings with main lobbies or to "front yards" of municipal buildings to create pleasant public gathering places.

➤ The new Clark County, Nevada, Government Center boasts landscaping that is both drought-tolerant and complementary to the building design and the natural environment. The center's planners have concentrated turf in a single multipurpose, functional area that provides a visual oasis as well as a community space for theater, music, and public gatherings.

➤ The village of Charlotte, North Carolina, is developing a mixed-use building project of 164 dwellings on 22 acres—while minimizing additional roads. Sustainability and ecological concepts, including construction-waste recycling and the use of graywater for irrigation, are part of the development process.

- ➤ The city of Chicago, Illinois, has launched a brownfield redevelopment program to promote new investment in older neighborhoods and inner suburbs. In 1993, Chicago formed an interdepartmental working group on brownfields to devise more responsive environmental and economic development policies, to develop economic models that account more accurately for the environmental and social costs and benefits of development decisions, and to implement pilot projects. Initial work on five brownfield sites has already resulted in remediation of the sites and buildings so that redevelopment can occur. These efforts will create local employment opportunities and improve the appearance and safety of the neighborhoods they target.
- ➤ After undertaking a regional planning effort, the city of Portland, Oregon, decided to concentrate development along mass-transportation corridors, encourage infill through zoning and loan incentives, and strive to retain green areas around the urban center.
- ➤ The city of Chula Vista, California, has developed telecommuting centers at decentralized neighborhood locations to reduce traffic congestion and air pollution. These centers offer fully equipped office and meeting rooms, videoconferencing and Internet access, and interactive video classrooms. The city encourages commuters to walk or cycle to the centers.
- ➤ To spur redevelopment in downtown Manhattan, the city of New York, the Alliance for Downtown New York, and other public and private development partners have established the New York Information Technology Center. Equipped with fiber optics; maximum band width, high-speed copper wire; Internet connectivity; state-of-the-art voice, video, and data transmission; and advanced telecommunications and data security, the building is a high-technology hub for the city's redevelopment efforts.
- ➤ The towns of Valmeyer, Illinois, and Pattonsburg, Missouri, following devastating floods in 1993, have taken the opportunity to replace and rebuild their communities, using sustainable development principles. To help avoid future flood disasters, the town of Valmeyer decided to relocate on higher ground, and, with resources from the U.S. DOE and state of Illinois, to incorporate energy efficient designs in its private and public buildings. Pattonsburg, working with the U.S. DOE and Federal Emergency Management Agency, developed a new town vision for the future that includes active public education and participation and passive solar land use plans.

LOCAL OPTIONS

- Develop a sustainable development plan for the community by scanning local resources and environmentally sensitive areas, mapping commercial and industrial areas, and identifying areas with the highest potential for public or private development or redevelopment.
- Promote the reuse of buildings by assessing existing structures to evaluate their suitability for physical renovation or for upgrades of utilities and telecommunications infrastructure to match current needs.
- Provide incentives for the redevelopment of inner-city areas, including brownfield sites, and for the use of resource-conserving practices when building on undeveloped greenfield areas.
- Assess transportation access—bus, bicycle, and pedestrian—when considering a site for development or redevelopment of municipal buildings.
- Assess the addition of information technology in new or existing buildings to reduce transportation needs and increase economic viability.
- Integrate transportation planning, including mass-transit and transportation-reduction measures, with long-range urban and regional land-use plans.
- Integrate sustainable landscaping principles, including retention of native plants, pleasing aesthetics, and multiple recreational uses, into the design of public outdoor areas.

- Provide guidelines for building orientation and siting that take advantage of solar access and other natural features.
- Integrate sustainable siting and building principles into disaster redevelopment projects.

Water

IMPLEMENTATION ISSUES

By regulation, education, and example, local governments are preventing water pollution, boosting water efficiency, protecting native vegetation, and using rainwater and graywater to meet water needs more resourcefully.

Local governments are implementing ordinances governing water runoff from construction and completed building sites to protect watersheds and the water quality of local creeks, streams, and lakes. Through public construction projects, cities and counties are also demonstrating to their communities that bioswales, semi-permeable pavement, and vegetative buffers can reduce non-point-source pollution.

Aware that efficient water usage impacts utility costs, wastewater treatment, and the quality of local water resources, jurisdictions are also promoting implementation of water-efficiency measures in all buildings: residential, multifamily, institutional, and commercial. Federal regulations have made indoor water-conserving fixtures, including 1.6-gallon toilets and efficient water-flow devices, readily available through most plumbing retailers; outdoor water conservation products are equally widespread. Local governments can recommend or require other water efficiency practices in their municipal projects.

Just as effective for cost-savings and the management of water resources are landscaping practices that use water-conserving or native plants. Public construction projects in many jurisdictions are educating residential and commercial builders about the use of native plants, plant-protection measures, and habitat preservation and restoration. Jurisdictions can compile an inventory of native plants to be used for public and private landscaping projects or direct builders to local nurseries or landscape architects that specialize in these plants.

Rainwater and graywater collection, despite their technical simplicity, are less easily implementable, but no less effective, strategies for water conservation. Communities may find these systems difficult to implement because of regulatory restrictions. Local governments can both provide examples of the effectiveness of these systems in public projects, and ensure that codes and permitting processes help, not hinder local builders from trying these alternatives.

A range of rainwater-collection systems, used for centuries in various forms, remain a practical option to collect water for irrigation and, in some communities, supply indoor water usage, including drinking water. Storage tanks or cisterns can be purchased in various sizes and colors and are available regionally.

Graywater systems for surface and subsurface applications are in place in many rural and in some urban areas. Many urban areas, however, may not allow installation of graywater systems, and if so, only as subsurface irrigation systems following specific health and usage regulations. Graywater systems can most easily be utilized during new construction, when separate collection and distribution lines can be installed most cost-effectively.

LOCAL ACTIONS

- Prince George's County, Maryland, has used bioretention practices in several revitalization, urban retrofit, and capital improvement projects designed to reduce urban runoff pollution entering waterways and, ultimately, the Chesapeake Bay. In one stormwater management project, the county added vegetation and settling ponds to an existing concrete drainage system; planted vegetative buffers between a parking area and the storm drain; and developed a constructed wetland to test the effectiveness of these practices in cleaning water runoff. The county has investigated, with the University of Maryland, ways to reduce non-point-source pollution resulting from pedestrian traffic and grounds-maintenance and storage practices at the university. Both partners explored improved practices for stormwater management and wildlife habitat retention. The university agreed to implement recommendations from the study as part of its normal maintenance operations.
- The city of Bellevue, Washington, has passed an ordinance tying stormwater bills to the amount of impermeable surface on each property within its jurisdiction. Each property in Bellevue is assessed in direct relation to its size and degree of development; fees from these assessments help fund water-quality protection. The city has established six categories of development, each assigned a coefficient for bill calculation purposes (wetland = 0.0, undeveloped = .25, light development = .40, moderate development = .50, heavy development = .75, very heavy development = 1.0). Any property can be downgraded one category if a water-detention area is constructed.
- The city of Portland, Oregon, Bureau of Environmental Services will build a new Water Pollution Control Laboratory to enable early detection of substances potentially harmful to operations of the city's wastewater treatment facility, and to reduce contaminants entering the Willamette River. The laboratory site will feature a state-of-the-art experiment in stormwater treatment: the Water Demonstration Garden, a pool with wetland plant life specially designed to clean stormwater naturally. The site will also feature a bio-engineered riverbank to stabilize the area, and a greenway along the waterfront.
- The city of Vancouver, Washington, is addressing limited water resources and rapid urban growth through the Climate Friendly Plant Program. This plant identification and marketing project, initiated by Vancouver's two primary water utilities, aims to reduce outdoor water usage by encouraging wide planting of native and non-native water-conserving vegetation commonly sold at local nurseries. These plants are often disease-and pest-resistant, reducing chemical pesticide use and resulting water pollution. Local utilities and nurseries market the city program.
- The city of San Diego, California, offers a free Residential Water Survey Program in which city technicians audit a home's indoor and outdoor water use and recommend specific conservation methods. The survey includes installation of low-flow showerheads, Xeriscape™ information, and a supply of native flower seeds. A typical household can reduce water consumption by 13 percent. Over 10,000 residents have participated in the program to date.
- The city of Austin, Texas, has developed three major watershed-protection ordinances to address urban runoff pollution of local waterways. Included in the ordinances are measures limiting impervious surfaces, encouraging buffer zones, limiting disturbances of natural streams, implementing erosion controls, and promoting construction of sedimentation and filtration basins. Integrated pest management plans that reduce outdoor chemical use are specifically required for projects in areas covered by the city's watershed ordinances, restrictive covenants, or zoning variances. Additional ordinances mandate protection of trees and natural areas, monitoring of water quality, and retrofits of pollution controls in areas identified as polluting.
- In another sustainable move, Austin has set a goal of reducing water consumption in municipal buildings by 30 percent. The city's plumbing codes require efficient fixtures, and suggest conservation practices for cooling towers, Xeriscape™ practices for landscapes, and use of rainwater, reclaimed-water, and graywater systems. Staff recommend

the collection and use of rainwater for irrigation, and the potential use of reclaimed water for irrigation, toilet-flushing, vehicle-washing, and cooling-tower make-up. Austin's Water and Wastewater Utility provide additional assistance in water-quality, health, and regulatory issues, particularly as these relate to the use of reclaimed water.

➤ Austin's *Sustainable Building Guidelines* are a valuable source of information on graywater and blackwater systems, as well as harvested rainwater collection. The guidelines include ordinances and regulations affecting use, a licensing and approval process, design considerations, and information on local experts and sources of systems components for storage and irrigation.

➤ Jordan Commons, a Habitat for Humanity housing development under construction in south Metro Dade County, Florida, is a model ecological community. Water conservation is one hallmark of its builders' efforts: all 187 homes will be fitted with water-efficient fixtures and 40 homes will feature graywater systems that use treated wastewater to recharge the aquifer and promote subsurface irrigation.

LOCAL OPTIONS

- Conduct an analysis of the non-point-source pollution impact of local water runoff from the built environment.
- Develop local guidelines to reduce non-point-source pollution and disruption to natural water cycles in the urban environment by reducing non-permeable surfaces and constructing vegetated drainage channels.
- Develop guidelines that require the collection of water runoff that may pollute local water resources during the construction or rehabilitation of buildings.
- Establish municipal landscape guidelines that promote local plants, which have low maintenance and water requirements.
- Design harvested-rainwater collection systems to supply irrigation water to local parks and recreation areas.
- Establish a water-fixture replacement program to upgrade equipment in existing municipal facilities, commercial buildings, and homes.
- Promote water conservation efforts and reduce water end-use in the design of new municipal facilities through water-conserving fixtures and graywater or harvested-water systems. Review local ordinances and modify them to allow the collection and use of harvested water, graywater, and reclaimed wastewater.
- Educate municipal, commercial, and residential building occupants about water conservation, pollution prevention, and construction-related practices—as well as pertinent local, state, and federal regulations—to ensure that water quality is maintained.

Materials and Equipment

IMPLEMENTATION ISSUES

Local governments that integrate sound soil maintenance and landscaping practices and efficient irrigation systems can reduce their use of natural resources, such as water, and maintenance supplies, such as pesticides or fertilizers. In doing so, they not only cut costs, but also benefit the environment—especially by restoring native plants and wildlife habitat.

Green building projects (and green buildings themselves) also offer local governments opportunities to educate their communities. By limiting permeable surfaces; using recycled-content outdoor equipment, such as trash cans or benches; and installing renewable-energy-powered lighting in outdoor public areas, cities and counties can demonstrate to their public the availability, durability, and practical application of green materials. For example, businesses, citizens, and public employees can work together in advisory committees to help shape green landscaping plans and environmentally sensitive choices of equipment and furnishings for public buildings, parks, and recreational areas.

LOCAL ACTIONS

- ➤ The city of Austin, Texas, suggests using ground-up wallboard (gypsum) as an amendment for clay soils; chipped wood from demolition for mulch; and recycled asphalt, concrete, and bricks for fill or aggregate.
- ➤ Codes in Metro-Dade County, Florida, allow demolition materials, such as concrete and bricks, to be used as fill in construction sites. They require the demolished material to be free of other substances, such as wood, that would contribute to sink holes. By reusing the material, builders avoid the landfill fees associated with demolition-waste disposal.
- ➤ The Health House '95, sponsored by the American Lung Association and built in Hennepin County, Minnesota, and the '95 Health House built in Orlando, Florida, both reflect a design concept called "naturescaping," used to incorporate native plants and recycled materials on the house sites.
- ➤ Metro-Dade County, Florida, offers property-tax breaks to commercial developers as incentives for preservation of existing vegetation on environmentally sensitive sites. Developers are required to actively maintain existing vegetation for 10 years in return for a tax break that is better, in some cases, than an agricultural exemption.
- ➤ The city of Austin, Texas, Nature Center, which provides a natural habitat for indigenous plants and animals, is a living learning tool for those who study the science and natural history of the area. Its educational resources include a pond trail exhibit and a hands-on compost demonstration area.
- ➤ The city of Durham, North Carolina used plants and recycled products for the landscape restoration of a park following the expansion of a road interchange. The city's Water Resources Department and its Parks and Recreation Department worked with citizen groups to plant several "pods" of trees and shrubs, reintroducing native species and eliminating labor-intensive turf.
- ➤ The city of Austin, Texas, offers the expertise of landscape architects from its Environmental Services and Conservation Department's Water Conservation Program to help other municipal departments design resource-efficient landscape and irrigation systems. The architects have developed a Preferred Plant List for municipal projects that emphasizes native and low-water plants, and recommended integrated pest management practices. Xeriscape™ landscapes in Austin, studies have shown, use 30 to 50 percent less water than traditional landscapes use.
- ➤ The city of Sarasota, Florida used a permeable pavement to allow public access to and parking on a parcel of land in a pineland marsh reserve. The pavement, a six-inch plastic cellular confinement system, known commercially as GEOWEB, is covered with six inches of stone in-fill and one inch of stone cover to allow both permeability and access, even during the rainy season. The system's cost is only one-third that of a traditional paved road.
- ➤ The cities of Atlanta, Georgia; Baltimore, Maryland; Miami, Florida; Milwaukee, Wisconsin; and Austin, Texas, are participating in the "Cool Communities" program, in partnership with American Forests and the U.S. Environmental Protection Agency. This program seeks to reverse heat-island effects of urban areas, to reduce energy usage

and global warming, by the strategic planting of trees and use of light-colored surfaces for roads, parking lots, and building roofs and walls.

➤ The city of San Diego, California, Park and Recreation Department developed efficient turf-irrigation systems to minimize water use. Irrigation system replacements, retrofits, and performance checks have resulted in a combined total reduction in water usage for 1990 to 1994 of 1,700,000 hundred cubic feet (HCF), a cost savings of over $2 million for the department despite the addition of over 40 new parks since 1989.

➤ Communities in Chittenden County, Vermont, have begun to set standards and guidelines for exterior lighting to preserve the region's natural nighttime beauty. The goal is to increase energy efficiency, provide clear standards and guidelines for lighting designs, and preserve nighttime landscapes. The municipalities of Burlington, Shelburne, and Richmond, key players in the effort, are all concerned about the control of overall illumination levels, glare, and color distortion from outside lighting. Other concerns include balancing aesthetics, safety and security, and the capital or operating costs of lighting fixtures; the impact of high-pressure sodium street lights on the natural and built environment; and, in some cases, discouraging the installation of new lighting in neighborhoods.

LOCAL OPTIONS

- Develop site-maintenance plans for municipal properties that include soil upkeep with mulch and composted materials, integrated pest management, reduced fertilizer use, and native plants with low irrigation needs. Use drip irrigation and programmable timers for irrigation systems with rain shut-off valves.
- Sponsor site design competitions. *Landscape Architecture* magazine, for example, sponsors an annual competition for innovative, ecologically sensitive residential landscape designs.
- Develop a native plant list for the region. Indicate a preference for native plants for landscaping projects on public property and make the list available for private developers.
- Involve the public in identifying and mapping trees of significance to the community. Develop a Tree Preservation Plan for municipal construction projects, and encourage commercial and residential projects to adopt it as a model.
- Designate the use of products with recycled content for the construction of park benches, fences, storage sheds, and walkways for municipal projects, when economically feasible. Locate regional sources for equipment and furnishings featuring recycled content or reusable materials.
- Require municipal projects to use semipervious parking pavers or no paving, where feasible, or require them to match a percentage of parking spaces with a certain number of new trees. Encourage these practices in commercial projects also.
- Develop lighting guidelines that balance safety, aesthetics, and community values. Consider renewable energy resources, such as photovoltaic systems, for outside lighting along landscapes, trails, and walkways, and for other electrical needs.

➔ RESOURCES

Resources for the Local Government Information chapters are located in the Appendix.

PART IV

Building Design

Introduction

Building design is moving into an extraordinary phase of evolution in this decade. Strategies that have been considered "cutting-edge" in the recent past—such as passive solar design, environmentally sensitive design, and design that emphasizes indoor environmental quality—are now becoming prominent and economically feasible. In Part IV, these strategies are applied to the design process to offer a new perspective on buildings—one that exceeds conventional practice in a variety of ways.

In Section A, the chapters deal with passive solar design through a discussion of daylighting, building envelope, and renewable energy—the basic strategies of green design that adapt a building to its site and climate. Section B focuses on building systems—heating, ventilating, and air-conditioning (HVAC) systems; lighting; and electrical technologies that support and must be integrated with the passive design in an efficient and appropriate manner. Other chapters in Section B address indoor environmental quality, including air quality and acoustics, and building commissioning. Section C provides a decision process and criteria for selecting environmentally sound materials for a construction project, and the means to incorporate environmental components into construction specifications.

An integrated approach is required for successful application of these strategies. The whole picture is one of a building as a complete system, with the building siting, form, envelope, systems, and contents simultaneously interacting together and fitting their setting in nature. The resulting building will perform as a resource-efficient and cost-effective system designed to enhance occupants' productivity and health. A whole-team approach, commencing early in the design process, is necessary to achieve this.

The greening of public and commercial buildings is a large agenda, perhaps too large for any individual or organization to undertake in one step. It is a real challenge to include or optimize all of these design strategies in one project, but every renovation or new building project can emphasize at least some of these strategies and achieve higher-than-normal levels of efficiencies and performance. The process is evolutionary and progresses incrementally.

SECTION A

Passive Solar Design

Passive solar design is a broad term used to encompass a wide range of strategies and options resulting in energy-efficient building design and increased occupant comfort. The concept emphasizes architectural design approaches that minimize building energy consumption by integrating conventional energy-efficient devices, such as mechanical and electrical pumps, fans, lighting fixtures, and other equipment, with passive design elements, such as building siting, an efficient envelope, appropriate amounts of fenestration, increased daylighting design, and thermal mass. Many passive buildings are compatible with active components such as solar hot water systems. In short, "passive solar design balances all aspects of the energy use in a building: lighting, cooling, heating, and ventilation. It achieves this by combining, in a single concept, the use of renewable resources and conventional, energy-efficient strategies."[1]

The basic idea of passive solar design is to allow daylight, heat, and airflow into a building only when beneficial. The objectives are to control the entrance of sunlight and air flows into the building at appropriate times and to store and distribute the heat and cool air so it is available when needed. Many passive solar design options can be achieved at little or no additional cost. Others are economically viable over a building's life-cycle.

The U.S. Department of Energy has shown that passive solar buildings use 47 percent less energy than conventional new buildings and 60 percent less than comparable older buildings. Passive solar design strategies can benefit most large buildings and all small buildings.[2] It has been used effectively in an estimated 17,000 commercial buildings in the United States—ranging from offices and warehouses to schools, health care centers, libraries, and airport terminals. Passive solar design is best suited to new construction and major renovation because most components are integral elements of the building. Depending on siting, the range of improvements planned, and the building's characteristics, a number of passive strategies can potentially be incoporated into existing buildings. For example, designers can consider using advanced glazings when replacing windows during a renovation.[3]

Properly designed and constructed passive solar buildings offer many benefits to building owners and occupants, including:[4]

- **Energy Performance:** Lower energy bills year-round.
- **Investment:** High economic return on the incremental investment on a life-cycle cost basis and greater financial independence from future rises in energy costs. These can lead to higher tenant retention and satisfaction, which can correlate to higher building value and lower risk (see Chapter 1, "The Economics of Green Buildings").
- **Comfort:** Greater thermal comfort, less reliance on noisy mechanical systems, solid construction (more thermal mass), sunny interiors, and open floor plans.
- **Productivity:** Increased daylighting, higher quality lighting systems, and reduced glare can increase worker productivity and reduce absenteeism (see Chapter 1, "The Economics of Green Buildings").
- **Low Maintenance:** Reduced building maintenance costs resulting from less reliance on mechanical systems.
- **Environmental:** Reduced energy usage and reliance on fossil fuels.

Successfully integrating passive solar design strategies requires a systematic approach that begins in the pre-design phase and carries throughout the entire design process. It is critical that the building owners and the design team agree to integrate passive solar design considerations during the appropriate project phases. The following passive solar design strategies should be included during the building-design process.[5]

- **Site Selection:** Evaluate building site options/positions for solar access and use of landscaping elements.
- **Programming:** Establish energy-use patterns and set priorities for energy strategies (e.g., daylighting versus efficient lighting); determine base-case conditions and conduct life-cycle cost analysis; establish an energy budget.
- **Schematic Design:** Maximize site potential by considering orientation, building shape, and landscaping options; conduct a preliminary analysis of representative building spaces as they relate to insulation, thermal mass, and window type and location; determine the available daylighting; decide on the need for passive heating or cooling load avoidance, lighting, and HVAC systems. Determine the preliminary cost-effectiveness of options and compare the budgets.
- **Design Development:** Finalize the analysis of all individual building zones, including analysis of design element options and life-cycle costs.
- **Construction Documents:** Simulate total building projections and develop specifications that meet the intent of energy-efficient design.
- **Bidding:** Use life-cycle cost analysis to evaluate alternates or "equals."
- **Construction:** Communicate to the contractor the importance of adhering to design elements and ensure compliance.
- **Occupancy:** Educate occupants on the intent of the energy design and provide an operations manual for maintenance staff.
- **Post-Occupancy:** Evaluate performance and occupancy behavior for comparison with goals.

