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Built Environment Image Guide Sustainable Design Principles

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Table of Contents

Executive Summary
The publication is written to raise the awareness level of sustainable design. This publication presents information on passive energy systems (primarily solar), how they work, and why they matter. Information on energy-efficient appliances and mechanical systems, water conservation, water treatment, recycling, and alternative building methods is also provided.

It covers approaches that help ensure a successful sustainable building project. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System provides a checklist for sustainable building project design and for tracking progress and success. A three-tiered design approach outlines a way to break down a project into clear components so one can see how components fit together and build off one another. A whole-site/whole-building team employing a three-tiered approach is another key to success. The publication also discusses the importance of commissioning.

INTRODUCTION

In 1987, the World Commission on Environment and Development defined **sustainable development** [bolded terms are defined in the glossary] as the ability to meet "today's energy needs without compromising the ability of future generations to meet theirs" (Miller 1997). See figures 1 and 2.

DOE/NREL

Figure 1—Wind farm in Palm Springs, CA.

DOE/NREL

Figure 2—Sacramento Municipal Utility District's 2-megawatt photovoltaic array in foreground.

Currently, residential and commercial buildings in the United States consume tremendous amounts of energy and produce large amounts of pollution. Seventy-six million residential buildings and approximately 5 million commercial buildings use one-third of all the energy consumed in the country and two-thirds of the electricity produced. Many of our natural resources are used to produce this energy. Heating, cooling, lighting, and producing materials for these uses account for "49 percent of the sulphur dioxide emissions, 25 percent of the nitrous oxide emissions, and 10 percent of particulate emissions [in this country]" (Giordano 2002). Thirty-eight million more buildings are expected to be constructed by 2010 leading to greater use and loss of natural resources.

Sustainable development is economically feasible and resource friendly. It can have a dramatic effect on the preservation of natural resources and on our indoor and outdoor health.

Sustainable buildings are sometimes referred to as "green" because they impact fewer resources during construction and during operation and maintenance. See figure 3. Reuse of building materials is encouraged as is use of locally grown and manufactured materials.

Figure 3—Lied Conference Center at Arbor Day Farm Foundation. The Lied Conference Center in Nebraska was designed by Alley Poyner Architects in 1993 as an "environmentally friendly building." The center has 14,000 square feet of meeting space and 144 guest rooms. The facility emphasizes energy efficiency, natural ventilation, water conservation, and the use of recycled material. Guest rooms include recycling bins. The Arbor Day Farm site also demonstrates land conservation practices and includes a fuelwood energy plant. The Lied Center is heated and cooled by burning waste wood from a saw mill operation and fuelwood trees grown on site.

Arbor Day Farm Foundation

APPROACHES TO SUSTAINABLE DESIGN PROJECTS

This publication was written to raise the awareness level about sustainable design. It covers approaches that help ensure a successful sustainable building project. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System provides a checklist for sustainable building project design and for tracking progress and success. A three-tiered design approach outlines a way to break down a project into clear components so one can see how components fit together and build off one another. A whole-site/whole-building team employing a three-tried approach is another key to success. The publication discusses the importance of **commissioning**. It also presents information on passive energy systems (primarily solar), how they work, and why they matter. Information on energy-efficient appliances and mechanical systems, water conservation, water treatment, recycling, and alternative building methods is also provided.

The LEED Green Building Rating System

One approach to achieving sustainable development is through use of the LEED Green Building Rating System. LEED provides a checklist for designing sustainable projects and for tracking progress and success as the project proceeds. The philosophy is that energy efficiency and reduced resource use can and should be incorporated into all facilities—new, remodeled, and leased.

LEED was developed by the U.S. Green Building Council for the U.S. Department of Energy as an effort "to develop a standard that improves environmental and economic performance of commercial buildings using established and/or advanced industry principles, practices, materials, and standards" (LEED 2001).

The LEED system currently encompasses four major areas.

- New construction and major renovation projects (LEED-NC).
- Existing building operations ((LEED-EB).
- Commercial interiors projects (LEED-CI).
- Core and shell development projects (LEED-CS).