The optimal combination of passive solar design features is not always intuitively obvious. In order to analyze the choices, a base case is established—a building that corresponds to the overall architectural program but does not use passive solar strategies. Energy and economic comparisons are made between the base case and various combinations of passive and energy-efficient design strategies. The final design is checked to confirm that energy performance goals established earlier have been met.

Passive building design starts with consideration of siting and daylighting opportunities and the building envelope; then building systems are considered. Almost every element of a passive solar design serves more than one purpose. Landscaping can be aesthetic while also providing critical shading or direct air flow. Window shades are both a shading device and part of the interior design scheme. Masonry floors store heat and also provide a durable walking surface. Sunlight bounced around a room provides a bright space and task light. Critical design areas include the following:[6]

- **Thermal Protection:** Provides appropriate levels of insulation and minimal air leakage.
- **Windows:** Transmit heat, light, and air between interior space and the outside environment.
- **Daylighting:** Reduces lighting and cooling energy use; creates a better working environment, leading to increased comfort and productivity.
- **Thermal Mass:** Stores excess heat in winter; in summer, cools down during the night and absorbs heat during the day. This can help to shift peak cooling and heating to off-peak hours.
- **Passive Solar Heating:** Allows heat to enter the building during the winter months and rejects it during the summer months through the use of appropriate amount and type of south-facing glazing and properly designed shading devices. Most valuable in cooler climates.
- **Energy-Efficient Lighting:** Uses efficient lamps, ballasts, controls, and luminaries coordinated with daylight and color of interior space to provide the requisite level of light.
- **Internal Heat-Gain Control:** Minimizes heat gain generated by lights, people, and equipment through the use of daylighting, thermal mass, efficient equipment selection, and venting.
- **Passive Cooling with Natural Ventilation:** Incorporates controlled air exchanges through natural or mechanical means. Helps to increase energy performance of buildings in most locations.
- **Energy-Efficient HVAC System:** Reduces system load by integrating above-listed design strategies and using measures such as efficient motors, heat pumps, variable speed drives, and sophisticated building controls.

Section A of the manual contains three chapters that address areas of primary importance for passive solar design: daylighting (Chapter 9), building envelope (Chapter 10), and renewable energy systems (Chapter 11). Although discussed in individual chapters, these three elements need to be considered in an integrated and simultaneous manner, along with energy-efficient mechanical and electrical systems, discussed in Chapter 12, "HVAC, Electrical, and Plumbing Systems." Review of such measures in isolation can lead to a reduction of the overall energy efficiency potential.

NOTES

1 Passive Solar Industries Council (PSIC) and National Renewable Energy Laboratory (NREL), *Designing Low Energy Buildings—Integrating Daylighting, Energy-Efficient Equipment, and Passive Solar Strategies* (Washington, D.C.: Passive Solar Industries Council, n.d.), 10.

2 Ibid., 2, 7.

3 U.S. Department of Energy, National Renewable Energy Laboratory, Federal Energy Management Program, "Renewable Energy Technologies for Federal Facilities" (brochure)(Golden, Colo.: National Renewable Energy Laboratory, September 1995).

4 PSIC and NREL, *Designing Low Energy Buildings*.

5 Ibid., 20-21.

6 Ibid., 11-18.

CHAPTER 9

Daylighting

Author

Loren E. Abraham

★ SIGNIFICANCE

Daylighting is the practice of bringing light into a building interior and distributing it in a way that provides more desirable and better-quality illumination than artificial light sources. This reduces the need for electrical light sources, thus cutting down on electricity use and its associated costs and pollution. Studies substantiate that daylighting creates healthier and more stimulating work environments than artificial lighting systems and can increase productivity up to 15 percent.[1] Daylighting also provides changes in light intensity, color, and views that help support worker productivity. Surveys have shown that 90 percent of employees prefer to work in spaces with windows and a view to the outside.[2] In one study, 75 percent of office and factory workers stated that daylight provides better quality illumination than artificial light.[3]

Daylighting significantly reduces energy consumption and operating costs. Energy used for lighting in buildings can account for 40 to 50 percent of total energy consumption. In addition, the added space-cooling loads that result from waste heat generated by lights can amount to three to five percent of total energy use. Properly designed and implemented daylighting strategies can save 50 to 80 percent of lighting energy.[4]

Greater use of daylighting can also provide advantages for the environment by reducing power demand and the related pollution and waste byproducts from power production. Lighting—and additional building cooling requirements from lighting—use an estimated 20 to 30 percent of total United States energy production.[5] About three-quarters of this amount is used to light commercial and industrial buildings. If extensive daylighting measures achieved only a 40 percent lighting energy savings, total national electricity consumption would be reduced by six to nine percent.[6] In addition, the greatest savings from daylighting occur during periods when sunlight is most intense, which coincides with periods of peak demand for heating, ventilating, and air-conditioning (HVAC) and refrigeration loads. Therefore, wider use of daylighting would reduce both the need for new peak demand capacity and overall power demand.

Daylighting requires the correct placement of openings, or *apertures,* in the building envelope to allow light penetration while providing adequate distribution and diffusion of the light. A well-designed system avoids excessive thermal gains and excessive brightness resulting from direct sunlight, which can impair vision and cause discomfort.[7] To control excessive brightness or contrast, windows are often equipped with additional elements such as shades, blinds, and light shelves. In most cases, the daylighting system should also include controls that dim or turn off lights when sufficient natural light is available to maintain desired lighting levels. It is also often desirable to integrate daylighting systems with the artificial lighting system to maintain required task or ambient illumination while maximizing the amount of lighting energy saved (see Chapter 12, "HVAC, Electrical, and Plumbing Systems").

Recent daylighting innovations offer a wide range of advanced, highly efficient, and, in some cases, highly engineered systems. In reviewing these options, the practitioner should recognize that higher efficiency and improved daylighting performance may entail additional costs. The benefits of daylighting include improved visual quality, better lighting-color rendition, reduced solar heat gain, and improved visual performance and productivity. These benefits can make any increased engineering and installation costs a worthwhile investment for the building owner or employer.

☞ SUGGESTED PRACTICES AND CHECKLIST

Design Process

Programming Phase

❑ **Establish daylighting performance objectives and requirements.**
Performance objectives may include savings in lighting-energy costs, cooling-load reductions, visual quality, and views to the outside. The designer should establish required illumination levels to meet the needs of the building occupants and the tasks they perform. *Table 1* provides illumination standards established by the Illuminating Engineering Society (IES). These levels have been reduced significantly over the past decades because it is now generally accepted that illumination can be reduced in situations where the quality of light is high and background surface reflectance is optimal. See *Table 2* for recommended interior surface reflectance values.

❑ **Analyze lighting performance needs using the following procedures:**
- Perform a solar-path analysis for the latitude at the site;
- Perform preliminary aperture-optimization studies (optimal window-to-floor ratio, optimal skylight-to-floor ratio);
- Determine the design illumination levels for various program functions based on IES standards (see *Table 1*); and
- Perform a preliminary life-cycle cost-benefit analysis. (Refer to Moore in "Resources" section.)

Preliminary Design Phase

❑ **Establish basic daylighting parameters as part of the building design.**
- Establish the location, shape, and orientation of the building on the site based on daylighting performance objectives as part of an integrated passive solar heating and cooling strategy.
- Establish fenestration design objectives based on optimization studies.
- Establish energy-efficient artificial illumination systems based on design illumination levels and energy-efficiency targets.
- Perform a preliminary life-cycle cost-benefit analysis of daylighting systems as an integrated part of the total building system. Consider qualitative benefits such as increased productivity and reduced absenteeism, as well as the direct costs of design systems when assessing costs and benefits. (Refer to Moore, in "Resources" section.)

RECOMMENDED ILLUMINATION LEVELS

Type of Activity	-3,-2 weight (footcandles)	-1 to +1 weight (footcandles)	+2,+3 weight (footcandles)
Public spaces with dark surroundings	2	3	5
Simple orientation for short, temporary visits	5	7.5	10
Working spaces with occasional visual tasks	10	15	20
Visual tasks of high contrast or large size	20	30	50
Visual tasks of medium contrast or small size	50	75	100
Visual tasks of low contrast or small size	100	150	200
Visual tasks of low contrast and very small size over prolonged periods	200	300	500
Exacting and prolonged visual tasks	500	750	1000
Very special visual tasks of extremely low contrast and small size	1000	1500	2000

Weight Factor Determination*

	Weight		
Task and Worker Characterisitcs	-1	0	+1
Worker Age	Under 40	40-55	Over 55
Speed and/or Accuracy	Not Important	Important	Critical
Reflectance of Background	> 70%	30-70%	< 30%

***Note: Use the Weight Factor Determination to establish the range of values as part of the design illumination requirements.**

Source: Illuminating Engineering Society. <u>Lighting Handbook.</u> (New York: IES, 1979.)

Table 1

RECOMMENDED SURFACE REFLECTANCE VALUES

Surface	Range of Surface Reflectance (low - high)
Ceiling	80% - 90%
Walls	60% - 65%
Floor	20% - 50%

Source: Illuminating Engineering Society. <u>Lighting Handbook.</u> (New York: IES, 1979.)

Table 2

- Determine the optimal effective aperture for toplighting strategies.
- Incorporate fenestration into the basic building geometry.
- Perform daylighting studies using computer-simulation tools and physical-model evaluation. Conduct studies of both direct-beam irradiance on a heliodon and diffuse sky illuminance under an artificial sky, if possible. (Refer to Evans, Hopkinson, Moore in "Resources" Section.)
- Establish lighting-control strategies, including the use of logical zoning and selection of either continuous dimming, stepped, or on-off switching.

Design Development Phase

❑ **Specify details for lighting systems and products.**

- Specify glazing materials based on climate, fenestration position, and solar orientation, maintaining the highest possible luminous efficacy (k-factor or ratio of visible transmittance to shading coefficient) and daylight factor (ratio of visible transmittance to total solar transmittance).
- Specify finishes based on the desired reflectance values for walls, ceilings, and floors (see *Table 2*).
- Based on a heliodon study or other solar-path analysis, determine the type and location of, and control methods for, shading systems that minimize or eliminate direct sun in work areas and moderate excessive brightness.
- Specify control systems, including photosensors, control zones and occupancy sensors, based on control strategies.
- Seek opportunities to integrate controls with other building energy-management systems.
- Incorporate flexible, ongoing capabilities for monitoring lighting conditions, including lighting-energy consumption and lighting operation hours by zone.
- Determine the method for reviewing and analyzing field-monitoring data and performing associated responsibilities.

Construction Phase

❑ **Confirm that specified practices and materials are installed properly.**

- Monitor direct sunlight penetration through fenestration and fine-tune the solar shading systems as required.
- Observe skylight installations and related flashing and sealants to verify that each installation is watertight and has been performed according to standard practices.
- Observe the final calibration and testing of lighting-control systems to verify that the installation functions as specified.

Post Occupancy Phase

❑ **Ensure that the building's daylighting features are in place and maintained for optimum performance.**

- Walk through the entire project and review all fenestration, solar controls, and lighting-control systems to verify that they are operational and as specified. Identify any potential visual-quality problems such as glare from excessively bright source or background illuminance. Monitor light levels in all spaces with a hand-held photometer and follow up on any variations from the design illuminance levels. Prepare a checklist of problems that need to be corrected and submit it to the contractors and building owner.
- Verify with the building owner that a glass-cleaning and systems-maintenance schedule is in place.
- Review the data collected from monitoring systems, analyze energy use, and compare the results with design targets.
- Identify individuals who are responsible for maintaining and making modifications to the lighting-control systems and ensure that they are familiar with proper procedures.

Lighting Systems

General Daylighting Principles

❑ **Avoid direct sunlight on critical tasks and excessive brightness.**
Direct sunlight in certain non-task areas can be helpful because it provides building occupants with information about outside weather conditions and the time of day. These factors can actually relieve the stress associated with being in a windowless space for long periods of time. However, when a critical task is performed in direct sunlight, the light can cause unacceptable contrast ratios, disability glare, or veiled reflection. In this situation, the work surface or computer screen reflects the light source so that it is difficult to see the intended task. The recommended maximum background-to-task ratio is 10 to one; the recommended maximum light source-to-background ratio is 40 to one.[8]

❑ **Bring the daylight in at a high location.**
The four basic types of daylight apertures are windows, skylights, roof monitors, and clerestories. Skylights, roof monitors, and clerestories tend to be more effective than windows because their high location in a building affords penetration of light into the building core. Windows, unless fitted with light shelves or venetian blinds, can sometimes cause unacceptable brightness levels and excessive contrast ratios of background to foreground, thereby creating visual problems.

❑ **Filter the daylight.**
Trees, plants, draperies, screens, translucent shades, and light-scattering glazings diffuse and distribute light while reducing its intensity.

❑ **Bounce daylight off of surrounding surfaces.**
Light shelves, louvers, blinds, and vertical baffles reflect and distribute light throughout a building interior. In general, the larger and softer the light source, the better the visual quality, the less the resulting eye strain, and the easier it is to function and perform a given task. In addition, when the light is nondirectional—that is, reflected from countless surfaces—shadows are avoided or eliminated, again improving visual quality.

❑ **Integrate daylight with other building systems and strategies.**
The most effective daylighting solutions work in concert with and not against other building systems or design strategies, for example, HVAC systems, including natural ventilation, passive solar heating and cooling, acoustic control systems, electrical lighting systems incorporating occupancy sensors, photocells and dimmable electronic ballasts, and building energy management systems (see Chapter 11, "Renewable Energy," and Chapter 12, "HVAC, Electrical, and Plumbing Systems").

Traditional Daylighting Strategies[9]

Sidelighting

❑ **Maintain a favorable room aspect ratio—the ratio of ceiling height and window height to depth of room from window** *(Figure 1).*

❑ **Establish an appropriate building footprint.**
For sidelighting strategies to work in the majority of building spaces, establish an appropriate building footprint. The ideal building depth is limited by the dimension required for a double-loaded corridor (that is, exterior window/wall-daylit room-corridor-daylit room-exterior window/wall). Frank Lloyd Wright prescribed the ideal width of a wing for daylighting as 13 meters, about 42 feet. This guideline offers almost infinite flexibility to explore various floor configurations (for example "L," "O," "U," "E," "X," and others). In addition, these configurations for sidelighting can be any number of stories high.

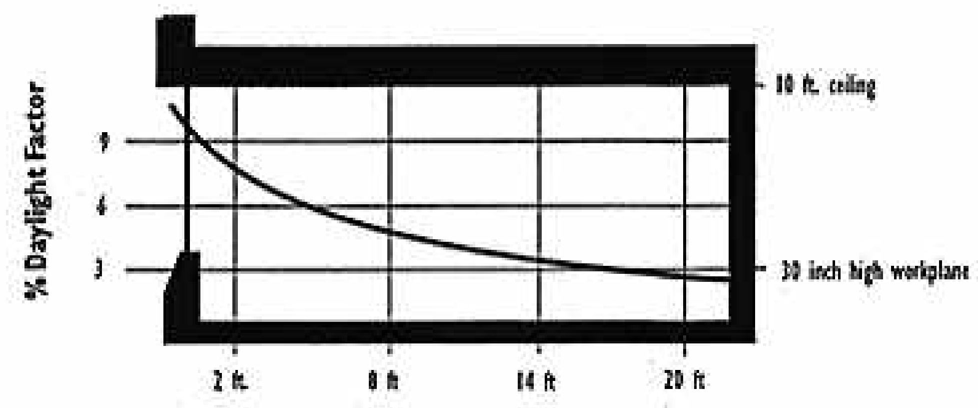
❑ **Specify the appropriate room reflectivity (surface reflectance).**
The amount of light that can be reflected to the back of a space from an outside wall with windows, and thus the comparative illumination levels between front and back, is

controlled by the reflectivity of the interior surfaces. The higher the reflectivity, the greater the illuminance values at the back of the space. Reflectance values also affect background brightness levels and therefore contrast ratios of task to background (refer to *Table 2*).

❑ **Rely on clerestories in addition to windows.**
In this strategy, which combines sidelighting and toplighting, vertical windows in a higher space are positioned adjacent to other windows, creating in a sense a "clear story" *(Figure 2)*. This method provides an excellent means of delivering daylight deep into an interior space.

Figure 1

ILLUMINATION RELATIVE TO DISTANCE INTO ROOM FROM WINDOW

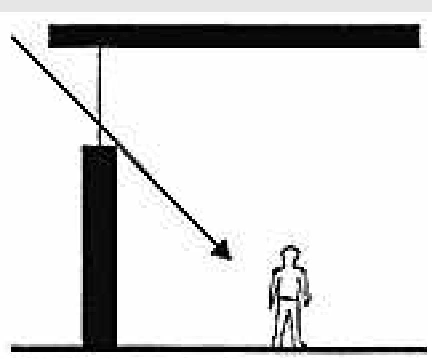


Toplighting

❑ **Consider a sawtooth roof form.**
A sawtooth roof uses a series of repetitive clerestories to provide uniform illumination over a large area *(Figure 3)* and is best designed in concert with passive solar heating and cooling strategies. The glazed openings in the sawtooth commonly face north, thereby providing a diffuse and uniform source of daylight. To take advantage of solar gains for heating purposes in colder climates, it may be advisable to face the openings south. In this case, however, solar controls may be needed to prevent glare, high contrasts, and veiling reflections. Overhangs, diffuse glazing materials, interior or exterior baffles, louvers, blinds, and shades are all effective means of accomplishing the required solar control.

Figure 2

CLERESTORY



❑ **Consider the use of roof monitors.**
Monitors are a type of clerestory that usually involves a stepped roof, allowing light to enter from two or more directions at once *(Figure 4)*. Monitors usually benefit from an overhang on the southern, eastern, and western exposures. An inherent advantage of using monitors is that the roof tends to act as a reflector or a light shelf for the monitor above. Extension of the roof plane to the interior of the glazing can sometimes enhance this effect while providing additional relief from direct sunlight penetration. In addition, monitors are less likely to leak than skylights.

Figure 3

SAWTOOTH ROOF

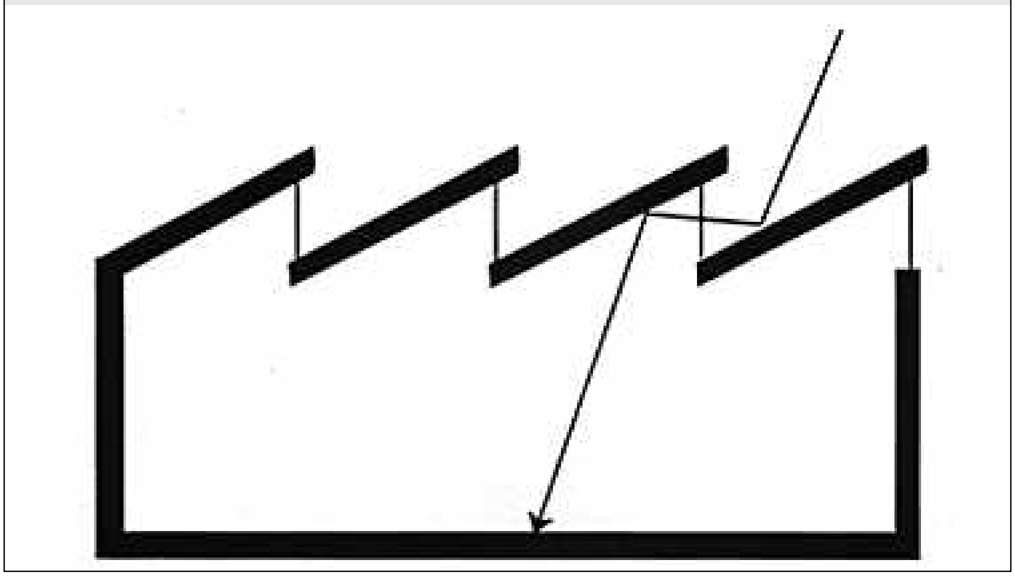
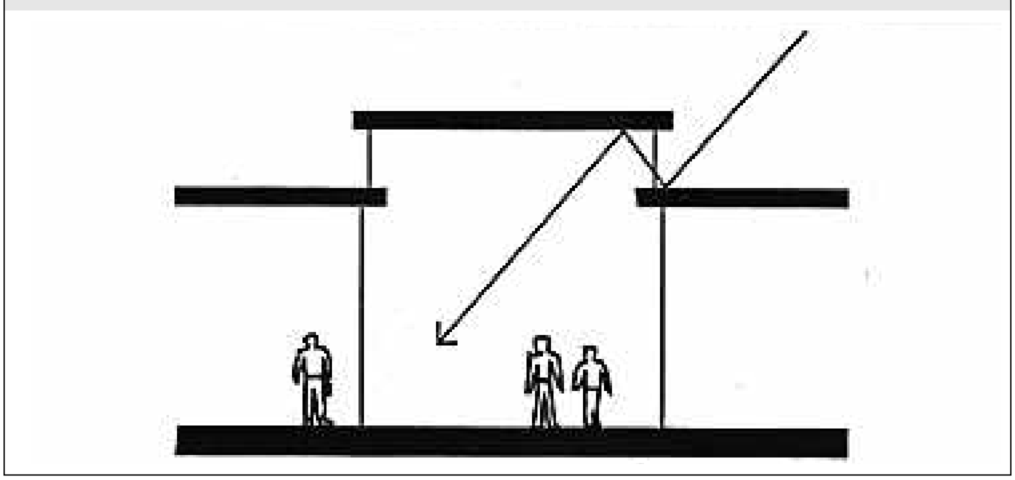


Figure 4

MONITOR



❑ **Use skylights.**

Skylights, horizontal openings in a roof, are the most common daylighting strategy in single-story buildings. When used judiciously, they offer the most efficient means of bringing light into a building because they generally have a 180-degree view of the sky. They are usually laid out on a grid so that the distance between the skylights is roughly 1.5 times the distance between the floor and ceiling planes. Optimal skylight-to-floor ratios may range from 5 to 10 percent or higher depending on the transmittance of the glass, the efficiency of the skylight design, the required illuminance level, the ceiling height, and whether the space is mechanically air conditioned.