Performance standards are being developed for core and shell projects, homes, and neighborhood developments.

Each LEED performance standard has six categories with several items within each category. The categories are:

- Sustainable sites.
- Water efficiency.
- Energy and atmosphere.
- Material and resources.
- Indoor environmental quality.
- Innovation and design process.

Points are given according to how well each item is met. See table 1.

Table 1—LEED-NC Version 2.2 Registered Project Checklist

LEED-NC

LEED-NC Version 2.2 Registered Project Checklist

<< enter project name >>
<< enter city, state, other details >>

Yes	?	No			
			Sustainable Sites		**14** Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density & Community Connectivity**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity	1
			Credit 5.1	**Site Development,** Protect of Restore Habitat	1
			Credit 5.2	**Site Development,** Maximize Open Space	1
			Credit 6.1	**Stormwater Design,** Quantity Control	1
			Credit 6.2	**Stormwater Design,** Quality Control	1
			Credit 7.1	**Heat Island Effect,** Non-Roof	1
			Credit 7.2	**Heat Island Effect,** Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
			Water Efficiency		**5** Points
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No			
			Energy & Atmosphere		**17** Points
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**Fundamental Refrigerant Management**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
			Credit 2	**On-Site Renewable Energy**	1 to 3
			Credit 3	**Enhanced Commissioning**	1
			Credit 4	**Enhanced Refrigerant Management**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

continued…

Yes	?	No			
			Materials & Resources		**13** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
			Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1
			Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
			Credit 3.1	**Materials Reuse**, 5%	1
			Credit 3.2	**Materials Reuse**,10%	1
			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1
			Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1
			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regic	1
			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regic	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No			
			Indoor Environmental Quality		**15** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Outdoor Air Delivery Monitoring**	1
			Credit 2	**Increased Ventilation**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Lighting	1
			Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
			Credit 7.1	**Thermal Comfort**, Design	1
			Credit 7.2	**Thermal Comfort**, Verification	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Yes	?	No			
			Innovation & Design Process		**5** Points
			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED® Accredited Professional**	1

Yes	?	No			
			Project Totals	**(pre-certification estimates)**	**69** Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

Credit U.S. Green Building Council

Specific requirements range from site selection, optimum use of daylight and views, water-use reduction, construction waste management, use of local/regional materials, optimum energy performance, use of renewable energy, and increasing ventilation effectiveness, to indoor use of low emitting materials.

In November 2005, the Forest Service, U.S. Department of Agriculture, a U.S. Green Building Council corporate member, adopted the requirement that new buildings over 2,500 square feet meet the LEED Silver certification level.[1] For more information visit their Web site.[2]

WHOLE-SITE/WHOLE-BUILDING APPROACH

Frank Lloyd Wright said, "The solution of every problem is contained within itself. Its plan, form, and character are determined by the nature of the site, the nature of the materials used, the nature of the system using them, the nature of the life concerned, and the purpose of the building itself."

The Team

The **whole-site/whole-building** approach requires a team for a successful outcome because nothing is designed in isolation; the architecture and the heat, ventilation, and air conditioning (HVAC) system designs are integrated. The team should include architects, building occupants, contractors, engineers, landscape architects, and property owners, and any other stakeholders or potential visitors can be included.

Figure 4—A design team onsite.

The Role of the Team: Site Design

A team approach is necessary to thoroughly assess and make informed decisions about site selection, building and facility siting, passive energy systems, and so forth. See figure 4.

Figure 5—The airport design in Rapid City, South Dakota, was strongly influenced by Frank Lloyd Wright's "Prairie Style."

Site selection is critical because the facility or building needs to be designed to fit harmoniously on the site. The team needs to gain an understanding of a site's plants, animals, soils, water, microclimates, other site characteristics, and its history. The team needs to explore how the site and potential development might influence ecosystems beyond its boundaries and how adjacent land uses influence the site. See figure 5.

A site is chosen for its ecosystem's ability to survive and function during construction and use. Once the site is chosen, take a "do no harm" approach to the ecosystem by using a light touch, disturbing only where necessary and appropriate. Limit environmental disruptions by defining onsite construction limits, which include the building footprint, room to move around the building's perimeter (25 feet around the building, for example), and equipment access to the site.

The Role of the Team: The Design Process

After the site is chosen, conceptual design of the building can begin. A team approach is necessary to achieve the desired highly integrated design. In Burke Miller's 1997 book, *Buildings for a Sustainable America: Case Studies*, he writes that each project had "a team of designers including architects, engineers, and key contractors [that] participated in the design process from concept to construction. The design team designed clear and specific goals relating to [site and] building use and resource efficiency. Each team took a whole-building approach to design. Instead of conceptualizing the project as simply a collection of architectural and mechanical features and parts, the design team approached the building as a dynamic whole system of interacting people, spaces, materials, and energy. This conceptual shift of seeing all aspects of the building design as interrelated meant that the team members designed all the elements of the building in relation to each other rather than in isolation. This allowed them to achieve multiple and interrelated goals, including energy efficiency, through strategies and technologies that work synergistically with each other" (Miller 1997). See figure 6.

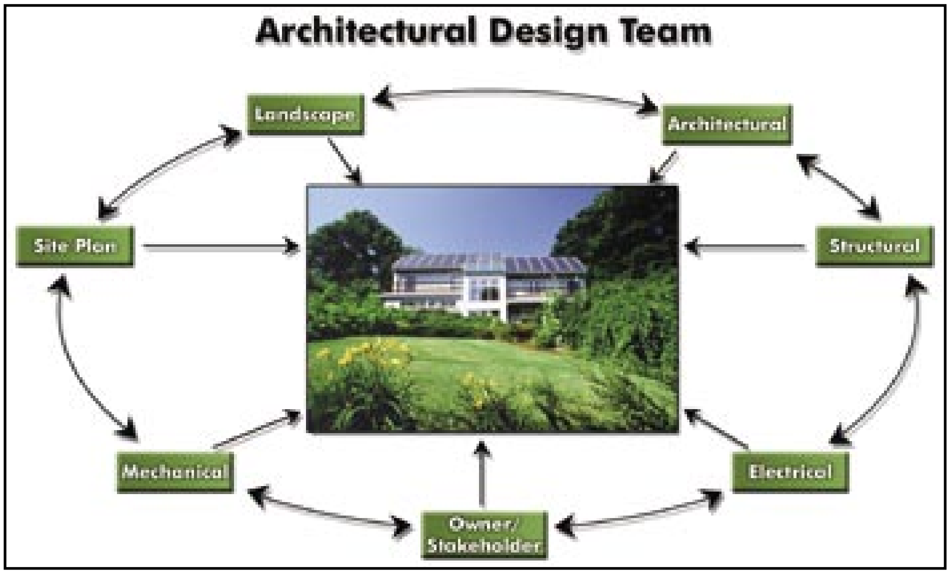


Figure 6—The Whole-Building Approach: The Design Team.

Three-Tiered Design Approach

In addition to a team approach, a three-tiered approach is used. This approach pays special attention to the design of heating, cooling, and lighting systems to produce comfortable, energy-efficient, economical, and sustainable buildings. Norbert Lechner, in *Heating, Cooling, Lighting: Design Methods for Architects*, championed this approach, which offers an organized method for energy efficient building design. See figure 7.

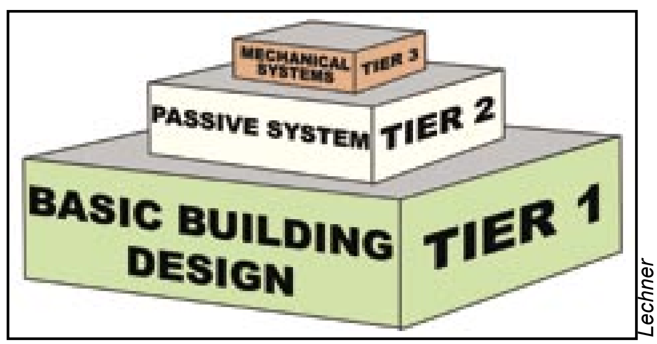


Figure 7—The three-tiered design approach (Lechner 2001).