Some problems with skylights include the potential for water leakage, the loss of some thermal insulation at the skylight locations, and the generally higher cost of the roof structure. Another drawback is the potential for heat gain during the warmer seasons, causing thermal discomfort or increased cooling costs. Because most skylight installations require diffuse glazing for solar control, they do not provide views to the outside. When skylights are used in a daylighting strategy, be sure to:

- Angle light wells to prevent loss of efficiency. The finished vertical surfaces below the skylight opening are known as the "light well." As the depth of the construction or the distance from the roof to the ceiling plane increases, it becomes more important that the light well be angled to prevent loss of efficiency of the skylight system.
- Use baffles below the skylight to reflect some of the incident light up onto the ceiling surface. This technique reduces the ratio of source-to-background contrast by making the ceiling a relatively large indirect light source.
- Consider roof design. When a skylight is used in conjunction with a sloped roof surface, the efficiency of the skylight is reduced in proportion to the slope of the roof, and the light distribution pattern becomes more like that of a sidelighting strategy. If the slope of the roof is to the north, solar control is less of a concern; if it is to the east, south or west, it is more of a concern.

Light Distribution Strategies

❑ **Use sloped or curved ceiling planes.**

Ceiling shape is the simplest mechanism for distributing light in a space. Sloping the ceiling from a high point at the window or skylight essentially has the same impact as maintaining a high ceiling throughout the space. Curving the ceiling can produce dramatic effects. The light from the window or skylight can be focused or collimated in the case of a concave surface or further diffused and spread in the case of a convex surface.

❑ **Optimize overhangs based on window height and latitude (solar altitude).**

Although usually necessary to exclude light and solar gain at unwanted times, overhangs always reduce the overall amount of daylight in the space and should therefore be designed with care, including an analysis of their year-round effect.

❑ **Incorporate light shelves with windows where appropriate.**

The light shelf is an extremely useful tool when used in conjunction with sidelighting strategies. This mechanism, a horizontal surface at or above eye level, serves to reflect light falling above the vision window up onto the ceiling and therefore deeper into the room *(Figure 5)*. At the same time, it reduces illumination immediately adjacent to the window, where illumination levels are typically too great to work comfortably. This has the effect of creating more even illumination throughout the space, even though the overall amount of light flux into the space is reduced.

❑ **Employ baffles, louvers, and reflectors as appropriate in conjunction with any of the above mentioned strategies for solar control.**

❑ **Integrate daylighting with luminous ceiling systems.**

Locating clerestories and skylights above luminous ceiling systems provides a unique method of integrating natural and electrical light sources. However, increased maintenance may be a concern.

Innovative Sidelighting Systems

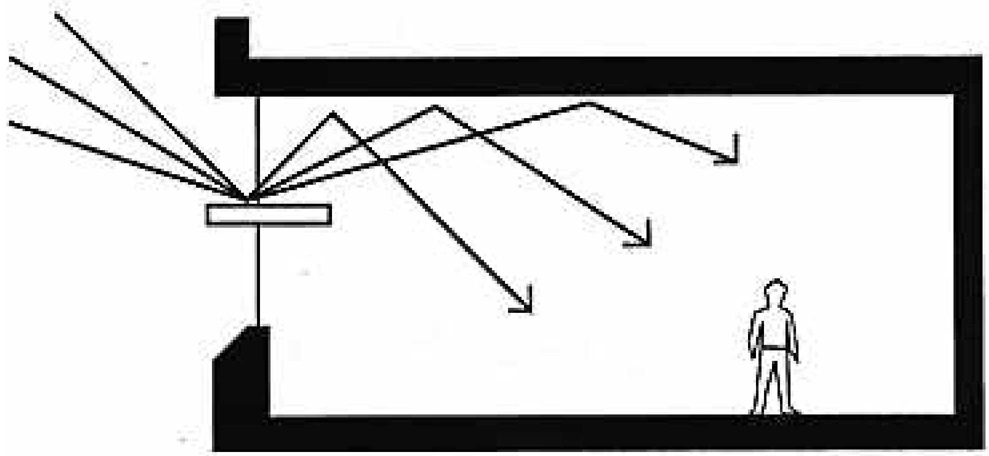
The primary challenges in sidelighting applications are: (1) the need for control of solar light and heat gains near windows; and (2) the transfer of light to the deeper zones away from the windows in order to extend the effective depth to which daylighting may be achieved. The following innovations can address these issues.

❑ **Consider using the currently available techniques:**

- Solar optic lens film (SOLF) applied to acrylic panels;
- Molded acrylic prismatic glazings or prismatic panels;
- Specular blinds or mirror panels;
- Holographic or diffraction-grating glazings; and
- Reflective films.

Figure 5

LIGHT SHELF



❑ **Consider solar shade and awning systems.**
These systems often project out from the building surface above the window or are in the same plane as the window glazing (usually in the upper portion of the window). They are engineered to collect light from a variety of angles and redirect it by specular reflection toward the deepest portion of the room and generally upward toward the ceiling plane.

❑ **Consider optical venetian-blind systems.**
These systems work like standard venetian blinds except that they have diffraction gratings or micro-fresnel lens surfaces and some have individual slats that are shaped like collapsed prisms. Like their standard miniblind counterparts, they can be operated manually with a wand-type actuator or automatically with new photosensor light-angle measuring systems and computer software control algorithms.

❑ **Consider advanced light-shelf systems.**
These systems utilize many of the same advanced glazing technologies as solar shading systems; however, they are arranged in projecting configurations that look and act like standard light shelves but offer much better control of light direction and higher efficiencies. While typical light shelves may be expected to maintain relatively even daylight illumination for a depth of up to 2.5 times the distance to the top of the window into the room, advanced light shelves (*Figure 6 and Figure 7)* should maintain even illumination up to four times the distance from the floor to the top of the glass opening under certain conditions.[10] Tracking systems have an advantage over passive systems in that they maintain more uniform efficiencies and resulting light-distribution patterns but have greater potential for problems and associated maintenance costs.

Innovative Toplighting Systems

The primary challenges to toplighting applications are the need for collimation of light vertically deeper into the interiors of high-rise buildings and the need for higher efficiency and better distribution control allowing greater distance between skylights in single-story applications.

❑ **Consider advanced systems such as active concentrating heliostats, passive collimating systems, and high-performance optical skylights.**[11]
Technologies that may be applied in these strategies are similar to those mentioned above for innovative sidelighting systems.

ADVANCED LIGHT SHELF

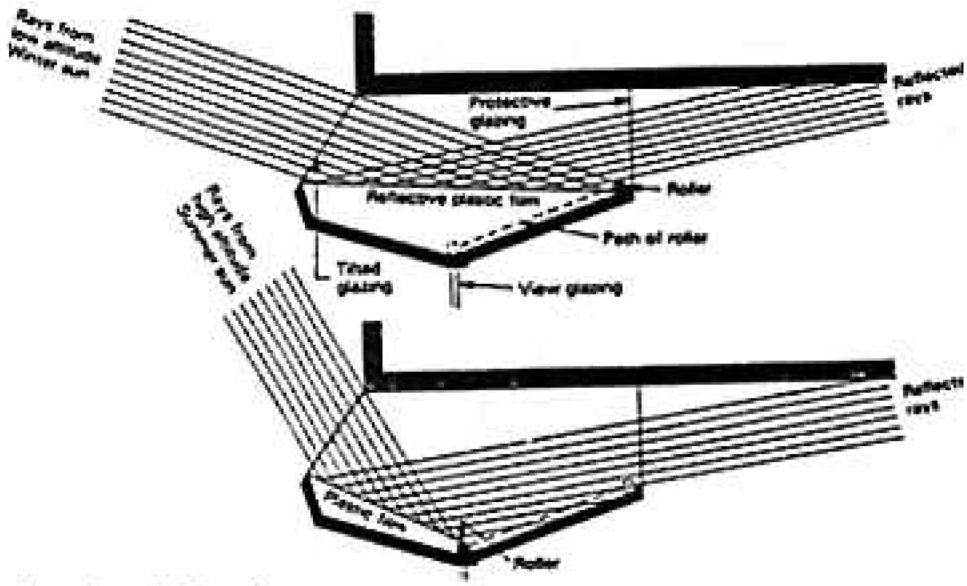
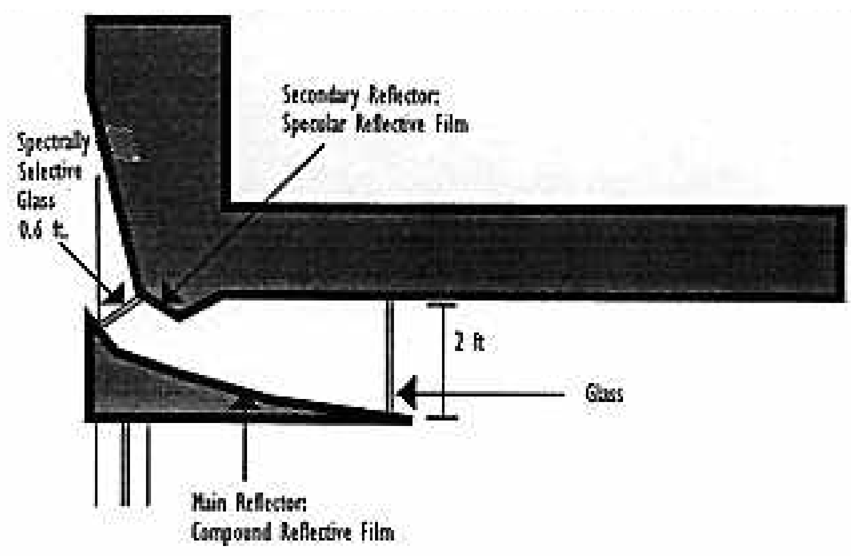


Figure 6

ADVANCED LIGHT SHELF



Source: Lawrence Berkeley National Laboratory, University of California at Berkeley

Figure 7

Innovative Core Daylighting Systems

❑ **Consider light-pipe distribution.**

Light-pipe distribution has been commercialized for use with high-output luminaires in commercial buildings where special security requirements, difficulty of access, or explosive or corrosive environmental conditions are present. The efficiency of light-pipe distribution is approximately 50 percent from source to delivered illumination.[12] Available systems include those where the light transfer is internal only, or where the pipe itself is a continuous light source.[13] Daylighting applications using this technology for light distribution use concentrating collectors or heliostats as high-intensity light sources.

Control Strategies

❑ **Integrate lighting controls to respond to available daylight.**

To capitalize on the potential energy savings associated with daylighting strategies, it is usually necessary to automate the reduction of electrical lighting operation. This can be accomplished in a variety of ways; however, hardware complexity, cost, wiring complexity, and types of lighting systems are all affected by desired control strategies. In addition, the subtlety of the lighting change actuated by the control systems is affected by the mode of controls selected (see Chapter 12, "HVAC, Electrical, and Plumbing Systems").

❑ **Ensure good control-system design.**

The chief failure of daylighting systems lies in the faulty design or installation of lighting controls. Several factors are critical to the correct functioning of daylighting control systems. Consider these practices to improve lighting control:

- Properly locate and calibrate the photosensors. Correct location and calibration of the photosensor for all daylighting control systems is critical. Ordinarily, a single photosensor will control a group or zone of light fixtures in order to reduce system cost. The sensor should "see" a mixture of both natural and electrical light and should not be located so as to be "fooled" by movement of occupants or objects in the space.
- Use proper zoning. Daylight levels vary greatly within a building depending on many factors. Typically, at least two zones—perimeter and core—should be established in a sidelighting situation. Toplighting situations usually require at least two or three zones. Where more sophisticated controls systems are used, calibrate and control each fixture individually based on a common reference photosensor.

❑ **Integrate daylight controls with other control strategies.**

In addition to controlling lighting to respond to levels of daylight, other lighting-control strategies are typically cost-effective in reducing lighting needs and thus reducing lighting and cooling energy consumption. These may include:

- Time or scheduling controls;
- Occupancy-sensor controls; and
- Lumen-maintenance control programs.

Some manufacturers of lighting-control and building energy systems allow daylighting-control strategies to be integrated with these additional control features in a single system with a central control and program terminal.

Emerging Glazing Technologies

❑ **Consider spectrally selective glazings.**

Specifying glazings with high visible-light transmittance is necessary for optimal energy savings. On the other hand, a low shading coefficient reduces relative heat gain through the glass, which lowers cooling loads. The daylight factor is the ratio of visible light transmittance to total solar transmittance; therefore, the higher the daylight factor, the better the choice for daylighting applications in general. Another measure is the luminous efficacy value (k-factor) which is the visible-light transmittance divided by the shading coefficient. A luminous efficacy of greater than 1.5 is excellent for daylighting applications. New glass coatings being engineered, such as the spectrally selective low-emissivity coatings offered by numerous glazing manufacturers, admit higher than 70 percent of visible light while blocking nearly 95 percent of the infrared spectrum.[14] These coatings may not be desirable, however, where passive solar heating is needed.

❑ **Consider switchable glazings.**
Although still in development and rather expensive, switchable glazings offer special attributes and may be appropriate for special applications. The different types of switchable glazings are:

- *Photochromic glass.* This light-sensitive glass darkens at a predetermined intensity level (like light-sensitive sunglasses).
- *Thermochromic glass.* This heat-sensitive glass becomes translucent at a predetermined temperature.
- *Electrochromic glass.* Electrically variable coatings become darkened with the application of current and clear as current is reduced.
- *Liquid crystal (LCD).* This material becomes clear with the application of electrical current and is translucent otherwise. Tints can be added to the liquid crystal films, giving them greater solar-control capabilities.

➜ RESOURCES

American Institute of Architects, Committee on the Environment. *Energy, Environment & Architecture*. Washington, D.C.: American Institute of Architects, 1991. Diverse anthology of case studies of recent energy-efficient buildings, most of which feature extensive daylighting systems.

Caudill, W. W., and B. H. Reed. *Geometry of Classrooms as Related to Natural Lighting and Natural Ventilation*. Research Report 36. College Station, Tex.: Texas Engineering Experiment Station, 1952. Graphically explores a range of effective daylighting solutions for educational buildings and discusses basic daylighting principles.

Evans, Benjamin H. *Daylight In Architecture*. New York: McGraw-Hill, 1981. A basic primer for building designers on visual quality, human-health aspects of natural light, and physical-modeling methods for simulating daylighting solutions.

Hastings, S. R., ed. *Passive Solar Commercial and Institutional Buildings: A Sourcebook of Examples and Design Insights*. International Energy Agency: Solar Heating & Cooling Programme. West Sussex, England: John Wiley & Sons, 1994. An extensive look at current energy-efficiency strategies with many excellent case studies primarily of recent European buildings.

Hopkinson, R. G.; and J. D. Kay. *The Lighting of Buildings*. New York: Praeger, 1960. Typically considered the "bible of daylighting," this dated but still completely valid text is a *must have* reference and technical sourcebook for the daylighting practitioner.

Illuminating Engineering Society of North America. *Lighting Handbook*. New York: Illuminating Engineering Society of North America, 1979.

Illuminating Engineering Society of North America. *Recommended Practice of Daylighting* New York: Illuminating Engineering Society of North America, 1979. A concise technical treatise on effective lighting with natural light.

Libbey-Owens-Ford Company. *Sun Angle Calculator.* Toledo, Ohio: Libbey-Owens-Ford Company, 1974. A great and easy-to-use tool for calculating sun angles for the entire day and year for your location.

Moore, Fuller. *Concepts and Practice of Architectural Daylighting.* New York: Van Nostrand Reinhold, 1991. This recent release includes some extremely useful performance characterization monographs for a wide variety of fenestration configurations and as some excellent cost-benefit analysis models. Also included is a fairly comprehensive survey on testing and monitoring equipment.

Ramsey, Charles George. *Ramsey/Sleeper Architectural Graphic Standards*. New York: John Wiley & Sons, 1988.

DESIGN TOOLS

AAMASKY, Skylight Design Analysis Tool. Easy-to-use design tool for layout and energy-cost and performance modeling of simple skylit spaces. Developed by Lawrence Berkeley National Laboratory (LBNL). Contact: American Architecture Manufacturers Association (AAMA), (708) 202-1350.

ADELINE. Advanced integrated lighting design and analysis package, incorporating DXF input capability, SCRIBE MODELLER, PLINK, SUPERLIGHT, SUPERLINK, and RADIANCE, for detailed and advanced analysis of complex buildings. Available for MS-DOS 486 platforms. Developed by LBNL. Contact: Steve Selkowitz, (510) 486-5064.

Building Design Advisor (BDA). Easy-to-use design tool for preliminary design phase being developed by LBNL. Alpha version currently available Contact: Constantinos Papamichael, (510) 486-6854.

DAYLITE, Daylighting design tool. Available for MS-DOS 386 and 486. Developed by the Graduate School of Architecture, University of California at Los Angeles. Contact: Murray Milne, (310) 825-7370.

DOE-2. Building envelope, building systems, and daylighting analysis package. DOE Version 2.1E available for MS-DOS and Windows (386 and 486) and UNIX workstations. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.

ENERGY-10, Low-Rise Building Design. Design manual and software. Windows-environment program for small commercial buildings allows early design evaluation of 16 energy-saving stategies including daylighting. Developed by National Renewable Energy Laboratory (NREL), Passive Solar Industries Council (PSIC), U.S. Department of Energy, and LBNL. Contact: Blaine Collison at PSIC, (202) 628-7400.

LUMEN MICRO 6.0. PC program that enables calculation of average illuminance, evaluated using the zonal cavity method, and point-by-point horizontal and vertical illuminances; generating tables, iso-contour maps, or perspective renderings of spaces lighted with equipment or daylighting components specified by the user. Available through Lighting Technologies, Boulder, CO.

POWERDOE. Windows-environment version of DOE-2 with user-friendly interface. Available in early 1996. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.

RADIANCE. Lighting and daylighting modeling tool for performing accurate photorealistic lighting simulation. Available for UNIX workstations. Developed by LBNL. Contact: Charles Erlich, (510) 486-7916.

SUPERLITE 2.0. Daylighting analysis tool. Available for MS-DOS 386 and 486. Developed by LBNL. Contact: Rob Hitchcock, (510) 486-4154.

NOTES

1 Joseph Romm and William Browning, *Greening the Building and the Bottom Line: Increasing Productivity Through Energy-Efficient Design* (Snowmass, Colo.: Rocky Mountain Institute, 1994).

2 Belinda Collins, *Windows and People.* An anthology of daylighting studies and surveys.

3 Advanced Design Research Group, *Daylighting Research and Product Development—White Paper* (Andersen Windows, 1993).

4 Energy savings from daylighting are documented in numerous examples and studies including: E-Source, *Lighting Technology Atlas*, Rocky Mountain Institute, 1988; S. Gates and J. Wilcox, *Daylighting Analysis for Classrooms using DOE-21b*, International Daylighting Conference (Phoenix, Febrarary 1983); R. McCluney, *The Case for Daylighting: An Annotated Bibliography.* (Cape Canaveral, Fla.: Florida Solar Energy Center, May 1984);Gordon, et al., *Performance Overview: Passive Solar Energy for Non-Residential Buildings* (Burt Hill Kosar Rittelmann Associates, March 1985); M. Weaver, "Retrofitting with Skylights Can Net Six-month Paybacks", *Energy User News*, July 4, 1983; and G. Franta, "Environmentally Sustainable Architecture in a Health Care Facility," and J.L. McGregor, "Emerging Solar Concentrating Daylighting System," in *Proceedings of Energy, Environment, and Architecture Conference*, (Atlanta, American Institute of Architects, Committee on the Environment, December 1991).

5 E-Source, *Lighting Technology Atlas* (Snowmass, Colo.: Rocky Mountain Institute, 1994), 21.

6 E-Source*, Lighting Technology Atlas*, 21; and U.S. Energy Information Service, *Annual Energy Consumption Report* (Washington, D.C.: GPO, 1994).

7 Advanced Design Research Group, *Daylighting Research and Product Development—White Paper.*

8 Illuminating Engineering Society. *IES Lighting Handbook*. (New York: IES, 1979).

9 Adapted from S.R. Hastings, ed., *Passive Solar Commercial and Institutional Buildings: A Sourcebook of Examples and Design Insights,* International Energy Agency: Solar Heating & Cooling Programme (West Sussex, England: John Wiley & Sons, 1994), 186.

10 Lilian O. Beltran, Eleanor S. Lee, Stephen E. Selkowitz, K. M. Papamichael, *The Design and Evaluation of Three Advanced Daylighting Systems: Light Shelves, Light Pipes and Skylights*. (Berkeley: Building Technologies Program Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, 1994).

11 Charles George Ramsey, *Ramsey/Sleeper Architectural Graphic Standards* (New York: John Wiley & Sons, 1988), 728-729.

12 E-Source, 57.

13 TIR Systems Ltd., Burnaby, British Columbia, Canada; and 3M Corporation, St. Paul, Minnesota hold patents on "Light Pipe™" and "Scotchlamp™" products respectively.

14 E-Source, 54.

CHAPTER 10

Building Envelope

Author
William Burke

★ SIGNIFICANCE

The building envelope, or "skin," consists of structural materials and finishes that enclose space, separating inside from outside. This includes walls, windows, doors, roofs, and floor surfaces. The envelope must balance requirements for ventilation and daylight while providing thermal and moisture protection appropriate to the climatic conditions of the site. Envelope design is a major factor in determining the amount of energy a building will use in its operation. Also, the overall environmental life-cycle impacts and energy costs associated with the production and transportation of different envelope materials vary greatly.

In keeping with the whole building approach, the entire design team must integrate design of the envelope with other design elements including material selection; daylighting and other passive solar design strategies; heating, ventilating, and air-conditioning (HVAC) and electrical strategies; and project performance goals. One of the most important factors affecting envelope design is climate. Hot/dry, hot/moist, temperate, or cold climates will suggest different design strategies. Specific designs and materials can take advantage of or provide solutions for the given climate.

A second important factor in envelope design is what occurs inside the building. If the activity and equipment inside the building generate a significant amount of heat, the thermal loads may be primarily internal (from people and equipment) rather than external (from the sun). This affects the rate at which a building gains or loses heat. Building volume and siting also have significant impacts upon the efficiency and requirements of the building envelope. Careful study is required to arrive at a building footprint and orientation that work with the building envelope to maximize energy benefit.

Openings are located in the envelope to provide physical access to a building, create views to the outside, admit daylight and/or solar energy for heating, and supply natural ventilation. The form, size, and location of the openings vary depending upon the role they play in the building envelope. Window glazing can be used to affect heating and cooling requirements and occupant comfort by controlling the type and amount of light that passes through windows.

Decisions about construction details also play a crucial role in design of the building envelope. Building materials conduct heat at different rates. Components of the envelope such as foundation walls, sills, studs, joists, and connectors, among others, can create paths for the transfer of thermal energy, known as thermal bridges, that conduct heat across the wall assembly. Wise detailing decisions, including choice and placement of insulation material, are essential to assure thermal efficiency.

☞ **SUGGESTED PRACTICES AND CHECKLIST**

Climate Considerations

❑ **Assess the local climate (using typical meteorological-year data) to determine appropriate envelope materials and building designs.**

The following considerations should be taken into account, depending on the climate type.

- In hot/dry climates use materials with high thermal mass. Buildings in hot/dry climates with significant diurnal temperature swings have traditionally employed thick walls constructed from envelope materials with high mass, such as adobe and masonry. Openings on the north and west facades are limited, and large southern openings are detailed to exclude direct sun in the summer and admit it in winter. A building material with high thermal mass and adequate thickness will lessen and delay the impact of temperature variations from the outside wall on the wall's interior. The material's high thermal capacity allows heat to penetrate slowly through the wall or roof. Because the temperature in hot/dry climates tends to fall considerably after sunset, the result is a thermal flywheel effect—the building interior is cooler than the exterior during the day and warmer than the exterior at night.
- In hot/moist climates use materials with low thermal capacity. In hot/moist climates, where nighttime temperatures do not drop considerably below daytime highs, light materials with little thermal capacity are preferred. In some hot/moist climates, materials such as masonry, which functions as a desiccant, are common. Roofs and walls should be protected by plant materials or overhangs. Large openings protected from the summer sun should be located primarily on the north and south sides of the envelope to catch breezes or encourage stack ventilation.
- In temperate climates, select materials based on location and the heating/cooling strategy to be used. Determine the thermal capacity of materials for buildings in temperate climates based upon the specific locale and the heating/cooling strategy employed. Walls should be well insulated. Openings in the skin should be shaded during hot times of the year and unshaded during cool months. This can be accomplished by roof overhangs sized to respond to solar geometries at the site or by the use of awnings.
- In colder climates design wind-tight and well-insulated building envelopes. The thermal capacity of materials used in colder climates will depend upon the use of the building and the heating strategy employed. A building that is conventionally heated and occupied intermittently should not be constructed with high mass materials because they will lengthen the time required to reheat the space to a comfortable temperature. A solar heating strategy will necessitate the incorporation of massive materials, if not in the envelope, in other building elements. Where solar gain is not used for heating, the floor plan should be as compact as possible to minimize the area of building skin.

(See also Chapter 11, "Renewable Energy.")

❑ **Assess the site's solar geometry.**

Solar gain on roofs, walls, and the building interior through window openings can be either a benefit or a hindrance to heating, cooling, and occupant comfort. A thorough understanding of solar geometry specific to the site is crucial to proper envelope design. (See also Chapter 5, "Sustainable Site Design" for further discussion.)

Building Shape and Orientation

❑ **Choose the most compact building footprint and shape that work with requirements for daylighting, solar heating and cooling, and function.**

The greater the amount of building skin in relation to the volume of space enclosed, the more the building is influenced by heat exchanges at the skin. Excluding consideration of window openings and glazing choices, if two building designs under consideration enclose the same volume, the one with the more compact plan will have greater thermal efficiency. A square floor plan is more thermally efficient than a rectangular one because it contains less surface area over which to lose or gain heat. However, this may not be the most efficient or desirable form when other considerations such as daylighting, passive solar heating and cooling, need for temperature variation, and occupant use patterns are included (see also Chapter 9, "Daylighting" and Chapter 11, "Renewable Energy").

❑ **Site and orient the building so as to minimize the effects of winter wind turbulence upon the envelope.**

The shape and orientation of the building shell has an impact upon wind turbulence and opportunities for infiltration through the envelope. However, an orientation that minimizes winter wind may also limit opportunities to make use of cooling breezes in summer. An understanding of the site-specific microclimate is needed. Coniferous trees may be used for windbreaks (see also Chapter 5, "Sustainable Site Design.")

Doors, Windows, and Openings

❑ **Size and position doors, windows, and vents in the envelope based on careful consideration of daylighting, heating, and ventilating strategies.**

The form, size, and location of openings may vary depending on how they affect the building envelope. A window that provides a view need not open, yet a window intended for ventilation must do so. High windows for daylighting are preferable because, if properly designed, they bring light deeper into the interior and eliminate glare. Vestibules at building entrances should be designed to avoid the loss of cooled or heated air to the exterior. The negative impact of door openings upon heating or cooling loads can be reduced with airlocks. Members of the design team should coordinate their efforts to integrate optimal design features. For passive solar design, this includes the professionals responsible for the interactive disciplines of building envelope, daylighting, orientation, architectural design, massing, HVAC, and electrical systems.

❑ **Shade openings in the envelope during hot weather to reduce the penetration of direct sunlight to the interior of the building.**

Use overhangs or deciduous plant materials on southern orientations to shade exterior walls during warmer seasons. Be aware, however, that deciduous plants can cut solar gains in the winter by 20 percent. Shade window openings or use light shelves at work areas at any time of year to minimize thermal discomfort from direct radiation and visual discomfort from glare.

❑ **In all but the mildest climates, select double- or triple-paned windows with as high an "R" value as possible and proper shading coefficients within the project's financial guidelines.**

The "R" value is a measure of the resistance to heat flow across a wall or window assembly (with higher values representing a lower energy loss). Shading coefficient is a ratio used to simplify comparisons among different types of heat reducing glass. The shading coefficient of clear double-strength glass is 1.0. Glass with a shading coefficient of 0.5 transmits one-half of the solar energy that would be transmitted by clear double-strength glass. One with a shading coefficient of 0.75 transmits three-quarters.

❑ **Select the proper glazing for windows, where appropriate.**
Glazing uses metallic layers of coating or tints to either absorb or reflect specific wavelengths in the solar spectrum. In this manner, desirable wavelengths in the visible spectrum that provide daylight are allowed to pass through the window while other wavelengths, such as near-infrared (which provides heat) and ultraviolet (which can damage fabric), are reflected. Thus, excess heat and damaging ultraviolet light can be reduced while still retaining the benefits of natural lighting. More advanced windows use glazings that are altered with changing conditions, such as windows with tinting that increases under direct sunlight and decreases as light levels are reduced. Research is being conducted on windows that can be adjusted by the building occupant to allow more or less heat into a building space.[1] (See Chapter 9, "Daylighting," for further discussion.)

Thermal Efficiency

❑ **Determine the building function and amount of equipment that will be used.**
The type of activity and the amount of equipment in a building affect the level of internal heat generated. This is important because the rate at which a building gains or loses heat through it skin is proportional to the difference in air temperature between inside and outside. A large commercial building with significant internal heat loads would be less influenced by heat exchanges at the skin than a residence with far fewer internal sources of heat generation.

❑ **In general, build walls, roofs, and floors of adequate thermal resistance to provide human comfort and energy efficiency.**
Roofs especially are vulnerable to solar gain in summer and heat loss in winter. Avoid insulating materials that require chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) in their production, as these are ozone-depleting compounds. Consider insulating materials made from recycled materials such as cellulose or mineral wool, if such items meet the project's performance and budgetary criteria. If the framing system is of a highly conductive material, install a layer of properly sized insulating sheathing to limit thermal bridging.

❑ **Consider the reflectivity of the building envelope.**
In regions with significant cooling loads, select exterior finish materials with light colors and high reflectivity. Consider the impact of decisions upon neighboring buildings. A highly reflective envelope may result in a smaller cooling load, but glare from the surface can significantly increase loads on and complaints from adjacent building occupants.

❑ **Prevent moisture buildup within the envelope.**
Under certain conditions, water vapor can condense within the building envelope. When this occurs the materials that make up the wall can become wet, lessening their performance and contributing to their deterioration. To prevent this, place a vapor-tight sheet of plastic or metal foil, known as a vapor barrier, as near to the warm side of the wall construction as possible. For example, in areas with meaningful heating loads, the vapor barrier should go near the inside of the wall assembly. This placement can lessen or eliminate the problem of water-vapor condensation.

❑ **Weatherstrip all doors and place sealing gaskets and latches on all operable windows.**
Careful detailing, weatherstripping, and sealing of the envelope are required to eliminate sources of convective losses. Convective losses occur from wind loads on exterior walls. They also occur through openings around windows and doors and through small openings in floor, wall, and roof assemblies. Occupants can experience these convective paths as drafts. Older buildings can prove to be a source of significant energy loss and added fuel and pollution costs. Inspect weatherstripping and seals periodically to ensure that they are air-tight.

❑ **Specify construction materials and details that reduce heat transfer.**
Heat transfer across the building envelope occurs as either conductive, radiant, or convective losses or gains. Building materials conduct heat at different rates. Metals have a high rate of thermal conductance. Masonry has a lower rate of conductance; the rate

for wood is lower still. This means that a wall framed with metal studs compared to one framed with wood studs, where other components are the same, would have a considerably greater tendency to transmit heat from one side to the other. Insulating materials, either filled in between framing members or applied to the envelope, resist heat flow through the enclosing wall and ceiling assemblies. Consider the following principles in construction detailing:

– To reduce thermal transfer from conduction, develop details that eliminate or minimize thermal bridges.
– To reduce thermal transfer from convection, develop details that minimize opportunities for air infiltration or exfiltration. Plug, caulk, or putty all holes in sills, studs, and joists. Consider sealants with low environmental impact that do not compromise indoor air quality.

❑ **Incorporate solar controls on the building exterior to reduce heat gain.**
Radiant gains can have a significant impact on heating and cooling loads. A surface that is highly reflective of solar radiation will gain much less heat than one that is adsorptive. In general, light colors decrease solar gain while dark ones increase it. This may be important in selecting roofing materials because of the large amount of radiation to which they are exposed over the course of a day; it may also play a role in selecting thermal storage materials in passive solar buildings. Overhangs are effective on south-facing facades while a combination of vertical fins and overhangs are required on east and west exposures and, in warmer areas during summer months, on north-facing facades. (See also Chapter 11, “Renewable Energy,” for more information.)

❑ **Consider the use of earth berms to reduce heat transmission and radiant loads on the building envelope.**
The use of earth berms or sod roofs to bury part of a building will minimize solar gain and wind-driven air infiltration. It will also lessen thermal transfer caused by extremely high or low temperatures. (See also Chapter 11, “Renewable Energy” for further discussion.)

Building Grounds

❑ **Coordinate building strategy with landscaping decisions.**
Landscape and other elements such as overhangs are integral to a building’s performance. Decisions about the envelope need to be coordinated with existing and new landscaping schemes on a year-round basis.

❑ **Reduce paved areas to lessen heat buildup around the building that will add to the load on the building envelope.**
Consider selection of a paving color with a high reflectance to minimize heat gain. Glare factors should also be considered.

(See also Chapter 7, “Site Materials and Equipment.”)

➜ RESOURCES

Allen, Edward. *How Buildings Work*. New York: Oxford University Press, 1980. Broadly summarizes in simple, graphic fashion what a building does and how it does it. It contains a wealth of information that should be useful to professionals and non-professionals alike.

Passive Solar Industries Council (PSIC) and National Renewable Energy Laboratory (NREL). *Designing Low Energy Buildings—Integrating Daylighting, Energy-Efficient Equipment, and Passive Solar Strategies*. Washington, D.C.: Passive Solar Industries Council, n.d.

U.S. Department of Energy. Energy Efficiency and Renewable Energy. Office of Building Technologies. *Windows and Daylighting: A Brighter Outlook*. Washington, D.C.: GPO, 1994.

Watson, Donald, ed. *The Energy Design Handbook*. Washington, D.C.: The American Institute of Architects Press, 1993. Presents design concepts and methods to create climate-responsive, energy-efficient architecture. It includes introductory explanations,

guidelines, examples, and references of energy design strategies appropriate to particular climates and applications.

Watson, Donald, and Kenneth Labs. *Climatic Building Design*. New York: McGraw-Hill, 1983. Provides an introduction and reference guide to climatic design, focusing on the art and science of using the beneficial elements of nature to create comfortable, energy-efficient and environmentally wise buildings. It includes a good discussion of energy exchange through the building envelope, and offers strategies for heat and energy exchange that minimize energy use and maximize occupant comfort.

DESIGN TOOLS

PASSIVE SOLAR DESIGN

BLAST. Calculates building loads, analyzes solar feasibility, predicts life-cycle costs, and helps select the optimal HVAC system for a building. Developed by Civil Engineering Research Laboratories, U.S. Army. Contact: University of Illinois, (800) UI BLAST

ENERGY-10, Low-Rise Building Design (Design manual and software). Windows-environment program for small commercial buildings allowing early design evaluation of 16 energy-saving strategies including daylighting. Developed by National Renewable Energy Laboratory (NREL), Passive Solar Industries Council (PSIC), U.S. Department of Energy (DOE), and Lawrence Berkeley National Laboratory (LBNL). Contact: Blaine Collison at PSIC, (202) 628-7400.

SERI-RES (also known as *SUNCODE)*. Useful for residential and small commercial buildings to analyze passive solar design and thermal performance. Developed by NREL and Ecotope Group. Contact: Ron Judkoff at NREL, (303) 275-3000.

TRNSYS. Modular FORTRAN-based transient simulation code that allows for simulation of any thermal energy system, particularly solar thermal, building, and HVAC systems. Developed by the Solar Energy Laboratory, University of Wisconsin. Contact: TRNSYS Coordinator , (608) 263-1589.

ENERGY-EFFICIENT DESIGN

BLAST. See Passive Solar Design. Contact: University of Illinois, (800) UI BLAST

DOE-2. Calculates energy use and life-cycle costs of design options. Includes building envelope, HVAC systems, and daylighting analysis package. DOE Version 2.1E available for MS-DOS and Windows (386 and 486) and UNIX workstations. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.

ENERGY-10, *Low-Rise Building Design*. See Passive Solar Design. Contact: Blaine Collison at PSIC, (202) 628-7400.

TRNSYS. See Passive Solar Design. Contact: TRNSYS Coordinator, (608) 263-1589.

DAYLIGHTING DESIGN

ADELINE. Advanced integrated lighting design and analysis package, incorporating DXF input capability, SCRIBE MODELLER, PLINK, SUPERLIGHT, SUPERLINK, and RADIANCE, for detailed and advanced analysis of complex buildings. Available for MS-DOS 486 platforms. Developed by LBNL. Contact: Steve Selkowitz, (510) 486-5064.

RADIANCE. Lighting and daylighting modeling tool for performing accurate photorealistic lighting simulation. Available for UNIX workstations. Developed by LBNL. Contact: Charles Erlich, (510) 486-7916.

SUPERLITE 2.0. Daylighting analysis tool. Available for MS-DOS 386 and 486. Developed by LBNL. Contact: Rob Hitchcock, (510) 486-4154.

NOTES

1 U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies, *Windows and Daylighting: A Brighter Outlook* (Washington, D.C.: GPO, 1994) 7, 8.

CHAPTER 11

Renewable Energy

Passive Solar Heating, Cooling, and Thermal Storage

Author
Lisa Heschong

★ SIGNIFICANCE

Integration of passive solar heating, cooling, and thermal storage features, along with daylighting, into a building can yield considerable energy benefits and added occupant comfort. Incorporation of these items into the building design can lead to substantial reduction in the load requirements for building heating and cooling mechanical systems. The passive solar measures and mechanical systems need to be evaluated on an *interactive* basis during the design process, since an increase in one, can lead to a decrease in the other.

Direct gain through south-facing glass is the most common method of passive solar heating. Sunlight is admitted through the glazing into the space to be heated, and typically absorbed by thermal mass materials. Other methods include indirect gain (e.g., using a sunspace or atrium) and thermal storage walls. Passive solar heating works successfully in many types of buildings, especially residential and smaller commercial, industrial, and institutional buildings. They benefit from passive solar designs because they are "envelope-dominated", that is, their space conditioning loads are determined primarily by climatic conditions and building envelope construction characteristics rather than by internal heat gains. Passive solar heating works particularly well in climates where many sunny days occur during the cold season but is also beneficial in other climates.

Passive solar cooling strategies include cooling load avoidance, shading, natural ventilation, radiative cooling, evaporative cooling, dehumidification, and ground coupling. Passive design strategies can minimize the need for cooling through proper selection of glazings, window placement, shading techniques, and good landscaping design. However, incorrect daylighting strategies can produce excessive heat gain. Minimization of cooling loads should be carefully addressed through proper design for both solar and conventional building design.

Thermal mass and energy storage are key characteristics of passive solar design.[1] They can provide a mechanism for handling excess warmth, therefore reducing the cooling load, while storing heat that can be slowly released back to the building when needed. The thermal mass can also be cooled during the evening hours by venting the building, reducing the need for cooling in the morning.

☞ SUGGESTED PRACTICES AND CHECKLIST

Passive Solar Heating

❑ **Analyze building thermal-load patterns.**
An important concept of passive solar design is to match the time when the sun can provide daylighting and heat to a building with those when the building needs heat. This will determine which passive solar design strategies are most effective. Commercial buildings have complicated demands for heating, cooling, and lighting;; therefore their design strategies require computer analysis by an architect or engineer.

❑ **Integrate passive solar heating with daylighting design.**
A passive solar building that makes use of sunlight as a heating source should also be designed to take advantage of sunlight as a lighting source (see Chapter 9, "Daylighting"). However, each use has different design requirements that need to be addressed. In general, passive solar heating benefits from beam sunlight directly striking dark-colored surfaces. Daylighting, on the other hand, benefits from the gentle diffusion of sunlight over large areas of light-colored surfaces. Integrating the two approaches requires an understanding and coordination of daylighting, passive design, electric lighting, and mechanical heating systems and controls.

❑ **Design the building's floor plan to optimize passive solar heating.**
Orient the solar collection surfaces, for example appropriate glazings in windows and doors, within 15 degrees of true south, if possible. Because of the solar path, the optimum orientation for passive solar buildings is due south. South-facing surfaces do not have to be all along the same wall. For example, clerestory windows can project south sun deep into the back of the building. Both the efficiency of the system and the ability to control shading and summer overheating decline dramatically as the surface shifts away from due south.

❑ **Identify appropriate locations for exposure to beam sunlight.**
Overheating and glare can occur whenever sunlight penetrates directly into a building and must be addressed through proper design. A "direct-gain" space can overheat in full sunlight and is many times brighter than normal indoor lighting, causing intense glare. Generally, rooms and spaces where people stay in one place for more than a few minutes are inappropriate for direct gain systems. Lobbies, atria, or lounges can be located along the south wall where direct sun penetrates. Choose glazings that optimize the desired heat gain, daylighting, and cooling load avoidance. (see Chapter 9, "Daylighting").

❑ **Avoid glare from low sun angles.**
In late morning and early afternoon, the sun enters through south-facing windows. The low angle allows the sunbeam to penetrate deep into the building beyond the normal direct-gain area. If the building and occupied spaces are not designed to control the impact of the sun's penetration, the occupants will experience discomfort from glare. Careful sun-angle analysis and design strategies will ensure that these low sun angles are understood and addressed. For example, light shelves can intercept the sun and diffuse the daylight. Workstations can be oriented north-south so that walls or high partitions intercept and diffuse the sun.

❑ **Locate thermal mass so that it will be illuminated by low winter sun angles.**
Building design should incorporate a sufficient amount of correctly located thermal mass to effectively contribute to the heating requirements and provide cooling benefits in the summer.

Passive Solar Cooling

❑ **Design buildings for cooling load avoidance.**

Minimization of cooling loads should be carefully addressed for both solar building and conventional energy-efficient building design. Design strategies that minimize the need for mechanical cooling systems include proper window placement and daylighting design, selection of appropriate glazings for windows and skylights, proper shading of glass when heat gains are not desired, use of light-colored materials for the building envelope and roof, careful siting and orientation decisions, and good landscaping design.

❑ **Choose one or more shading strategies.**

- Install fixed shading devices, using correctly sized overhangs or porches, or design the building to be "self-shading." Fixed shading devices, which are designed into a building, will shade windows throughout the solar cycle. They are most effective on the south-facing windows. The depth and position of fixed shading devices must be carefully engineered to allow the sun to penetrate only during predetermined times of the year. In the winter, overhangs allow the low winter sun to enter south-facing windows. In the summer, the overhangs block the higher sun.
- Plant trees and/or bushes to shade the windows at the right time of day and season (see Chapter 7, "Site Materials and Equipment"). Deciduous vegetation is often an attractive and inexpensive form of shading, because it follows the local seasons, not the solar calendar. In the warm south, where more shading is needed, trees leaf out earlier, while in the cold north, where solar heat is beneficial late into spring, trees wait until the weather warms up before they leaf out. Trees can be strategically planted on east and west sides to block the rising and setting sun. Bushes can be positioned to block undesirable low sun angles from the east or west, and deciduous vines trained to grow over trellises make easily controlled shading systems. Evergreen trees trimmed so that their canopies allow low winter sun underneath but block the high summer sun can be very effective. Properly placed vegetation can also guide air flows toward buildings for natural ventilation and can block cold winter winds. Vegetation and groundcover also contribute to evaporative cooling around a building.

  Vegetation used for shading should be properly located so as not to interfere with solar gain to buildings in winter. Deciduous trees can reduce winter solar gain by 20 percent or more and should not be placed in the solar access zone. Also note that trees require maintenance, pruning, watering and feeding. As they grow they change their shading pattern, and they can be damaged or killed, leaving the building exposed.
- Consider awnings that can be extended or removed. Movable awnings are an old tradition and an excellent solution to the variation between seasons and the solar year. When rolled out in the summer, they not only provide deep shade but also lend a colorful touch to a building's facade. When rolled up in winter, they allow more sun into the building and avoid snow loads and/or excessive weathering.
- Consider exterior roll-down shades or shutters. An enormous variety of vertical shading devices are readily available. Wooden shutters are the most traditional. Also available are many exterior-grade fiberglass and plastic fabrics that cut out a significant amount of sunlight but still allow a clear view through the window. However, they do not prevent the glare problems caused by low-angle sun. Opaque steel or plastic roll-down shutters have proved reliable and long-lasting. Although expensive, they can also provide additional storm and vandalism protection.
- Limit east/west glass. Glass on these exposures is harder to shade from the eastern morning sun or western evening sun. Vertical or egg-crate fixed shading works well if the shading projections are fairly deep or close together; however, these may limit views. North-facing glass receives little direct solar gain, but does provides diffuse daylight.[2]

❑ **Consider other cooling strategies.**

– Design the building to take advantage of natural ventilation. Natural ventilation uses the passive stack effect and pressure differentials to bring fresh, cooling air through a building without mechanical systems. This process cools the occupants and provides comfort even in humid climates. Buildings using this design will incorporate operable windows or other means of outdoor air intakes. Wingwalls are sometimes used to increase the convective air flow. Other features include fresh air inlets located near floor level, use of ceiling fans, and the use of atriums and stairwell towers to enhance the stack effect. Caution should be used not to increase the latent load (i.e., the increased cooling load resulting from condensation) by bringing in moist outside air.