"The first tier is the architectural design of the building itself to minimize heat loss in the winter, to minimize **heat gain** in the summer, and to use light efficiently. Poor decisions at this point can easily double or triple the size of the mechanical equipment and energy eventually needed. The second tier involves the use of natural energies through such methods as passive heating, cooling, and **daylighting** systems. The proper decisions at this point can greatly reduce the unresolved problems from the first tier. Tiers one and two are both accomplished through architectural design of the building. Tier three consists of mechanical equipment using mostly non-renewable energy sources to handle the [energy] loads that remain after tiers one and two have reduced the loads as much as possible" (Lechner 2001).

Each tier is built on the available information from the previous one. For example, in the site design and community planning chapter, Lechner (2001) explains that the first tier is site and landscape design. Topics include site selection as it pertains to topography and microclimates, solar access, shadow patterns, site planning, solar zoning, wind and site design, plants and vegetation, and landscaping. Once the site limitations and building orientation are known schematic drawings are made.

The second tier makes use of passive systems. One passive system, for example, is daylighting, which reduces the need for electric lights. Daylighting design for the facility is based on studies done in the first tier, which determined how much light was available. This greatly influences the design of the building, as well as the cost to operate the building over its expected lifetime.

Once the role of passive systems in tier two has been determined, the team moves on to the third tier—mechanical systems. The need for and sizes of mechanical systems fill in for what was not covered by tiers one and two. See table 2.

Table 2—The three-tiered approach to the design of heating, cooling, and lighting systems (Lechner 2001).

	Heating	Cooling	Lighting
Tier 1	**Conservation**	**Heat Avoidance**	**Daylight**
Basic Building Design	• Surface-to-volume ratio	• Shading • Exterior colors	• Windows • Glazing type
Tier 2	**Passive Solar**	**Passive Cooling**	**Daylighting**
Natural Energies and Passive	• Direct gain • Trombe wall	• Evaporative cooling	• Skylights • Clerestories
Tier 3	**Heating**	**Cooling**	**Electric Light**
Mechanical and Electrical	• Furnace • Ducts	• Refrigeration machine	• Lamps • Fixtures

Lechner

Commissioning Plan

A commissioning plan includes the design and construction phases, and maintenance of the facility. Commissioning is "a plan that verifies and ensures that building elements and systems are designated, installed, and calibrated to operate as intended" (Miller 1997). It is an essential part of any project. This process begins at the inception of a project and continues after the building is built.

PASSIVE ENERGY SYSTEMS

Passive Solar: A Renewable Energy System

Passive solar energy is a renewable energy source available in all climate zones. Bruce Miller's 1997 book, *Buildings for a Sustainable America: Case Studies*, features many passive solar designs for houses and commercial buildings. His case studies show that the size of mechanical systems needed to heat, ventilate, and air condition a specific building are greatly reduced by taking advantage of passive solar energy designs. Energy-efficient appliances and HVAC units also reduce energy usage. In the case studies, total energy reduction varied from 40 to 82 percent and electrical load reduction varied from 52 to 77 percent. These figures indicate a significant monetary and resource savings. See figure 8.

DOE/NREL

Figure 8—This 2,320 square foot Pittsboro, North Carolina, house is designed to capture and manage the sun's radiation and natural breezes for heating and cooling, resulting in a building 66 percent more efficient than conventional houses in the area. The overhangs shade the windows from unwanted summer solar gains.