– Consider radiative cooling in appropriate climates. Radiative cooling, also known as nocturnal radiative cooling, uses design strategies that allow stored heat to be released to the outside. This strategy is particularly effective in climates and during seasons of the year when the daytime-nighttime temperature differences are meaningful. Night flushing of buildings uses radiative cooling principles. Building thermal storage serves as a heat sink during the day, but releases the heat at night, while being cooled with night air.

– Consider ground coupled cooling. Ground coupling is achieved by conductive contact of the building with the earth. The most common strategy is to cool air by channeling it through an underground tunnel. Another strategy provides cool air by installing a tube in the ground and dripping water into the tube. This reduces the ground temperature through evaporation.

– Consider evaporative cooling strategies. This cooling method works when water, evaporating into the atmosphere, extracts heat from the air. Evaporative cooling is most appropriate in dry climates, such as the Southwest.

– Use dehumidification in humid climates. Dehumidification is required in climates having high humidity levels, and therefore latent loads, during portions of the year. Common strategies include dilution of interior moisture by ventilating with less humid air, condensation on cooled surfaces connected to a heat sink, and desiccant systems.

Thermal Storage

❑ **Determine if excess heat should be stored or vented.**

Thermal mass in a passive solar building is intended to meet two needs. It should be designed to quickly absorb solar heat for use over the diurnal cycle and to avoid overheating. It should provide slow release of the stored heat when the sun is no longer shining. Depending upon the local climate and the use of the building, the delayed release of heat may be timed to occur a few hours later or slowly over days. Careful selection of the thermal storage medium, its location in the building, and its quantity are important design and cost decisions. Venting, another solution for handling stored heat, can rid the building of late afternoon heat or exhaust heat when the building's thermal mass is already saturated. Venting can also be viewed as a form of economizer cooling, using outside air to cool the building when the outside air is cooler than the building's thermostat setting[3] Venting requires an exhaust fan tied to a thermostatic control or flushing using natural ventilation.

❑ **Choose one or more thermal storage strategies.**

There are two basic thermal storage strategies using thermal mass. "Direct" thermal storage materials, such as concrete masonry or tiles, are placed directly in the sunlight so that intense solar energy enters them quickly. "Diffuse" thermal storage materials are placed throughout the building. They can absorb heat by radiation, the reflectance of sunlight as it bounces around a room, and via air heated elsewhere in the building (e.g., sunspaces and atria). Several storage strategies are presented below.

– Consider concrete, tile, brick, stone, or masonry floors. Flooring using these materials, exposed to direct sunlight, is probably the most common form of thermal storage selected for passive solar buildings. Masonry materials have high thermal capacity; their natural dark color aids in the absorption of sunlight. They also provide an attractive and durable floor surface, are widely available, and readily accepted by contractors and building occupants. Masonry's effectiveness can be inhibited if occupants place furniture and carpets over the floors. To address this, use masonry floors only in the areas where direct heat gain and storage is required.

– Consider a Trombe wall—a south-facing masonry wall covered with glass spaced a few inches away. Sunlight passes through the glass and is absorbed and stored by the wall. The glass and airspace keep the heat from radiating back to the outside. Heat is transferred by conduction as the masonry surface warms up, and is slowly delivered to the building some hours later.

  Trombe walls can provide carefully controlled solar heat to a space without the use of windows and direct sunlight, thus avoiding potential problems from glare and overheating, if thermal storage is inadequate. The masonry wall is part of the building's structural system, effectively lowering costs. The inside, or discharge, surface of the Trombe wall can be painted white to enhance lighting efficiency within the space. However, the outside large dark walls sheathed in glass must be carefully designed for both proper performance and aesthetics.

– Consider masonry or concrete walls insulated on the outside. Many buildings, especially low-rise commercial buildings, are constructed with concrete or masonry walls that can provide excellent thermal mass to absorb excess solar heat and stabilize indoor temperatures. In most climates masonry walls are most energy-efficient when they are insulated on the outside of the building, which allows them to absorb excess heat within the building, without wicking it away to the outside.

  However, there are barriers to using this technique. It is not common practice for contractors, and it may seem redundant to cover up an existing excellent weather surface. Insulated masonry also adds extra width to a wall, making it difficult to finish at the edges of windows, roofs, and doors.

  Fortunately, new technologies have lowered the cost and increased the options for insulated masonry. Various foam insulations are available in panels that can be adhered directly to the masonry surface and then protected with a troweled- or sprayed-on weathering skin, and masonry insulated structural panels are also available. Manufacturers are also developing self-insulating masonry materials that both increase the thermal capacity of the building and slow the flow of heat through the walls.

– Consider using double gypsum board throughout the building. Increase the thermal capacity of a building by simply increasing the thickness of the gypsum board used on interior wall surfaces of the building or by using thicker gypsum board products. Increasing the thickness of all of the wall surfaces can raise the thermal capacity of the building for little additional material cost and practically no labor cost. It has the added benefits of increasing the fire safety and acoustic privacy of interior spaces. This diffuse thermal mass approach depends on effective convective airflows since room air is the heat-transfer medium. To really "charge" the walls, temperatures within the space must be allowed to fluctuate a little more than standard design assumptions, on the order of 5° F above and below the thermostat setting.

– Consider water-storage containers for thermal mass. Water has a very high thermal capacity, about twice that of common masonry materials. Water also has the advantage that convection currents distribute heat more evenly throughout the medium. Passive solar designers have experimented with a wide variety of water-storage containers built primarily into walls. Creative solutions include enclosing water containers in seating boxes under south windows or using water as an indoor feature such as a large tropical aquarium, pond, or pool.

Active Solar Systems

★ SIGNIFICANCE

Active solar collector systems take advantage of the sun to provide energy for domestic water heating, pool heating, ventilation air preheat, and space heating. Active solar systems should be integrated with a building's design and systems only after passive solar and energy-conserving strategies are considered.

Water heating for domestic use is generally the most economical application of active solar systems. The demand for hot water is fairly constant throughout the year, so the solar system provides energy savings year-round. Successful use of solar water heating systems requires careful selection of components and proper sizing. Major components of a system include collectors, the circulation system that moves the fluid between the collectors and storage, the storage tank, a control system, and a backup heating system.[4]

An active solar water heating system can be designed with components sized large enough to provide heating for pools or to provide a combined function of both domestic water and space heating. Space heating requires a heat-storage system and additional hardware to connect with a space heat distribution system. An active solar space heating system makes economic sense if it can offset considerable amounts of heating energy from conventional systems over the life of the building or the life of the system. The system equipment, which can be costly, should be evaluated on a life-cycle basis, using established project financial criteria acceptable to the building owner.

☞ SUGGESTED PRACTICES AND CHECKLIST

General Considerations

❑ **Determine if the climate and building usage is appropriate for an active solar collection system.**
The energy savings for active solar systems depend upon the amount of available solar radiation, projected uses of the system, and the proper system design.

❑ **Determine the financial feasibility of an active solar system.**
A life-cycle cost analysis should be carried out for the up-front and operational costs, and expected energy savings, of an active solar system compared with conventional systems. The financial analysis should be performed over the projected life of the system—a minimum of 10 years. Based on the resulting estimated calculations, the project owner can make a determination of the financial feasibility of investment in the active solar system.

❑ **Determine an appropriate location for solar collectors on or near the building.**
- Locate collectors to maximize exposure to sun. Numerous solar engineering texts describe criteria for optimizing the orientation (ideally due south) and tilt of the collector according to latitude, climate, and usage. Collectors intended for winter space heating have a steeper slope than collectors designed for year-round hot-water heating. Vertically mounted wall collectors and horizontal roof collectors have also been used in various systems.
- Locate collectors to avoid shading from nearby buildings and vegetation. A study of sun angles and local sky obstructions should help determine the best location on the site. For large commercial buildings, the most common location for good solar access is on the highest level of a flat roof.
- Locate collectors to avoid vandalism and safety hazards. Collectors can be attractive targets for vandals. Their flat surface is well suited to graffiti, and glass cover plates can be broken. The more visible the collectors, the more they may attract the attention of vandals.

- Locate collectors to avoid blinding hazards from reflected sunlight. In addition to absorbing the sun's energy, almost all collectors reflect light at certain angles. This reflection is undesirable when directed at the occupants of another building and can be hazardous if directed toward a road or machine operator.

❑ **Design collectors to withstand all weather conditions.**
Heavy snow loads, ice storms, and especially hailstorms can damage collector glass. Tempered glass or reinforced glass is often used to increase resistance. Structures supporting collectors have to be designed to survive wind loads from all directions. A structural engineer should be consulted to ensure compliance with all structural codes.

❑ **Design and locate collectors to maintain a clean surface and facilitate cleaning.**
Dirt and dust on collector glazing can easily reduce system efficiency by 50 percent or more. Insist upon a location and system materials that minimize dirt collection. A regular maintenance schedule is aided by easy access to the collectors, a source of water, and a nearby drainage system. Very large, tall, or horizontal collectors may need to be designed to support the weight of maintenance personnel. In some cases, rainwater may provide adequate surface cleaning.

❑ **Minimize heat losses from the system.**
- Minimize the distance from collection to the storage source. The longer the run from the collectors to storage, the greater the heat loss and reduced system efficiency. For solar heating, locate storage near the central heating system.
- Optimize insulation of collectors, ducts, pipes, and storage. Greater insulation should be installed for higher-temperature collection levels.
- Place duct and piping runs within conditioned space. This design can be advantageous during the heating season, but may be disadvantageous during the cooling season.

❑ **Avoid over-designing to ensure the longevity of an active solar system.**
- Minimize controls. Control technology, along with computer and sensor technology, has advanced significantly over the past years, making older versions quickly obsolete. New systems provide higher efficiencies and greater returns on investment. In addition, the design and building management team should provide maintenance staff with system controls training to optimize system operations.
- Minimize maintenance. A system that is self-maintaining is likely to have a higher efficiency and lower failure rate, and thus the best economic payback. Generally, the fewer moving parts, the less maintenance required. Active solar space-heating systems generally are not operating year-round, so their moving parts must be reliable enough to work intermittently. Pressure-relief valves, self-cleaning surfaces, and overheating sensors pay for themselves by extending the life of the system.
- Maximize access to collectors, pipes, ducts, and storage areas. Assume that all parts of a system may have to be maintained and replaced in the future, and make sure that maintenance and replacement will not be difficult. Pipes and ducts buried in walls and under concrete slabs will be costly to fix, and thus are more likely to be abandoned.

Active Solar Hot Water

❑ **Select the type of solar hot-water heater according to climate, cost, and operations and maintenance preferences.**
There are five types of solar water-heating systems:
- *Thermosyphon Systems*. These systems heat water or an antifreeze fluid, such as glycol. The fluid raises by natural convection from collectors to the storage tank, which is placed at a higher level. No pumps are required. In thermosyphon systems fluid movement, and therefore heat transfer, increases with temperature, so these systems are most efficient in areas with high levels of solar radiation.
- *Direct-Circulation Systems*. These systems pump water from storage to collectors during sunny hours. Freeze protection is obtained by recirculating hot water

from the storage tank, or by flushing the collectors (drain-down). Since the recirculation system increases energy use while flushing reduces the hours of operation, direct-circulation systems are used only in areas where freezing temperatures are infrequent.

- *Drain-Down Systems*. These systems are generally indirect water-heating systems. Treated or untreated water is circulated through a closed loop, and heat is transferred to potable water through a heat exchanger. When no solar heat is available, the collector fluid is drained by gravity to avoid freezing and convection loops in which cool collector water reduces the temperature of the stored water.
- *Indirect Water-Heating Systems*. In these systems, freeze-protected fluid is circulated through a closed loop and its heat is transferred to potable water through a heat exchanger with 80 to 90 percent efficiency. The most commonly used fluids for freeze protection are water-ethylene glycol solutions and water-propylene glycol solutions.
- *Air System*s. In this indirect system the collectors heat the air, which is moved by a fan through an air-to-water heat exchanger. The water is then used for domestic or service needs. The efficiency of the heat exchanger is in the 50 percent range.

Direct-circulation, thermosyphon, or pump-activated systems, require higher maintenance in freezing climates. For most of the United States, indirect air and water systems are the most appropriate. Air solar systems, while not as efficient as water sytems, should be considered if maintenance is a primary concern since they do not leak or burst.[5]

❑ **Consider a pre-heat or full-temperature system.**

- A low-temperature solar water-heating system can be sized to provide only hot-water preheating. When hot water is needed, the warm water from storage is boosted to full temperature with a conventional gas or electric-based hot-water system. These systems can be relatively simple, with reduced collector size, lower insulation levels, and small boosting system, making them attractive options.
- Higher-temperature solar hot-water systems can be designed to provide full-temperature hot water. A conventional gas or electric backup system is used only when there is no sun for extended periods. A high-temperature system can save more in fuel costs, but with the tradeoff of more expensive equipment.

❑ **For systems using water as a collection medium, consider the following issues:.**

- Prevent stagnation. If a system is allowed to stagnate in direct sun, very high temperatures can quickly result, causing collector materials to deteriorate rapidly. and causing closed piping or storage tanks to burst from excessive pressure. Stagnation can be avoided by venting or slow circulation of some water to keep the collectors cool; a drainback system can also be used.
- Provide freeze protection. Freeze protection is important, even in nonfreezing climates, because an extreme weather event can cause substantial damage to a system. In desert climates, systems can freeze even on relatively warm nights because their heat radiates outward to the cool night sky, dropping the system temperature to freezing. The strategies used to protect a water system from freezing are determined by the main system type (e.g., direct-circulation, draindown, or closed-loop).
- Avoid calcification and corrosion. Calcification is the buildup of minerals inside a collector and its pipes caused by "hard" water circulating through the system. Open systems that circulate city water are especially vulnerable. Mineral scales eventually clog the system, reducing flows and pump efficiency. Water can also be slowly corrosive of both metals and organic compounds. Gaskets and sealants can be quite vulnerable. Closed-loop systems can compensate with buffering chemicals to maintain a neutral pH.
- Plan for leaks. Any failure of a water-based system is likely to result in a leak. Provisions should be made to contain all possible leaks and prevent water from

harming other building components. Electrical equipment, and any personnel working on the electrical equipment, should be protected from exposure to leaking water.

- Select a heat-storage strategy. Almost all water systems involve thermal storage. This is typically done by collecting the heated water in storage tanks for use as needed. The simplest systems circulate the heated water directly. More complex systems use one or more heat exchangers to isolate system components, adding the potential for more sophisticated levels of control.
- Minimize pumps and pump energy. Systems using pumps can require significant energy usage. Each pump also requires control logic that raises the complexity and cost of the system. Failure of a pump by stagnation or freezing can result in significant damage.

Active Solar Heating Systems

❑ **Select an active solar heating system and collection medium appropriate for the building's heating and cooling system.**

A solar heating system should be designed to be compatible and interactive with conventional HVAC systems in the building. Water-based systems tend to be most compatible with HVAC systems that also use water as a distribution mechanism, though some interface with air distribution systems. Air-based systems tend to be most appropriate when the building uses a large, centralized air-distribution system. A central heating system has sophisticated controls and centralized ducts that can interface well with a central solar thermal-storage source.

❑ **Evaluate water-based collectors.**

A water-based system typically uses heat exchangers to move heat from the collection medium to the heat-storage or distribution medium. Heat exchanges can transfer heat to water-storage, water-distribution, and also air-distribution systems. (See also the "Active Solar Hot Water" section for additional issues to consider.)

❑ **Consider air-based collectors.**

Air-based systems are the least complex of active systems; therefore, they avoid many of the problems of water collectors. Air collectors are typically simple, flat-plate collectors with plastic covers. They are easily serviced, and have less extreme and costly failures. While safe from freezing or boiling, they do take up considerably more surface area, and their ducts and fans require more space than water pipes and pumps. In addition, sealing an air system against leakage and finding and repairing leaks are more difficult than repairs in water-based systems. When considering air collectors:

- Determine the use of the system. A very simple air system can provide preheated air for a mechanical system. This is basically a heating economizer, and it can use control logic similar to that of a cooling economizer. The resulting energy savings are significant if sunny weather typically coincides with the hours when the building needs heat.
- Determine heat storage needs. Heating requirements in commercial buildings are greatest in the early morning and evening, when solar heat is not available. These buildings require a thermal-storage system to provide solar heat, on an as-needed basis, after it has been collected.

❑ **Consider ventilation air preheat systems.**

This space heating system uses solar energy to preheat ambient air and bring it into a building's ventilation systems. The system utilizes a dark-colored, perforated, unglazed collector, integrated into the building structure, to preheat the air. These systems have efficiencies as high as 75 percent, require low maintenance, and can be installed economically, depending on the building type, climate, and fuel costs.[6]

Photovoltaics

★ SIGNIFICANCE

Photovoltaic (PV) technology is the direct conversion of sunlight to electricity using semiconductor devices called solar cells. Photovoltaics are almost maintenance-free and seem to have a long life span. The photoelectric conversion process produces no pollution and can make use of free solar energy. Overall, the longevity, simplicity, and minimal resources used to produce electricity via PV systems make this a highly sustainable technology.

PVs are currently cost-effective in small, off-grid applications such as microwave repeaters, remote water pumping, and remote buildings. While the cost is high for typical applications in buildings connected to the electric power grid, the integration of PVs into commercial buildings is projected to greatly increase over time. In fact, worldwide PV manufacturing is growing at a healthy annual rate of more than 20 percent, and the focus of research is to reduce the cost of PV systems, and to integrate PV into building design.

The most common technology in use today is single-crystal PVs, which use wafers of silicon wired together and attached to a module substrate. Thin-film PV, such as amorphous silicon technology, is based on depositing silicon and other chemicals directly on a substrate such as glass or flexible stainless steel. Thin-film PV materials can look almost like tinted glass. They can be designed to generate electricity from a portion of the incoming light while still allowing some light to pass through for daylighting and view. Thin films promise lower cost per square foot, but also have lower efficiency and produce less electricity per square foot compared to single-crystal PVs.

PV panels produce direct current, not the alternating current used to power most building equipment. Direct current is easily stored in batteries; a device called an inverter is required to transform the direct current to alternating current. The cost of reliable batteries to store electricity, and the cost of an inverter, increase the overall cost of a system.

With an inverter creating alternating current, it is possible to transfer excess electricity generated by a photovoltaic system back into the utility grid rather than into batteries for off-grid systems. In this case, the utility grid becomes a virtual storage system. Most utilities are required to buy such excess site-generated electricity back from the customer. Recently, through what is called a "net-metering law," a few state legislatures or public utility commissions have mandated that utilities pay and charge equal rates regardless of which way the electricity flows. Building owners in such states will find PVs more economically attractive.

☞ SUGGESTED PRACTICES AND CHECKLIST

Installation Sites

❑ **Consider conventional and remote electrical uses for PV power.**

- Conventional uses include communications or testing devices that need to operate continuously without supervision or require direct current. Park districts and transportation departments have installed small PV systems to power emergency telephone stations. Water districts have installed PV systems to power monitoring equipment.
- Remote uses include applications in off-grid areas and for small, isolated electric uses. For example, isolated communities can store medical supplies in refrigerators powered by PVs. Any appliance that can run off a 12-volt battery with direct current is a good application for remote PVs because it does not require an inverter to create alternating current.
- Recreational areas far from utility service, such as parks, beaches, and campsites, are

especially good candidates for PV power. With battery backup and an inverter, public facilities, concessions, and guard stations can be powered with reliable electricity off the grid and without the noise of a generator.

❑ **Consider utility-integrated PVs where utility demand charges are very high and there is extensive sunshine during the facility's peak electric loads.**

❑ **Consider PV-driven battery backup systems where air-quality restrictions limit the use of gas generators for emergency backup.**

Building Integration

❑ **Rack-mount PV systems or mount them directly on roof and wall surfaces.**
Optimizing the panel's tilt to the sun improves performance. Most existing commercial buildings have large, flat roofs exposed to lots of sun, making them good candidates for PV arrays. New buildings can be designed with sloped surfaces that can optimize PV exposure to the sun. The PV panels can be designed as the primary "weather skin" for sloped roofs or walls and can be integrated into shading devices.

❑ **Watch for the commercial availability in the near future of partially transparent PV panels for use as window-shading devices.**
The panels would allow diffuse light through a window while also producing electricity from energy that would otherwise be rejected from the building.

Landscape Integration

❑ **Consider the use of large PV arrays to generate electricity while shading parking lots or other outdoor areas.**
This application is especially appropriate where the PVs are used to generate electricity for parking lot lighting or recreational uses.

❑ **On a smaller scale, PVs can be used to economically power night-time walkway and landscape lighting.**
A small PV panel mounted above the light collects energy during the day and charges a small battery that powers the light for a preset number of hours at night. This type of stand-alone system saves the cost of underground electrical service (see also Chapter 7, "Site Materials and Equipment").

➜ RESOURCES

PASSIVE SOLAR/INTEGRATED DESIGN

Balcomb, J. Douglas, editor. *Passive Solar Buildings.* Cambridge, Mass.: MIT Press, 1992.

Brown, Linda R. "SERF: A Landmark in Energy Efficiency." *Solar Today*. American Solar Energy Society. May/June 1994.

Burt Hill Kosar Rittleman Associates and Mim Kantrowitz Associates. *Commercial Building Design: Integrating Climate, Comfort, and Cost.* New York: Van Nostrand Reinhold Co., 1987.

Cook, Jeffrey, editor. *Passive Cooling,* Cambridge, Mass.: MIT Press, 1989.

Cook, Jeffrey and Mike McEvoy. "Naturally Ventilated Buildings: Simple Concepts for Large Buildings." *Solar Today*. American Solar Energy Society. March/April 1996.