Basic Passive Solar Design Principles

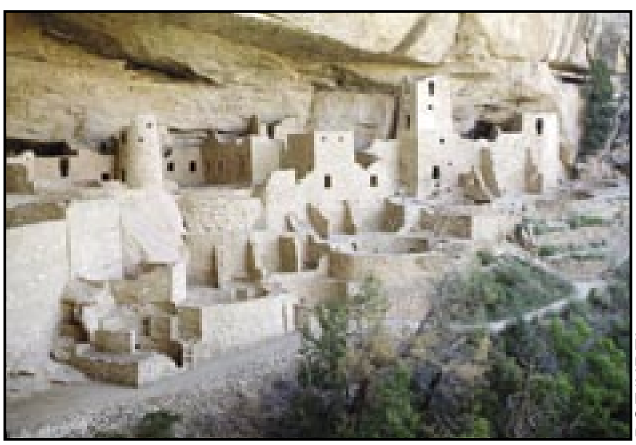
Passive energy systems rely on architectural design and materials to supply energy to either cool or heat a building. Conserving resources and understanding the relationships between design and energy use have created the need for architecture that reflects sustainability principles. Principles include building orientation, daylighting, **thermal mass storage**, thermal efficiency, and insulation and air infiltration. See figure 9.

DOE/NREL

Figure 9—Concrete passive solar house in Colorado.

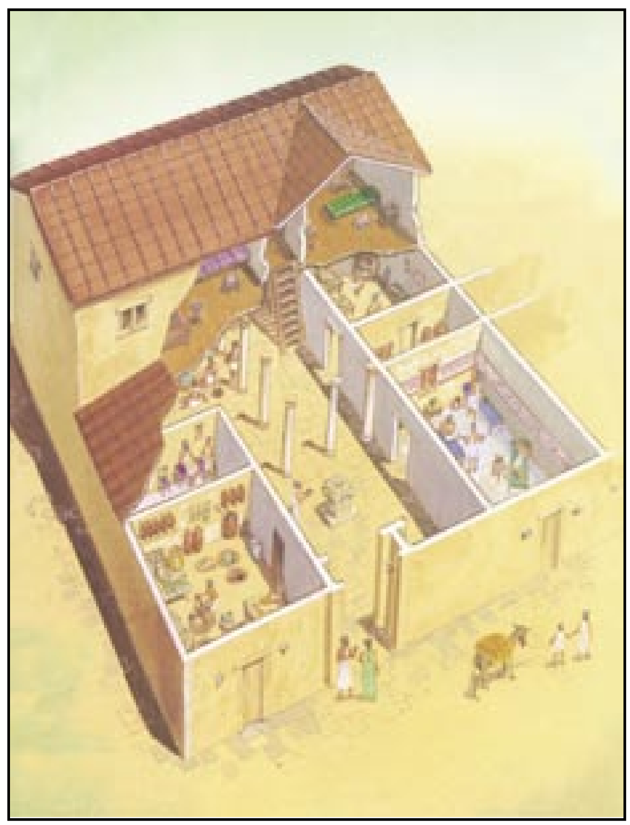
Building Orientation

Ancient civilizations in Egypt, Greece, Rome, and the Americas understood the power of the sun and how to take advantage of it by orienting their buildings to use the sun's energy. See figures 10 and 11.



DOE/NREL

Figure 10—Anasazi dwellings with passive solar design. The overhanging rock ledges block the summer sun, but allow the warming winter rays.



Heinemann Interactive Library

Figure 11—This ancient Greek house, circa fifth century B.C.E., uses a passive solar design. The front faced south, the front door led into an open air porch or portico. All the rooms in the house opened to the portico so that they could use the heat that collected there during the day.

According to Miller (1997), a building should be "longer than wide with the long sides facing within 15 degrees of due south and north." See figure 12.

Figure 12—Long axis of the U.S. Fish and Wildlife Service's National Conservation Training Center in West Virginia is oriented to capture daylight and solar gain.

DOE/NREL

Daylighting and Heat Gain

Design features for daylighting include roof orientation, light shelves, open floor plan, roof monitor or vertical skylight (glass perpendicular to roof), a "litetrium" (the hollow center of a building with a giant skylight over the center), and advanced glazings. Daylighting also allows for some passive solar heating. Well-designed daylighting delivers more useful light with less heat gain than even the most efficient fluorescent lights, resulting in reduced electrical requirements for cooling. See figures 13 and 14.

DOE/NREL

Figure 13—Daylighting is used extensively in this classroom/auditorium at Oberlin College's Adam Joseph Lewis Center for Environmental Studies, Ohio.