International Energy Agency Solar Heating and Cooling Programme. *Passive Solar Commercial and Institutional Buildings: A Sourcebook of Examples and Design Insights.* West Sussex, United Kingdom: John Wiley and Sons, Ltd., 1994.

Jenior, Mary-Margaret. "Solar Buildings for a Sustainable America." *Solar Today*. American Solar Energy Society, March/April 1994, 12-15.

Jones, Robert W. and Robert D. McFarland. *The Sunspace Primer.* New York: Van Nostrand Reinhold Co., 1994.

Passive Solar Industries Council and National Renewable Energy Laboratory. *Designing Low Energy Buildings*. Washington, D.C.: Passive Solar Industries Council, n.d.

Solar Energy Research Institute. *The Design of Energy-Responsive Commercial Buildings*. New York: John Wiley and Sons, 1985.

Thayer, Burke Miller. *Buildings for a Sustainable America—Case Studies*. Boulder, Colo.:American Solar Energy Society, n.d. Compendium of case studies on passive solar designed buildings.

ACTIVE SOLAR DESIGN

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. "Solar Energy Utilization," Chapter 30 in *ASHRAE Handbook, HVAC Applications.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1995. Extensive summary of solar fundamentals and current applications of active solar technology. Good bibliography and additional references.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. *Active Solar Heating System Design Manual*. Atlanta: ASHRAE, n.d. Provides architects, engineers, and designers of large active solar water and space heating systems with design information for a variety of applications, system types, and locations.

Chandra, Subrato, Philip W. Fairey III, and Michael M. Houston. *Cooling with Ventilation*. (SERI/SP-273-2966) Golden, Colo.: Solar Energy Research Institute (National Renewable Energy Laboratory) 1986.

Duffie, J. A., and W. A. Beckman. *Solar Engineering of Thermal Processes*. New York: John Wiley, 1980. Standard engineering text.

National Renewable Energy Laboratory. "Solar Ventilation Preheating," *Renewable Energy Technologies for Federal Facilities*. Golden, Colo.: NREL, September 1995.

Short, W.; D. Packey; and T. Holt. *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies.* Technical publication TP-462-5173. Golden, Colo.: National Renewable Energy Laboratory, March 1995. Presents the federal government's approach to evaluating the economics of various renewable technologies. Includes life-cycle cost procedures and examples of various applications, including photovoltaics.

U.S. National Bureau of Standards. *Performance Criteria for Solar Heating and Cooling in Commercial Buildings.* Technical note 1187. Washington, D.C.: GPO, 1984.

PHOTOVOLTAICS

International Energy Agency Solar Heating and Cooling Programme. *Photovoltaics in Buildings: A Design Handbook for Architects and Engineers*. London, U.K.: James and James Ltd., 1996.

Thornton, J. "Economics of Photovoltaics Versus Line Extensions: Selected Case Studies," in *Solar 94: Proceedings of the 1994 American Solar Energy Society Annual Conference.* Boulder, Colo.: American Solar Energy Society, 1994**.** Presents examples of photovoltaic applications for various remote locations.

U.S. Department of Energy. *Solar Electric Buildings: An Overview of Today's Applications*. (DOE/GO-10096-253 or NTIS pub. DE 96000524). Washington, D.C.: GPO, 1996. Examples of various types of photovoltaic systems installed on commercial and residential buildings and as stand-alone systems.

U. S. Department of Energy. *Photovoltaic Fundamentals* (DOE/CH10093-117-Rev. 1, NTIS pub. DE91015001). Washington, D.C.: GPO, 1995. A short review of photovoltaic technologies and current developments in the field.

DESIGN TOOLS

PASSIVE SOLAR DESIGN

BLAST. Calculates building loads, analyzes solar feasibility, predicts life-cycle costs, and helps select the optimal HVAC system for a building. Developed by Civil Engineering Research Laboratories, U.S. Army. Contact: University of Illinois, (800) UI BLAST

ENERGY-10, Low-Rise Building Design (Design manual and software). Windows-environment program for small commercial buildings allowing early design evaluation of 16 energy-saving strategies including daylighting. Developed by National Renewable Energy Laboratory (NREL), Passive Solar Industries Council (PSIC), U.S. Department of Energy (DOE), and Lawrence Berkeley National Laboratory (LBNL). Contact: Blaine Collison at PSIC, (202) 628-7400.

SERI-RES (also known as *SUNCODE)*. Useful for residential and small commercial buildings to analyze passive solar design and thermal performance. Developed by NREL and Ecotope Group. Contact: Ron Judkoff at NREL, (303) 275-3000.

TRNSYS. Modular FORTRAN-based transient simulation code that allows for simulation of any thermal energy system, particularly solar thermal, building, and HVAC systems. Developed by the Solar Energy Laboratory, University of Wisconsin. Contact: TRNSYS Coordinator , (608) 263-1589.

ENERGY-EFFICIENT DESIGN

BLAST. See Passive Solar Design. Contact: University of Illinois, (800) UI BLAST

DOE-2. Calculates energy use and life-cycle costs of design options. Includes building envelope, HVAC systems, and daylighting analysis package. DOE Version 2.1E available for MS-DOS and Windows (386 and 486) and UNIX workstations. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.

ENERGY-10. See Passive Solar Design. Contact: Blaine Collison at PSIC, (202) 628-7400.

TRNSYS. See Passive Solar Design. Contact: TRNSYS Coordinator , (608) 263-1589.

DAYLIGHTING DESIGN

ADELINE. Advanced integrated lighting design and analysis package, incorporating DXF input capability, SCRIBE MODELLER, PLINK, SUPERLIGHT, SUPERLINK, and RADIANCE, for detailed and advanced analysis of complex buildings. Available for MS-DOS 486 platforms. Developed by LBNL. Contact: Steve Selkowitz, (510) 486-5064.

RADIANCE. Lighting and daylighting modeling tool for performing accurate photorealistic lighting simulation. Available for UNIX workstations. Developed by LBNL. Contact: Charles Erlich, (510) 486-7916.

SUPERLITE 2.0. Daylighting analysis tool. Available for MS-DOS 386 and 486. Developed by LBNL. Contact: Rob Hitchcock, (510) 486-4154.

SOLAR HOT WATER SYSTEM DESIGN

F-Chart. Used for active solar system design applications, including water storage heating, domestic water heating, and pool heating. Versions for Mac, DOS, and Windows. Contact: F-Chart Software, Middleton, Wisconsin, (608) 836-8531 .

TRNSYS. See Passive Solar Design. Contact: TRNSYS Coordinator , (608) 263-1589.

PHOTOVOLTAIC DESIGN

PV F-Chart. A comprehensive PV system analysis and design program for utility interface, battery storage and stand-alone systems. Contact: F-Chart Software, Middleton, Wisconsin, (608) 836-8531.

NOTES

1 Passive Solar Industries Council. *Designing Low Energy Buildings.* Washington, D.C.: Passive Solar Industries Council, n.d., 60.

2 Ibid.; p. 39.

3 Ibid.; p. 60.

4 Ibid.; p. 96.

5 Ibid.; p. 95.

6 National Renewable Energy Laboratory. “Solar Ventilation Preheating,” *Renewable Technologies for Federal Facilities*. (Golden, Colo.: NREL, September 1995.)

SECTION B

Buildings Systems and Indoor Environmental Quality

Designing and installing environmentally sound and energy-efficient systems have a long-term impact on the cost-effective operations of a building and on the productivity of building occupants. Chapter 12 in this section provides guidance on types of heating, ventilating, and air-conditioning (HVAC) system components that will most effectively meet design goals and also examines lighting and other electrical systems for efficiency in products and practices.

Indoor environmental quality is also reviewed, with a focus on indoor air quality (IAQ) and acoustics as two aspects that can affect building occupants' health and productivity. Chapter 13 outlines strategies to achieve good IAQ through control of contaminant sources and occupant activity and through good ventilation and building maintenance practices. Chapter 14 discusses how desired sound control levels can be reached through design practices, construction techniques, and attention to mechanical systems and surface finishes.

Building commissioning, a practice to ensure building systems are installed, operate, and are maintained to meet design goals, is discussed in Chapter 15.

CHAPTER 12

HVAC, Electrical, and Plumbing Systems

Heating, Ventilating, and Air-Conditioning

Author
Clark Bisel

★ SIGNIFICANCE

The amount of energy used annually by heating, ventilating, and air-conditioning (HVAC) systems typically ranges from 40 to 60 percent of the overall energy consumption in a building, depending on the building's design, the use of renewable energy strategies, climate, the building's function, and its condition. HVAC systems also affect the health and comfort of building occupants. These systems serve an essential function and are identified as problem areas more often than other occupancy issues.

HVAC system requirements increased dramatically in the twentieth century in response to changes in other design practices, such as greater use of glazing, sealed buildings, alternate envelope systems with greater thermal loads, larger building floorplates, and more extensive use of artificial lighting and occupant equipment. As a result, buildings have become more dependent on fossil-fuel energy sources instead of natural energy flows such as climate, temperature, and solar conditions.

Before the first energy crisis in the United States in the 1970s, HVAC systems in many commercial buildings were often designed to maintain comfort by simultaneously heating and cooling, with minimal regard for energy use. Additional inefficiencies caused by lighting that used two to three times the energy of modern systems, minimally insulated building envelopes, and other factors further compounded the growth in energy use. The result was excessive energy loss as heating and cooling plants were operated in "opposition" to each other during most hours when the building was occupied, regardless of climatic conditions. Systems such as constant-volume, double-duct and perimeter-induction systems were predominant and were designed primarily for comfort, not energy conservation.

After the energy crisis, design and operating practice shifted drastically. Outdoor ventilation rates were reduced to very low (and now considered unhealthy) levels, lighting levels were decreased, and building temperatures were kept at the outer limits of the comfort range. This resulted in greater occupant dissatisfaction. Since that time, advancements have led to greater precision in maintaining indoor temperature (and often humidity) and indoor air-quality levels, thus increasing the level of HVAC performance and decreasing energy use.

The goal of environmentally sound HVAC system design is to meet occupant needs through the most efficient and environmentally positive means at the lowest initial and life-cycle costs. Solutions that have evolved provide environmental comfort while accounting for climatic conditions, use of space, and building technology. These green system designs take into consideration factors such as solar orientation, floorplate depth, thermal mass, insulation, selection of architectural materials, placement and type of doors and windows, and natural ventilation.

Heating and cooling needs are affected by the performance of interrelated building systems and characteristics, including passive solar design elements such as daylighting, climate-sensitive envelope, and efficient lighting, as well as user equipment needs and other heating loads. The appropriate HVAC solution should be determined only when the full design team has thoroughly reviewed the requirements and contributing thermal loads of these interrelated systems and has carefully considered all efficiency gains possible through design strategies. The design team should also review the budgetary impact of different options. Decisions made in the pre-design phase using this integrated approach will typically lead to reduced energy requirements and lower HVAC system costs.

☞ SUGGESTED PRACTICES AND CHECKLIST

Pre-Design Process

❑ **Develop a conceptual computer model that illustrates projected energy use and sources.**
This conceptual model can serve as a baseline for comparison of system options. The basic framework of the model is the proposed building design, including architectural and systems information. The computer model should be "tuned" to reflect actual performance data from similar types of buildings. A local utility can be helpful in providing this information. The project team should integrate system options and "packaged" solutions. A parametric process can be used to evaluate the impact that a change in one variable would have on the remaining systems—for example, the impact that a different glazing size and type would have on heating, cooling, and lighting. The model can be used to analyze these options on a case-by-case, integrated basis. Each iteration should be reviewed for its relative energy and financial outcomes.

❑ **Use this suggested approach in performing the analysis.**

– Explore passive solar strategies and non-energy-intensive HVAC and lighting opportunities that harness natural processes. Daylighting, natural ventilation, evaporative cooling, thermal mass coupling, energy recovery systems, and other processes may be appropriate. Free cooling directly with outside air or evaporative cooling with water may offer excellent energy-saving opportunities in certain climates.
– Consider the building envelope and integrate this with general architectural issues such as solar strategies, glazing, daylighting, and access.
– Fine-tune the proposed building footprint and orientation to maximize energy benefits.
– Recognize that thermal mass can be beneficial in providing a flywheel effect to reduce after-hours environmental conditioning and morning warm-up loads in the specific microclimate.
– Optimize the energy benefits of glazing selections, sizing, and locations for each building facade.

- Review the interaction between daylighting and artificial illumination. The benefit of reduced lighting energy needs and the resulting HVAC savings are substantial.
- Consider architectural elements such as louvers, blinds, and horizontal and vertical shades to reduce direct solar radiation into the occupied space when not desired (cooling load avoidance).
- Control the infiltration of unwanted air through window-wall detailing, sealing, and building pressurization.
- Consider increased insulation levels for various systems to reduce loss factors.
- Consider vapor barriers to reduce latent (moisture) loads.
- Reduce internal heat gains from office equipment, appliances, ambient lighting, and task lighting. Review design criteria for occupant needs, including lighting and electric power, comfort, and occupant density. Consider options to reduce the energy needs of user equipment.
- Design systems and components for ease of maintenance.
- Incorporate ventilation for healthy indoor air quality and balanced energy use.

❑ **Design the HVAC system and consider potential options.**
After all systems have been optimized in the model, design the resulting HVAC system and reduce energy requirements. This will lead to lower energy and operational costs.

❑ **Improve control systems by using computer software programs and sensors to operate building systems in accordance with occupancy patterns.**

❑ **Develop accurate pricing.**
Prepare realistic cost estimates for all of the modeling and energy-based decisions. Make final decisions on a life-cycle cost basis, reviewing all up-front and annual operating costs.

(See also Chapter 9, "Daylighting," Chapter 10, "Building Envelope", and Chapter 11, "Renewable Energy," for more information on pre-design considerations.)

HVAC Design Guidelines

❑ **Define the project design criteria.**
The design criteria should reflect an understanding of the building's use, occupancy patterns, density, passive solar opportunities, office equipment, lighting levels, comfort ranges, and specific needs. Actual operating data from similar buildings is of value in this process. When determining final criteria, the design team should build in flexibility to accept future changes in the design. The design criteria should outline a process and goals for evaluating energy efficiency, based on project economics and owner performance requirements.

❑ **Use advanced design methods.**
Utilize the best design tools available to accurately size and select system components. Specify equipment that meets the calculations and do not oversize. Plan for effective ways to meet future load increases without sacrificing current energy requirements. Use computer-based analysis tools to evaluate building load, select equipment, and simulate complete system performance (such as DOE-2.1, ENERGY-10, TRNSYS, and BLAST). Annual simulations are the best tool for evaluating the complex interaction between building systems. (See "Resources" section for more information on Design Tools.)

❑ **Design for part-load efficiency.**
Select equipment that remains efficient over a wide range of load conditions. Size systems to accommodate multiple stages of capacity that can be activated in sequence. Buildings operate at part-load status most of the time. Peak system loads occur infrequently and are usually caused by the simultaneous occurrence of multiple factors such as peak occupancy, temperature extremes, and use of occupant equipment. HVAC systems need to respond to various loads in order to achieve the greatest overall efficiency.

❑ **Optimize system efficiency.**
HVAC systems consists of several different types of equipment including fans, pumps, chillers/compressors, and heat-transfer equipment. The performance of the overall HVAC system should be optimized over that of any individual component. For example, the cooling system components should be optimized as a system, including the chiller, pumps, cooling tower, cooling coil, and distribution piping.

❑ **Design for flexibility.**
The HVAC design should provide flexibility to address future changes in the building and its functions and use over time. Planning for change includes factoring in potential new users.

Control Systems

❑ **Design a building-management control system.**
The continued development of microprocessor-based building controls and sensors has led to a revolution in control-system applications. Individual equipment components often contain electronic intelligence and the ability to coordinate their operations with those of other system components.

- Consider the use of direct digital control (DDC) electronic systems for all functions, including central equipment control and zone-level management. This provides greater energy-efficiency capabilities, accuracy, and flexibility. Zone-level control features are important because sensors in each zone directly measure factors such as temperature, airflow, lighting, and whether the area is occupied or unoccupied. These control features are linked to the central systems and can be used to optimize system functions.

❑ **Train building engineers to use the control system for greater comfort and efficiency.**
Proper use of the control system's remote reporting, diagnostic, and troubleshooting capabilities allows the building engineer to monitor and modify system operations for optimal energy efficiency, lighting use and HVAC performance.

❑ **Integrate the operation of all components and install a centralized computer interface throughout the project.**
Coordinate various building management functions (energy, lighting, life safety, security, elevators, etc.) by integrating occupancy sensors, daylighting control, temperature control, and ventilation levels.

❑ **Ensure that HVAC control systems include the following functions:**

- Basic features
  - a. Comfort control (temperature, humidity)
  - b. Scheduled operation (time-of-day, holiday and seasonal variations);
  - c. Sequenced modes of operation;
  - d. Alarms and system reporting; and
  - e. Lighting and daylighting integration.
- Additional capabilities
  - a. Maintenance management;
  - b. Indoor-air-quality reporting;
  - c. Remote monitoring and adjustment; and
  - d. Commissioning flexibility.

Air-Delivery Systems

❑ **Use variable-air-volume systems.**
This approach reduces energy use during part-load conditions and takes advantage of each zone's operational characteristics.

❑ **Avoid reheating for zone temperature control.**
Consider a dedicated-perimeter heating system and the use of room return air for heating to minimize outdoor-air reheat penalty.

❑ **Reduce duct-system pressure losses.**
The amount of fan energy used to distribute air throughout a building is significant. Most ductwork sizing does not generally take into account the distribution system as a whole. However, computer-based programs for sizing ductwork are becoming widespread. These programs facilitate improved analysis that can reduce energy losses. A good design should strategically locate balancing dampers to improve energy efficiency. The use of round or flat oval ductwork will reduce energy losses and minimize acoustical radiated noise.

❑ **Reduce duct leakage and thermal losses by specifying low-leakage sealing methods and good insulation.**

❑ **Consider proper air distribution to deliver conditioned air to the occupied space.**
Optimal selection and location of air diffusers will save energy and improve comfort control. Select diffusers with high induction ratios, low pressure drop, and good partial-flow performance.

❑ **Use low-face velocity coils and filters.**
Reducing velocity across coils and filters will reduce the amount of energy lost through each component. It also will allow more efficient fan selection, and reduce noise attenuation needs.

❑ **Use cold-air systems.**
Consider a design that supplies air at lower temperatures to reduce airflow requirements and fan energy usage. This offers additional benefits of lower indoor air humidity and potentially higher room temperatures.

❑ **Design equipment and ductwork with smooth internal surfaces.**
This will minimize the collection of dust and microbial growth. Be sure to provide adequate access for inspection and cleaning.

Central Equipment

❑ **Evaluate chiller selection.**
Chiller options are routinely evaluated on larger projects but often are overlooked as a component of smaller, packaged equipment. High-performance chiller equipment is available in all sizes. Integrated controls that work with other HVAC components to increase operating flexibility are also available. Open-drive compressors eliminate one source of loss by not rejecting the compressor motor heat into the refrigerant flow. The energy and cost savings associated with of converting or retrofitting outdated chillers that contain environmentally harmful refrigerant should be assessed. The use of evaporative cooling equipment should be considered for greater efficiency.

❑ **Evaluate a multiple-chiller system with units of varying size.**
Most installations with a chiller plant should have multiple chillers of different sizes. An alternative is to provide variable-speed drives for improved chiller operation during part-load conditions. This approach allows the most efficient chiller operation for low loads.

❑ **Consider desiccant dehumidification.**
These systems are effective where latent loads are significant, such as in humid climates or low-humidity spaces. Adsorbent enthalpy wheels (which use exhaust air to dehumidify or to cool supply air) or heat-regenerated enthalpy wheels can significantly reduce electrical power needs for refrigerant-based dehumidification. (See also Chapter 11, "Renewable Energy.")

❑ **Consider absorption cooling.**
This approach typically changes the energy source from electricity to gas and can reduce energy costs; however, it is not likely to reduce energy use inside the building. Although not as efficient as electrically driven chillers, absorption chillers permit the use of a lower cost fuel. A heat source, such as steam, natural gas, or high-temperature waste heat, usually drives the absorption refrigeration process. Direct-fired gas equipment can also be selected to provide hot water for building heating needs in addition to chilled water.

❑ **Consider thermal energy storage.**

The heating and cooling loads of a building vary on a daily and seasonal basis. Thermal energy storage (TES) makes it possible to manage a building's utility usage, or conduct "load management." A TES system generates and stores thermal energy on a daily, weekly, or longer basis. It can shift the use of more expensive peak utility energy to less expensive off-peak time periods. Ice banks and stratified chilled water are the most common examples.

❑ **Evaluate hydronic pumping systems.**

Primary and secondary pumping systems with variable-speed drives are worth consideration because of their effects on part-load energy use. Pressure losses in piping can be reduced by selecting pipe sizes with a lower pressure drop factor. The design should optimize total head loss with a minimum of flow-balancing controls. New systems that use hydronic system additives to reduce system friction losses and associated pumping energy are being developed.

❑ **Evaluate heat exchangers.**

Select heat exchangers with low approach temperatures and reduced pressure drops.

❑ **Consider other heating-system equipment and enhancements.**

It is advisable to use condensing boilers, match output temperatures to the load, use temperature reset strategies, and select equipment with good part-load ability. Specify multiple, staged operations wherever possible.

❑ **Evaluate heat-recovery options.**

Where simultaneous heating and cooling loads occur, evaluate the use of heat-recovery chillers. High ventilation loads benefit from air-to-air heat-recovery systems for both sensible (i.e., direct heating or cooling requirements) and latent loads.

Efficiency-Enhancement Options within HVAC Components

❑ **Consider additional improvements to energy efficiency.**

- High-efficiency motors are suggested for all applications because of their energy savings capabilities, longer life, and reduced maintenance costs. Motors should be of the proper size to avoid the inefficiencies of oversized equipment.
- Variable-speed drives have advanced significantly over recent years. They offer a proven means of substantially reducing the energy used by fans, chillers, and pumps under part-load conditions. Electronic drives are considered the best option; drive controller and motor selection are also important considerations.
- Mechanical drive efficiency can be improved to reduce losses in the power transmitted from a motor to the motor-driven equipment. Consider direct-drive equipment options and review actual loss factors on belt- or gear-driven equipment.
- Direct digital control (DDC) systems offer greater accuracy, flexibility, and operator interface than pneumatic systems. Use sensors that have the greatest accuracy to improve energy efficiency and performance.
- Advanced control strategies using DDC systems include system optimization, dynamic system control, integrated lighting and HVAC control, and variable-air-volume (VAV) box airflow tracking.