DOE/NREL

Figure 14—Big Horn Home Improvement Center uses daylighting to substantially reduce electric lighting and cooling loads.

"Windows…admit **solar gain** and assist with natural cooling. Solar gain (heat from the sun) through windows comes in two forms, direct and indirect.

"**Direct gain** is radiant heat resulting from sunlight admitted directly to the interior through south-facing windows, which warms the interior surfaces (walls, furniture, floors, etc.)…

"For direct gain, the south-facing windows are sized for the climate, type of window used, and the amount of **thermal mass** [inside the building]. The simplest application of direct gain is called "sun-tempering." In a sun-tempered home, the south-facing window area is equal to no more than 7-10 percent of the floor area" (Miller 1997).

Sun-tempering can be a no-cost method for passive heating because no extra windows are added to the building, only moved to the south side.[3] The window area is increased on the south side and decreased on other sides, particularly the north and west sides of a building.

DOE/NREL

Figure 15—This sunspace acts as thermal mass. The low wall on the right and the hard floor surface absorb solar radiation (solar gain, heat) during the day and release heat into the structure at night as the indoor air temperature cools. The air temperature in the area is fairly even day and night. This effect is to substantially reduce heating bills.

Indirect gain is the heat held in a sunspace or **Trombe wall**. See figure 15. A sunspace is essentially a sunroom or solarium. As the air in the space heats, it moves to other rooms and can also be circulated using fans. A Trombe wall is a glass-fronted, south-facing concrete wall that sunlight heats during the day. The wall radiates heat inside the building as the indoor air temperature cools at night. See figure 16.

DOE/NREL

Figure 16—A Trombe wall.

More information about passive solar heating is available at the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) official Web site.[4]

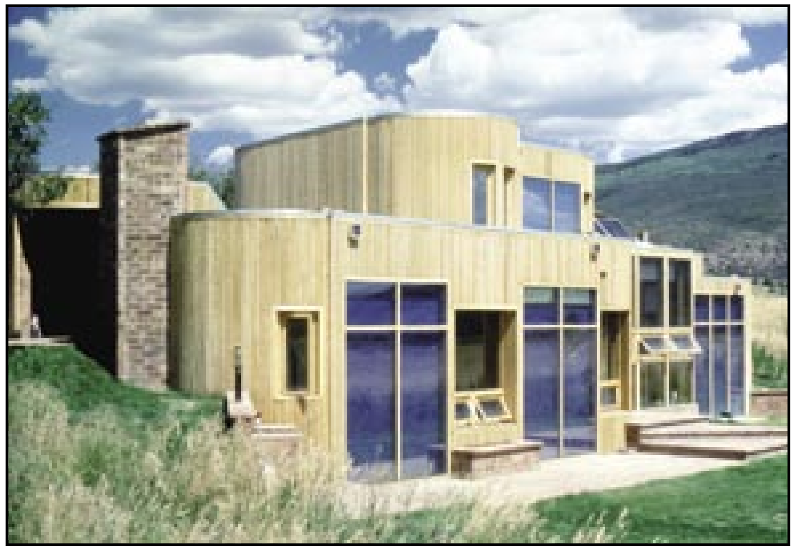
DOE/NREL

Figure 17—Applegate, California, house with passive solar design.

Solar Contribution

Solar contribution is "the percent of the total heating load that is met through a combination of direct gain, **indirect gain**, and thermal mass storage. The solar contribution does not indicate over-all performance, but simply describes the sun's contribution to the total package—the integrated combination of thermal efficiency, passive heating, and thermal storage" (Miller 1997). See figures 17 and 18.

Figure 18—This house, located at 7,500 feet in the Rocky Mountains near Aspen, Colorado, obtains 90 percent of its required heat during the winter from the sun. Solar features include a Trombe wall, direct gain, and a sunspace.