❑ **Undertake independent system testing, adjustment, and balancing to improve efficiencies and comfort.**

Building Commissioning

- ❑ **Use the commissioning process (see Chapter 15, "Building Commissioning") to ensure that HVAC operations meet expectations.**
  Energy-saving features often have not met the design predictions in actual operation. The process of building "commissioning"—documenting that a completed building meets the original design intent and the owner's objectives—has evolved to reduce or eliminate this shortfall. Commissioning activities should begin at the inception of design and continue through completion of construction and occupancy. Commissioning should be tailored to each project. The process is governed by a commissioning plan that defines performance-test requirements, responsibilities, schedules, and documentation. The level of detail involved in commissioning depends on the project's complexity.

Balancing Energy and Indoor Air Quality

Energy efficiency and indoor air quality (IAQ) can be closely linked through integrated design strategies for ventilation systems. (See Chapter 13, "Indoor Air Quality," and Chapter 16, "Materials," for more information on reducing pollutant sources.) To balance energy efficiency and indoor air quality needs, consider the following:

- ❑ **Begin the design process with the goal of maximizing IAQ performance and energy efficiency.**
  Project goals and performance guidelines for both areas are needed.
- ❑ **Include dedicated ventilation systems.**
  With dedicated and controlled ventilation air fans and dampers and/or dedicated ventilation distribution, the quantity of air can be regulated, measured, and documented. This provides greater certainty that acceptable air ventilation is maintained. Ventilation air can be separately conditioned for improved energy efficiency.
- ❑ **Consider heat-recovery options.**
  High ventilation loads benefit from air-to-air heat-recovery systems for both sensible and latent loads. Air that is exhausted from the building can be used to precondition air entering the building, thus reducing energy needs (however, care should be taken not to reintroduce exhaust air into the supply airstream). Run-around hydronic loops and heat pipes are two solutions that improve energy efficiency.
- ❑ **Reduce pollutants.**
  Install separate exhaust systems in areas with high indoor air pollution sources such as kitchens, janitorial closets, photocopier areas, and office equipment rooms.
- ❑ **Institute ventilation demand strategies.**
  Regulate quantities of ventilation air based on specific occupancy needs. For example, sensors that detect occupancy, carbon dioxide, and volatile organic compounds (VOCs) can be used to monitor occupant loads and provide greater fresh-air intake. Consider air cleaning with high-efficiency filtration.
- ❑ **Consider diffuser selection.**
  Provide proper air distribution to deliver conditioned air to the occupants' work areas. The selection and location of diffusers can save energy and improve operation of the HVAC system control. Select diffusers with high induction ratios, low pressure drop, and good partial-flow performance. Locate diffusers for proper airflow, not on the basis of a simplistic pattern. Coordinate the layout with furniture and partitions.
- ❑ **Consider underfloor air distribution.**
  Once the solution only for computer rooms, displacement ventilation is gaining acceptance for other building spaces, particularly in milder, low-humidity climates. Underfloor air systems can operate at higher supply-air temperatures with much lower fan energy requirements. IAQ is improved because of greater quantities of ventilation air and uniformity of distribution.

❑ **Perform a pre-occupancy flushout.**
The building controls can be programmed to initiate the flushing of a building with outside air prior to occupancy. This reduces indoor pollutants and pre-cools the space with night-time air. Running the HVAC system with a higher or continuous supply of fresh air is also beneficial during initial occupancy after construction.

❑ **Consider the use of evaporative cooling equipment.**
Primarily in dry climates, greater use of outdoor air can translate into improved effectiveness for direct or indirect evaporative cooling equipment, reducing mechanical refrigeration needs. However, proper maintenance is essential to prevent IAQ problems caused by microbial contamination. (See also Chapter 11, "Renewable Energy.")

Renovation and Retrofit Issues

HVAC system renovations are initiated for a variety of reasons. It is important to consider all of the following issues during this process:

❑ **Consider chlorofluorocarbon (CFC) changeout.**
Retrofits offer an opportunity to replace or convert an existing refrigeration system to one that uses an environmentally benign refrigerant.

❑ **Replace outdated systems or components.**
Existing HVAC systems may be at the end of their expected life.

❑ **Address and correct past problems with ventilation and indoor air quality.**
(See Chapter 13, "Indoor Air Quality," and Chapter 21, "Operations and Maintenance").

❑ **Re-size components to current requirements.**
Existing system components may be oversized, especially after efficiency improvements are made to other systems (e.g., lighting reductions). The retrofit process allows system components to be matched to actual loads with a corresponding efficiency gain.

❑ **Improve occupant comfort.**
An assessment of occupant issues related to temperature control and ventilation levels can lead to renovations that improve comfort levels and productivity.

❑ **Eliminate code deficiencies.**
Upgrade components to comply with changes in building codes or comply voluntarily with current codes.

❑ **Install new building-control system.**
Control-system technology is far more advanced than it was several years ago. Modern systems can be used to manage multiple buildings, alarms, and zones. The purchase and installation costs of such systems may be justified based on energy savings and better indoor air quality.

Lighting

★ SIGNIFICANCE

Artificial lighting constitutes 20 to 30 percent of all energy use in a commercial building and approximately one-fifth of all electrical energy use in the United States.[1] Reductions in energy use can be achieved with natural daylighting, advanced lighting technology, and efficient lighting design.

Artificial light has been generally overused in most buildings. Current building codes mandate a maximum lighting power density of 1.5 to 2.5 watts per square foot. Nevertheless, a lighting power density of 0.65 to 1.2 watts per square foot can be achieved while still providing a fully functional, well-lit space. With additional improvements from control systems that reduce usage during periods of non-occupancy, the use of daylighting, and light-level maintenance and tuning control, energy savings of more than 50 percent are possible. Because reduced lighting generates less heat, HVAC cooling requirements are lowered as well.[2]

Daylighting, a standard design goal for all but the last 50 years, is often overlooked in today's design practice (see Chapter 9, "Daylighting"). Green building design guidelines should encourage the maximum use of natural light, supplemented by artificial systems as needed. Increased daylighting levels are now required by many building energy codes. The design team should be aware of basic options and methods for integrating effective daylighting with the control of artificial lighting performance. This demands close coordination and support among all members of the design team.

Building form, orientation, and envelope design play key roles in effective daylighting integration and should be considered by the design team in the pre-design phase. Computerized modeling and visualization tools can aid in quantitative and qualitative evaluation. Utilization of reflected light is another important factor in efficient and effective lighting. As much as 30 percent of light in most office environments comes from light reflected off walls, ceilings, tables, and other furniture. The use of bright colors and highly reflective surfaces on walls, ceilings, and furniture can play a major role in energy savings.

☞ SUGGESTED PRACTICES AND CHECKLIST

Lighting Design Guidelines

- ❑ **Include the entire design team in the design of building massing, orientation, and envelope to achieve greater daylighting contribution.**
  Understand and take advantage of the specific daylighting characteristics at the building site (see Chapter 9, "Daylighting").
- ❑ **Incorporate the most energy-efficient technology for lamps, fixtures, and control equipment.**
- ❑ **Consider all lighting functions (including the ambient system, task lights, emergency and 24-hour lighting, exterior lights, exit lights, and public-area lighting).**
- ❑ **Use sophisticated design analysis, including computer simulation, for system design.**
  Computer design tools such as the LUMEN MICRO, ADELINE, SUPERLITE, and RADIANCE programs are useful for avoiding the conventional practice of overlighting spaces. (See Chapter 9, "Daylighting" for more information on Design Tools.)
- ❑ **Consider using the guidelines of the Illuminating Engineering Society (IES).**
  Avoid the use of outdated, higher light-level standards. The IES guidelines provide specific target illumination levels for various visual tasks. Criteria should include illumination levels and luminance ratios since uniformity plays an important part in perceived lighting adequacy. Some variation of light is helpful for providing occupant comfort and more accurately reflects actual outside daylight conditions.
- ❑ **Design for specific visual tasks.**
  Typical lighting methodologies often do not tailor the lighting criteria and the resulting system to the visual task. With the visual display terminal (VDT) becoming standard in all building types, lower ambient lighting levels are gaining greater acceptance. Some professionals believe that overlighting VDT office environments causes visual fatigue because of the excessive contrast between the VDT and surrounding environment, resulting in lower productivity and long-term health problems.
- ❑ **Consider task-lighting systems that reduce general overhead light levels.**
  Provide supplemental task illumination only in required areas, with higher light levels only at the focal point of the visual task rather than throughout the entire space.

❑ **Match the quality of light to the visual task lighting requirement.**

The quality is more important than the quantity of light delivered to the visual task. A high-quality lighting solution requires less light to yield the same visual performance. Light quality involves the following factors:

- Luminance ratio limits;
- Veiling reflections (reflection of light source in visual task);
- Reflected glare;
- Shadows;
- Color; and
- Intensity.

For example, indirect lighting systems that reflect light off the ceiling can produce a low level of uniform, low-glare light that is sufficient for VDT lighting needs, with energy-saving results.

❑ **Improve lighting design and energy efficiency by performing several key activities in the early phases of architectural space planning.**

- Coordinate the lighting plan (reflected ceiling plan) with furniture layout. Areas such as walkways or service spaces can "borrow" light from adjacent work areas.
- Coordinate daylighting to be available in spaces such as walkways, lounges, and areas intended for recreation and other public uses where the variation of color, intensity, and direction of light are desirable. In other spaces such as offices and conference rooms where lighting quality is important for performance of visual tasks, daylighting needs to be controlled properly for brightness and direction of light.
- Where possible, group occupants with similar work schedules together. This allows lighting in other areas to be turned off during unoccupied periods.

❑ **Improve room-cavity optics.**

The use of smooth, high-reflectance surfaces can greatly improve the efficiency of natural and artificial lighting. For example, use:

- Light- or neutral-colored surfaces to improve reflected light;
- Fine-fissured ceiling tiles with a smooth, reflective surface;
- Light shelves for introduction and control of natural light; and
- Low office partitions to avoid shadows and dark zones.

Lighting Fixtures and Lamps

❑ **Specify efficient lamps for the intended use.**

Choices in lamps have greatly expanded during the recent revolution in lamp technology to include:

- T8 fluorescent lamps;
- Compact fluorescent lamps;
- Lower-wattage, high-color-rendering HID lamps;
- Compact reflector HID lamps (such as PAR30 and PAR38);
- Halogen lamps with infrared reflectors; and
- Sulfur bulbs.

❑ **Use electronic ballasts.**

One of the biggest improvements in fluorescent lighting efficiency over the past few years has been the introduction of reliable electronic ballasts, which are 10 to 20 percent more efficient than the most efficient magnetic-coil-type ballast. Electronic ballasts energize lamp phosphors at a higher frequency which eliminates flicker and offers better light quality while using less energy. Selecting electronic ballasts with the appropriate capacity of light output (known as the "ballast factor") makes it possible to match light output from fixtures and lamps to the specific design requirement. Dimmable ballasts (stepped and continuously dimming) provide a significant increase in efficiency when used in conjunction with the control opportunities discussed below. The latest ballasts have substantially reduced induced harmonics, one of their previous drawbacks, and high power factors. The use of electronic ballasts with HID lamps has been found to limit the color shift often inherent in HIDs and standard magnetic ballasts.

❑ **Improve optical control.**

Construction and retrofit projects can take advantage of new improvements in optical control by providing more light for the visual task and reducing glare or spilled light while also enhancing energy efficiency. Reflectors within the fixture that direct and control light into the space are now computer-designed and optimized for better efficiency and control. Louver-finish options are also available for visual comfort and integration into a VDT-intensive area. Specifying fluorescent fixtures with heat extraction over the lamp cavity also improves fixture efficiency by allowing the lamp to operate at a cooler temperature and produce more light output.

Lighting Controls

❑ **Provide effective lighting control.**

Among the greatest benefits of energy-efficient lighting are those resulting from effective lighting control. The most basic function is time-of-day control to turn lights on and off. In addition:

- Use occupancy sensors to detect when occupants are present in a space and to turn off lights when the space is unoccupied. Studies have shown that this results in a potential energy savings of more than 60 percent, depending on type of occupancy. Recent project experience indicates that occupancy sensors are less costly to install than programmable-control or dual-level manual switching.[3]
- Incorporate daylighting control strategies. Every building should provide the means to control the electric lighting system in response to natural light from all envelope sources. Dimmable and stepped daylighting controls are two options that take advantage of the latest technology. Continuously dimmed control systems have the highest level of energy savings and user acceptance. They also offer additional energy-saving operational strategies but have greater initial cost than stepped daylighting controls (see Chapter 9, "Daylighting").
- Incorporate lumen-maintenance controls that use photocells to continuously dim ballasts to maintain desired illumination levels and adjust lamp output in response to variable outputs. Lumen output from light fixtures and lamps will be reduced over the course of their operating lives because of factors such as inherent lamp lumen depreciation and dirt accumulation on the fixture. Controlling light fixture energy, and thus light output, overcome these factors to achieve energy savings.
- Incorporate light-level tuning. Develop light-fixture layouts according to the layout of workstations or illumination criteria. This is preferable to the practice of designing fixture layouts for visual appeal, uniformity, and standardization of lamps. Dimmable ballasts allow lighting levels to be dimmed or "tuned" to the desired light levels, reducing energy use accordingly.

Additional Lighting Considerations

❑ **Use efficient exit signs.**

Modern exit signs use only one to six watts, compared to 40 watts for older signs. The energy savings can be sizable given the large quantity of exits and the need for continuous operation of exit signs.

❑ **Consider improved task-lighting products.**

Inefficient incandescent and under-counter strip fluorescent fixtures are outdated when compared to the products now available on the market, such as 15-watt compact fluorescent task lights. Issues such as luminance ratios (critical in VDT environments), veiling reflectance glare, and asymmetrical light distribution are important factors for task lighting. High-performance task lights, compact fluorescent sources, asymmetric reflectors, and electronic ballasts should be specified. These measures can reduce energy use by more than 50 percent. Some task lights are available with occupancy sensors

Renovation and Retrofit Issues

❑ **Convert existing light fixtures.**
Consider all design-related issues such as appropriate light level and quality, architectural and furniture layout, and room cavity optics, as well as replacement and proper disposal of older ballasts containing polychlorinated biphenyls (PCBs). If major renovations are planned (such as new roofs and replacement windows), also consider daylighting improvements.

Electrical Power Systems

★ SIGNIFICANCE

Office technology, including telecommunication devices, personal computers, networks, copiers, printers, and other equipment that has revolutionized the workplace in the last 10 years, together with appliances such as refrigerators and dishwashers, makes up the fastest-growing energy load within a building. The consumption of energy to run these devices can be comparable to that of a building's mechanical or lighting systems. The design and management team should advise building users of the energy impact of efficient office equipment and appliances. The latest equipment offers energy reductions of more than 75 percent.[4]

Local area networks (LANs) and peer-to-peer computing create significant energy loads within a building because they create a demand for 24-hour operation. In addition, it is estimated that office computers consume over 26 billion kilowatt-hours of electricity annually, costing over $2 billion; this may increase five-fold in the next decade. Decentralized information processing also demands increased HVAC support. LAN rooms, telephone closets, and even some general office areas need to maintain 24-hour "computer-room" cooling and humidity requirements year-round, further increasing energy demands and costs.[5]

The indirect environmental costs of energy consumption associated with office equipment include the release of significant amounts of carbon dioxide, sulfur dioxide, and nitrogen oxide into the atmosphere each year. Office automation and telecommunications systems have led to a dramatic increase in the volume of CFCs in the workplace to meet the demands of distributed, packaged air conditioners and halon fire-protection systems.

Office technology contributes to "electromagnetic pollution" in the workplace, an issue that is beginning to generate increased research and public concern. Radio-frequency emissions from electronic devices and their interconnecting cables can cause mutual interference. Radio frequencies associated with microwave and satellite dishes, cellular telephones, and two-way radios may be harmful to building occupants, but additional research is required before a consensus in the scientific community can be achieved.

The electrical-power distribution system should deliver power reliably and efficiently throughout a building. Losses result in wasted heat energy. Measures that reduce loss and match power distribution to the various electrical loads in the building should be considered. Electrical loads may also degrade power quality and introduce wasteful harmonics or change power factors.

☞ SUGGESTED PRACTICES AND CHECKLIST

Design Considerations

❑ **Specify energy-efficient office equipment.**

The U.S. Environmental Protection Agency (EPA) and the electronics industry are working to cut the power consumption of desktop computers by 50 percent by the year 2000 through the Energy Star program. The program encourages the use of special features to put personal computers, printers, and copy machines into a low-energy "sleep" mode when idle. In addition, energy-saving computer chips, originally developed for laptop computer applications, will be used in desktop machines. Look for the Energy Star label when making equipment purchases. The EPA also publishes a list of energy-efficient retrofit kits for older computer equipment.

❑ **Specify energy-efficient appliances.**

Many energy-efficient and environmentally sound appliance alternatives now exist. New refrigerators consume less than one-half the energy of older models. In addition, some are CFC-free. Dishwashers that use less than one-half of the water and energy consumed by older models are also available.

❑ **Consider higher system voltages.**

Less energy is lost in distribution systems with higher system voltages. This factor is often ignored in an effort to minimize initial construction costs. The long-term impact of lower voltages typically is not quantified.

❑ **Improve power factor.**

Power factor is the ratio of active power to apparent power. The electrical load may shift the phased relationship between electric current and voltage, thereby altering the power factor. These shifts are often caused by large motors. Poor power factor results in increased distribution and motor losses that require additional energy. Use motor selection, proper motor sizing, and corrective equipment (such as capacitor banks) appropriately.

❑ **Use K-rated transformers.**

K-rated transformers better accommodate electric power irregularities or harmonics. They can be used when tenant equipment (such as personal computers) introduces harmonics on the power system. These devices accept the harmonics without a reduction in system rating or efficiency.

❑ **Size conductors correctly.**

Selecting conductors of the proper size can reduce voltage drop and power losses and should be considered, particularly for more concentrated loads. Neutral leg current flow, associated with equipment that has switched power supplies, should be addressed in design.

Renovation and Retrofit Issues

❑ **Optimize energy use of current equipment and specify more efficient systems with future equipment procurement.**

❑ **Retrofit computers with shut-off devices.**

Some users believe that turning off equipment can *shorten* its lifetime; however, equipment manufacturers have stated otherwise. Low-cost devices that sense periods of inactivity can automatically turn off computer equipment after a set period of time. These individual computer devices can be set to turn off a computer's central processing unit (CPU) and monitor separately. These devices have been shown to be extremely cost-effective, with payback periods of around one year.

Plumbing Systems

★ SIGNIFICANCE

Water use in buildings has two environmental impacts: (1) the direct use of water, a limited resource; and (2) the expenditure of energy used in water pumping, purification, treatment, and heating. This section considers the energy-use aspects associated with water usage within a building, including pumping and hot-water heating (see also Chapter 11, "Renewable Energy"). Other chapters discuss additional water-use strategies, such as graywater systems and landscape irrigation (for example, see Chapter 6, "Water Issues").

The overall amount of energy used to pump, treat, and heat water can approach 10 percent of a utility company's output. The primary areas where improvement is possible are: (1) more efficient water generation and end-use devices, (2) reduced storage losses in hot-water equipment, (3) reduced piping and pumping losses, and (4) reduction in hot-water temperatures to provide the minimum acceptable temperature for intended use.

☞ SUGGESTED PRACTICES AND CHECKLIST

Hot-Water Heating

❑ **Consider hot-water heating options.**
Analyze and specify efficient equipment options. Heat pumps, heat recovery processes, tankless water heaters, and combination space heating-water heating systems are options that can improve efficiency significantly.

❑ **Reduce hot-water system standby losses.**
Losses from distribution piping and hot-water storage tanks can be more than 30 percent of heating energy input. Tank insulation, anti-convection valves and heat traps, as well as smaller heaters with high recovery rates, can reduce these loss factors.

❑ **Evaluate system configuration.**
Consider the benefits of localized hot-water equipment versus centralized equipment by evaluating the types of loads served. Localized heating equipment options for small isolated loads may include electric heat-tracing devices which use a linear-resistance heating element wrapped around the piping.

❑ **Reduce hot-water service temperatures.**
Confirm the lowest hot-water temperature needed for the usage or equipment. Lowering the hot-water supply temperature reduces initial heating-energy and system losses. This approach should be limited to a minimum water temperature so as not to allow growth of harmful bacteria in piping.

❑ **Install hot-water system controls.**
Appropriate controls optimize energy use. Time-of-day equipment scheduling is a basic function; the use of certain applications may benefit from temperature optimization features.

❑ **Consider solar hot-water heating**
Consider solar systems based on building type, hot-water needs, and solar conditions at project site (see Chapter 11, "Renewable Energy").

Water-Pumping Systems

❑ **Use low-flow plumbing fixtures.**
Low-flow fixtures may seem to be a water conservation method, but they also save energy because they reduce pumping energy and water heating. Products are available for a wide range of applications and have become standard in many areas.

❑ **Use water-booster pumps.**

Use packaged pumping systems with staged pump operation to better serve part-load flow conditions, such as after hours. Systems can include a pressurized tank to further reduce pump cycling and improve efficiency.

❑ **Prepare an efficient plumbing system layout.**

Prepare an efficient design for the layout of pumping and piping distribution, including:

- Simple, short piping runs with minimum offsets and pressure control stations;
- Stacking of water services in multi-story buildings;
- Gravity flow of effluent from buildings without mechanical sump pumps; and
- Calculation of minimum pressure requirements for distribution and booster pumps if necessary.

Utility Company Rebates and Assistance

★ SIGNIFICANCE

Over the past decade, utility companies across the country have developed both technical and financial programs to help their customers understand and implement energy-efficiency measures. These programs have garnered substantial customer awareness and response. With deregulation however, the utility industry is now beginning a radical restructuring of customer-service access that is expected to change the nature of utility involvement in promoting energy efficiency.

The industry now considers energy-efficiency issues for buildings under the broader concept of demand-side management (DSM), which encompasses all methods available to customers to reduce, modify, or control the use of energy. Utilities first became interested in DSM issues because of their desire to control peak utility supply requirements or to shift energy service to time periods most beneficial to their generation or transmission systems. Interest in actually reducing customer energy use came only after public utility commissions (PUCs), which regulate investor-owned utilities, identified the need to initiate more aggressive programs. By giving the utilities an economic return on efficiency investments, the PUCs developed the financial mechanism to reward utilities for promoting efficiency gains. In turn, the utilities have marketed energy efficiency to customers and created programs that offer incentives to install efficient systems.

The future of DSM programs will be driven by the future of utility deregulation, although the direction of change is uncertain. Deregulation effects power generation and distribution as well as energy costs. “Retail wheeling,” an element of deregulation, allows the customer to negotiate with competing utilities to obtain service and select the most economical alternative regardless of geographical location. The loss of customers by a local utility could result in higher rates for remaining customers.

☞ SUGGESTED PRACTICES AND CHECKLIST

❑ **Obtain input from utilities early in the design process.**

The design team should meet with the designated account representative to learn about current and future design and financial incentive programs, including rebates or loans.

❑ **Seek out utility resources and design assistance.**

Some utility companies have recognized that additional assistance in the form of educational or technical offerings can be valuable to both the building owner and design professional. Offerings may include:

- Early project review by a utility-sponsored design group to solicit ideas on daylighting contributions and reduced HVAC requirements and to involve the group in creation of computer-based energy models for the project;

- Energy learning centers with classroom and library facilities; and
- Technical seminars on specific issues provided for general information.

❑ **Institute rebate documentation and verification measures with utility.**
Verification of system performance at construction completion may be needed for more complex efficiency measures or custom rebate applications. Utilities are interested in seeing that design-efficiency objectives are realized in operation and are beginning to offer rebate incentives for building commissioning.

❑ **Assess the impact of deregulation.**
Track current energy use and estimate the potential exposure to energy cost increases. Project any plans for building expansion and related modifications and their anticipated energy usage; consider energy-efficiency options as an alternative to increased supply needs.

➜ RESOURCES

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. *HVAC Applications*. Atlanta: ASHRAE, 1995.

______. *HVAC Systems and Equipment* . Atlanta: ASHRAE, 1992.

______. *Fundamentals*. Atlanta: ASHRAE, 1993.

______. *Refrigeration*. Atlanta: ASHRAE, 1994.

Series of technical handbooks considered the most comprehensive HVAC reference available. These handbooks introduce design issues and provide extensive technical documentation for engineering purposes. ASHRAE is responsible for the development of practice standards for specific issues such as ventilation and energy. ASHRAE also publishes a monthly journal, which includes technical articles on a variety of topics, including energy efficiency.

Bobenhausen, William. *Simplified Design of HVAC Systems*. New York: John Wiley & Sons, Inc., 1994.

Fink, Donald G., and H. Wayne Beaty, eds. *Standard Handbook for Electrical Engineers*. 13th ed. New York: McGraw-Hill, Inc., 1993. A general reference document for electrical system design.

Illuminating Engineering Society of North America. *IES Recommended Practice for Lighting Offices Containing Computer Visual Display Terminals*. RP-24. New York: Illuminating Engineering Society of North America, 1989.

______. *IES Recommended Practice of Daylighting*. RP-5. New York: Illuminating Engineering Society of North America, 1979.

Part of a series of technical handbooks and other references that are essential in the understanding of natural and artificial lighting systems. They are published by the leading professional society for lighting design.

Institute of Electrical and Electronics Engineers. *Electric Power Systems in Commercial Buildings—Grey Book*. IEEE Standard 241-1990. New York: Institute of Electrical and Electronics Engineers, 1991. A general reference in the design of electrical power distribution.

Lovins, Amory B., Brady Bancroft, Michael Shepard, and Robert Bishop. *State of the Art: Water Heating*. Snowmass, Colo.: Rocky Mountain Institute, 1991. An excellent resource for energy-efficient design, including background on efficiency issues and discussion of potential future developments across the spectrum of commercial/institutional energy use issues.

Lovins, Amory B., David Houghton, Robert Bishop, Bristol L. Stickney, James Newcomb, Michael Shepard, and Bradley Davids. *State of the Art: Space Cooling and Air Handling*. Snowmass, Colo.: Rocky Mountain Institute, 1992.

Lovins, Amory B., Joel Neymark, Ted Flanigan, Patrick Kiernan, Brady Bancroft, and Michael Shepard. *State of the Art: Drivepower*. Snowmass, Colo.: Rocky Mountain Institute, 1989.

Lovins, Amory B., and Robert Sardinsky. *State of the Art: Lighting*. Snowmass, Colo.: Rocky Mountain Institute, 1990.

Pilgrim, William L., and Richard E. Stonis. *Designing the Automated Office*. New York: Whitney Library of Design, 1984. Contains a good overview of design issues and related energy-efficiency topics in office design.

Rea, Mark S., ed. *Lighting Handbook: Reference & Application*. New York: Illuminating Engineering Society of North America, 1993.

DESIGN TOOLS

PASSIVE SOLAR DESIGN

BLAST. Calculates building loads, analyzes solar feasibility, predicts life-cycle costs, and helps select the optimal HVAC system for a building. Developed by Civil Engineering Research Laboratories, U.S. Army. Contact: University of Illinois, (800) UI BLAST

ENERGY-10, Low-Rise Building Design (Design manual and software). Windows-environment program for small commercial buildings allowing early design evaluation of 16 energy-saving strategies including daylighting. Developed by National Renewable Energy Laboratory (NREL), Passive Solar Industries Council (PSIC), U.S. Department of Energy (DOE), and Lawrence Berkeley National Laboratory (LBNL). Contact: Blaine Collison at PSIC, (202) 628-7400.

SERI-RES (also known as *SUNCODE)*. Useful for residential and small commercial buildings to analyze passive solar design and thermal performance. Developed by NREL and Ecotope Group. Contact: Ron Judkoff at NREL, (303) 275-3000.

TRNSYS. Modular FORTRAN-based transient simulation code that allows for simulation of any thermal energy system, particularly solar thermal, building, and HVAC systems. Developed by the Solar Energy Laboratory, University of Wisconsin. Contact: TRNSYS Coordinator , (608) 263-1589.

ENERGY-EFFICIENT DESIGN

BLAST. See Passive Solar Design. Contact: University of Illinois, (800) UI BLAST

DOE-2. Calculates energy use and life-cycle costs of design options. Includes building envelope, HVAC systems, and daylighting analysis package. DOE Version 2.1E available for MS-DOS and Windows (386 and 486) and UNIX workstations. Developed by LBNL. Contact: Fred Winkleman, (510) 486-4925.

ENERGY-10, *Low-Rise Building Design*. See Passive Solar Design. Contact: Blaine Collison at PSIC, (202) 628-7400.

TRNSYS. See Passive Solar Design. Contact: TRNSYS Coordinator , (608) 263-1589.

DAYLIGHTING DESIGN

ADELINE. Advanced integrated lighting design and analysis package, incorporating DXF input capability, SCRIBE MODELLER, PLINK, SUPERLIGHT, SUPERLINK, and RADIANCE, for detailed and advanced analysis of complex buildings. Available for MS-DOS 486 platforms. Developed by LBNL. Contact: Steve Selkowitz, (510) 486-5064.

RADIANCE. Lighting and daylighting modeling tool for performing accurate photorealistic lighting simulation. Available for UNIX workstations. Developed by LBNL. Contact: Charles Erlich, (510) 486-7916.

SUPERLITE 2.0. Daylighting analysis tool. Available for MS-DOS 386 and 486. Developed by LBNL. Contact: Rob Hitchcock, (510) 486-4154.

NOTES

1 Armory B. Lovins and Robert Sardinsky, *State of the Art: Lighting* (Snowmass, Colo.: Rocky Mountain Institute, 1990).

2 Paul Beck, "Pushing the Energy Envelope," *Consulting-Specifying Engineer* 18, no. 6 (1995).

3 Electric Power Research Institute (EPRI), "High-Efficiency Electric Technology Fact Sheet" (Palo Alto: EPRI, 1994).

4 Mark Ledbetter and Loretta A. Smith, "Guide to Energy-Efficient Office Equipment" (Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE), 1993).

5 Ledbetter and Smith, "Guide to Energy-Efficient Office Equipment."

CHAPTER 13

Indoor Air Quality

Author
Anthony Bernheim

★ SIGNIFICANCE

With potentially hundreds of different contaminants present in indoor air, identifying indoor air quality (IAQ) problems and developing solutions is extremely difficult.[1] The study of indoor air quality is a relatively recent endeavor. Although much is known about the health effects of poor design and ways to overcome them through good design, a tremendous amount of research is needed in this complicated field. Over the past few years, several entities have undertaken considerable efforts to further the research and science in this area, including government agencies such as the U.S. Environmental Protection Agency (EPA), National Institute of Standards and Technology (NIST), National Institute of Occupational Safety and Health (NIOSH), and Occupational Safety and Health Administration (OSHA), and professional societies such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and American Society for Testing and Materials (ASTM). The results of such activities will lead to more definitive IAQ practices, standards, and performance targets.

In the absence of such information and industry consensus, this chapter attempts to provide guidance on general industry practices for improved IAQ. These suggested practices should be updated and refined by the professional as more information becomes readily available.

The quality of indoor air results from the interaction of many complex factors *(Figure 1)*, each contributing different effects.[2] The ways in which these factors contribute to IAQ may be summarized as follows:

- **Construction materials, furnishings, and equipment.**
  These items may emit odor, particles, and volatile organic compounds (VOCs), and adsorb and desorb VOCs. Individual VOCs from a specific material may combine with VOCs from other materials to form new chemicals. VOCs and particulates can cause health problems for occupants upon inhalation or exposure. In the presence of adequate heat and moisture, some materials provide nutrients that support the growth of molds and bacteria, which produce microbial volatile organic compounds (MVOCs).[3]

These organisms can affect occupants adversely if fungal spores containing mycotoxins and allergens or the MVOCs are inhaled. A great deal of research remains to be done to identify individual metabolic gases, their odors, the microbes that produce them, and the human response to molds and fungi.

- **Building envelope.**
  The envelope controls the infiltration of outside air and moisture, and may include operable or inoperable windows.
- **Ventilation systems.**
  Acoustical materials in heating, ventilating, and air-conditioning (HVAC) systems may contribute to indoor air pollution in the same way as construction materials, mentioned above. Ventilation systems also control the distribution, quantity, temperature, and humidity of air.
- **Maintenance.**
  Lack of maintenance allows dirt, dust, mold, odors, and particles to increase. The use of high-VOC cleaning agents pollutes air.
- **Occupants.**
  The number of occupants and the amount of equipment contribute to indoor air pollution. People and pets are major sources of microorganisms and airborne allergens in indoor environments.[4] Occupant activities also can pollute the air.

MAJOR FACTORS CONTRIBUTING TO INDOOR AIR QUALITY

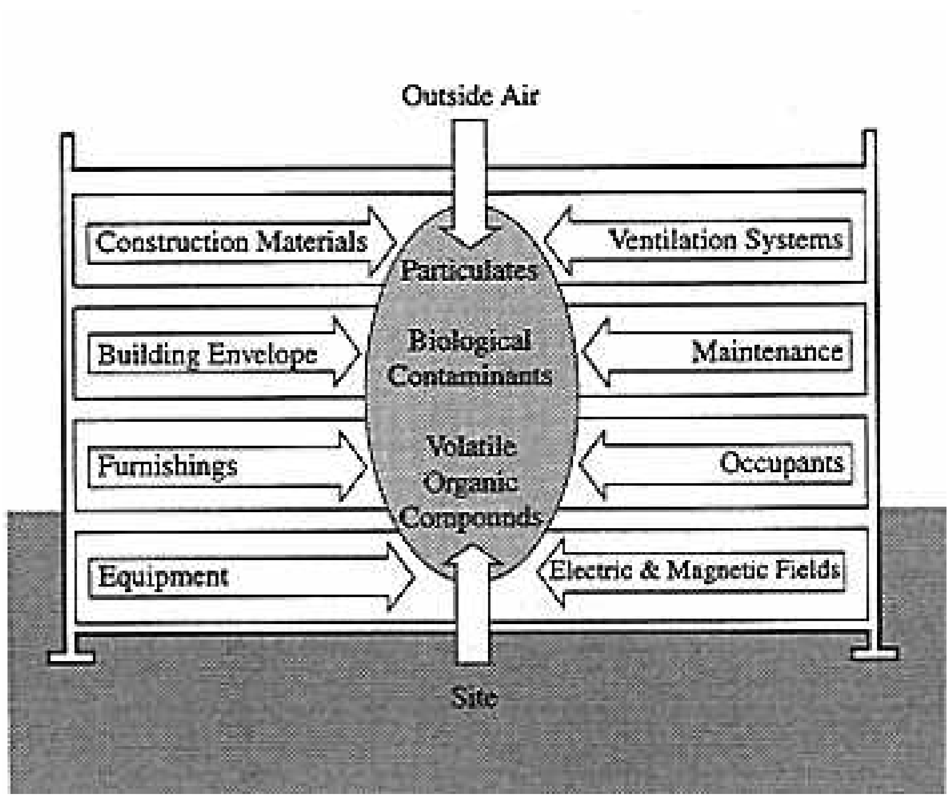


Figure 1

- **Electric and magnetic fields (EMF).**
  The possible health effects of electric and magnetic fields generated by power lines and electric appliances are not well understood at this time. There is considerable debate regarding possible health effects of these sources.[5] More research is required.

Poor indoor air quality can cause human illness, which in turn may result in increased liability and expense for building owners, operators, design professionals, and insurance companies. It can also lead to lost productivity of building occupants, resulting in economic losses to employers.[6] In the long term, these costs may exceed the additional initial cost, if any, of environmentally sound design in both new construction and renovation. Health problems that can result from poor indoor air quality may be short-term to long-term, and range from minor irritations to life-threatening illnesses. They are classified as follows:

- **Sick-Building Syndrome (SBS)**
  SBS describes a collection of symptoms experienced by building occupants that are generally short-term and may disappear after the individuals leave the building. The most common symptoms are sore throat, fatigue, lethargy, dizziness, lack of concentration, respiratory irritation, headaches, eye irritation, sinus congestion, dryness of the skin (face or hands), and other cold, influenza, and allergy type symptoms.[7]
- **Building-Related Illnesses (BRI).**
  BRIs are more serious than SBS conditions and are clinically verifiable diseases that can be attributed to a specific source or pollutant within a building. Examples include cancer and Legionnaires' disease.[8]
- **Multiple Chemical Sensitivities (MCS).**
  More research is needed to fully understand these complex illnesses. The initial symptoms of MCS are generally acquired during an identifiable exposure to specific VOCs. While these symptoms may be observed to affect more than one body organ system, they can recur and disappear in response to exposure to the stimuli (VOCs). Exposure to low levels of chemicals of diverse structural classes can produce symptoms. However, no standard test of the organ system function explaining the symptoms is currently available.[9]

☞ SUGGESTED PRACTICES AND CHECKLIST

General Approaches to IAQ

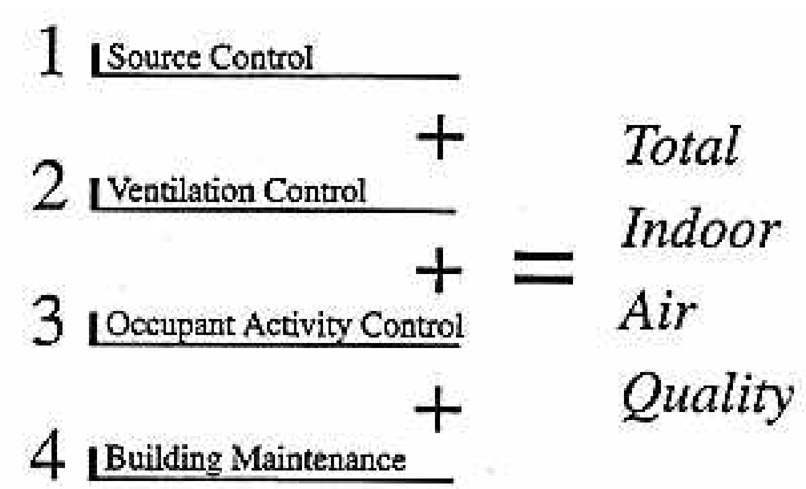
- ❑ **Employ an integrated approach.**
  Even though current building codes are relatively silent on IAQ issues, a number of principles and practices have been developed to promote good IAQ designs that require a coordinated approach to building design. To achieve this goal, employ an organized and integrated approach that involves the building's owner, operator, design professionals, contractor, and tenants.
- ❑ **Practice "prudent avoidance."**
  In cases where research is not definitive, which involves most cases at this time, a recommended alternative is to practice "prudent avoidance" of specific materials and systems that have been proven to contribute to IAQ problems. A "prudent avoidance" strategy means limiting the building occupants' exposure to these materials and systems when this can be accomplished at a reasonable cost and with reasonable effort.
- ❑ **Evaluate the costs and benefits of all strategies.**
  This analysis should include an understanding of initial and life-cycle costs weighed against the potential IAQ benefits such as reduced health risk, increased productivity gains, the associated economic benefits, and the long-term benefits to society, which at this time are somewhat difficult to determine and quantify.

Design Principles

Design for improved indoor air quality involves four interrelated principles *(Figure 2)* that should be implemented as a whole: source control, ventilation control, occupant activity control, and building maintenance.

Figure 2

FOUR PRINCIPLES OF INDOOR AIR QUALITY DESIGN



Source Control

There are many sources of potentially harmful air contaminants in buildings *(Figure 3)*. Contaminants may originate indoors, outdoors, from occupants, and from within the mechanical system of the building. VOCs and MVOCs may be emitted into the air from building materials, products, equipment, and furniture.[10] Pollutant sources can be controlled, reduced, or eliminated to produce a healthier indoor environment. Strategies for source control are listed below.

- ❑ **Set source-control priorities that are feasible within the project budget, project schedule, and available technology.**
  Priority materials for source control are materials that will be prevalent in the building and are the most highly volatile (that is, they emit odors, releasing irritating and potentially toxic chemicals to the air, or may be susceptible to microbial growth). Identify and evaluate the priority materials, equipment, and furniture for use on the project.
- ❑ **Establish the building owner's and occupants' criteria and guidelines for improved IAQ.**
- ❑ **Request Material Safety Data Sheets (MSDSs) for priority materials from product manufacturers.**
  OSHA regulations stipulate that product manufacturers must provide MSDSs with information on chemical identification, hazardous ingredients, physical/chemical characteristics, fire/explosion hazard data, reactivity data, health hazard data, spill and leak procedures, special protection information, and special precautions. However, MSDSs provide limited IAQ information, in part because the regulations do not require the identification of proprietary information or chemicals. Therefore, MSDSs should not be relied upon as the sole source of IAQ information, although they may provide the first level of information on potential IAQ concerns for some materials. In many cases, they may be the only source of information because "acceptable" third-party emissions testing information is not readily available.

SOURCES OF POTENTIALLY HARMFUL CONTAMINANTS AND DISCOMFORT IN BUILDINGS

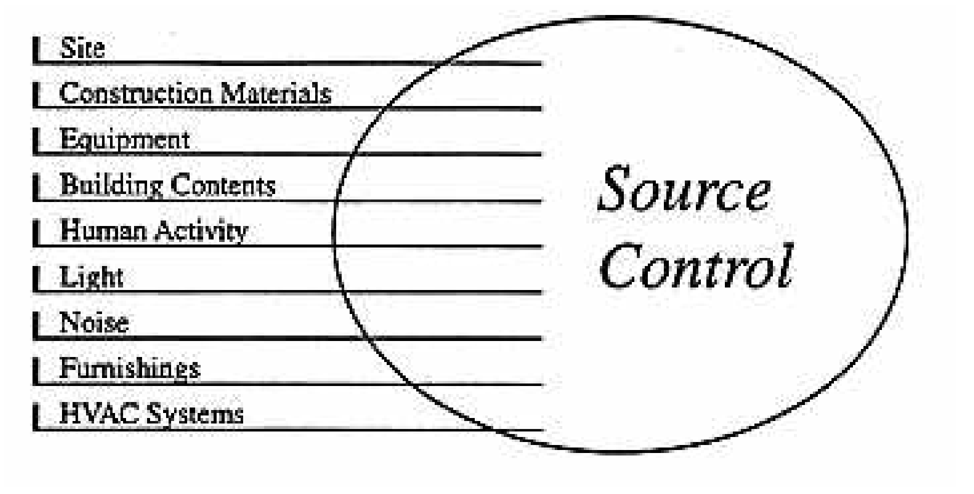


Figure 3

When chemicals or hazardous materials are identified in MSDSs, refer to the *Hazardous Chemicals Desk Reference* and existing regulations and guidance for information about their health effects and toxicity.[11] (For additional information regarding the interpretation of MSDSs, see Chapter 16, "Materials.")

❑ **Perform the following steps to evaluate the materials, products, and furniture in terms of their VOC contribution to indoor air:**

– Establish acceptable limits for total volatile organic compounds (TVOCs) and individual VOCs for the project. These limits should be based on regulatory requirements, guidelines, known health effects, and the professional advice of an IAQ specialist.

At the time of publication of this manual, there are no laws or codes setting acceptable levels of overall TVOC concentrations for general indoor environments or TVOC and VOC emissions from materials, products, and furniture. Some of the uncertainty associated with emissions from materials is caused by lack of standardized testing procedures and inconsistency of data reported in the literature. ASTM has developed a general guidance standard for emission testing, however it is not specific for materials. Further research and development is needed to advance the state of the art to the point where reliable emissions data based on consensus standards are available.

– Request emissions test data from the manufacturer for each priority material, product, and furniture item. The data should be based on predetermined and agreed upon chamber test methods, from the manufacturer. Reports from chamber tests should include the following information:

a. Clear definition of the materials and their origin, age, and history.
b. Clear specification of the test methods, conditions, and parameters.
c. Emission rates for TVOCs and individual VOCs as a function of time.
d. Identification of hazardous VOCs and chemicals that are listed in any of the following internationally recognized regulatory and guidance chemical lists:
   1. California Environmental Protection Agency, Air Resources Board (ARB), list of Toxic Air Contaminants (California Air Toxics);[12]
   2. California Health and Welfare Agency, Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65), which lists chemicals known to cause cancer and reproductive toxicity;[13]