DOE/NREL

Thermal Mass Storage for Heating and Cooling

Thermal mass storage operates on a principle similar to the Trombe wall. "Concrete, brick, tile and other masonry materials are the most commonly added thermal mass. These materials absorb and release heat slowly and can be easily and inexpensively integrated into a house design. They are most effective when dark-colored and located in direct sunlight. Adding thermal mass allows the designer to add a proportionate amount of south-facing glass. The solar gain afforded by the extra glass is absorbed by the mass during the day, keeping the house from overheating. The stored heat is then released at night as the indoor temperatures drop below the temperature of the mass itself. The combination of glass and thermal mass increases the performance and energy-saving characteristics of the building. While this often entails a modest cost increase, it may also allow designers to eliminate or reduce the size of the HVAC system" (Miller 1997). See figure 19.

Figure 19—The 10,550-square-foot design for the St. Benedict Child Care Center in Louisville, Kentucky, takes advantage of the sun's heat and light with its atrium and its large, south-facing and clerestory windows. The air core flooring system captures and stores energy from solar and internal gains, creating a radiant heating effect. Overhangs avoid unwanted solar gain during summer months.

DOE/NREL

In climates where there is a highly variable range in temperature throughout the day, too much thermal mass can cause a building to require more energy, since it is so hard to turn around the effects fo thermal inertia to make cooler inside as the day warms up outside, for example.

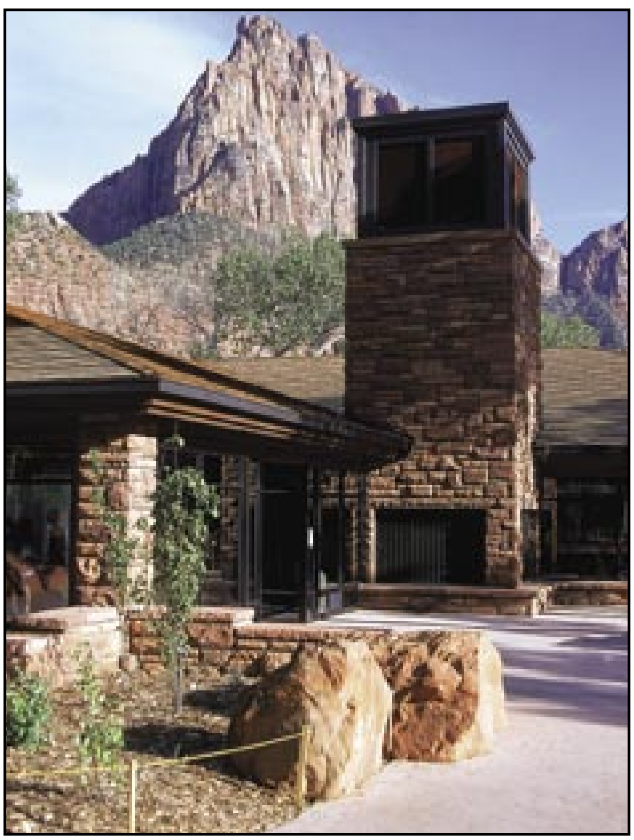
Strategies for passive solar cooling include using "overhangs for south-facing windows, minimal west-facing window area, shade trees, thermal mass, and cross ventilation. Thermal mass, which stores heat in the winter to release to living spaces in the evening, works in reverse in the summer. The mass cools down in the evening (in locations with cool evening temperatures) and retains that coolness the next day, moderating the effect of high outdoor daytime temperatures on the indoor comfort level" (Miller 1997). See figures 20-22.

DOE/NREL

Figure 20—This building design has large windows for daylighting and an overhanging roof to shade the windows in summer.

Figure 21—Zion Visitor Center, Zion National Park, Utah—daylighting lights the interior and the floor absorbs solar gain (thermal mass storage) for heating in winter.

DOE/NREL



DOE/NREL

Figure 22—The Zion Visitor Center, Zion National Park, Utah, uses a cooling tower to move cool air into the building.

The right sized overhang will shade windows in summer and allow sun through in the winter when the sun is low in the sky.

THERMAL EFFICIENCY

The building envelope, which includes the floors, windows, doors, roof, and walls and their specific construction design and insulation factors, plays an important role in determining the building's thermal efficiency. "The three primary considerations in envelope design are the: 1) type and amount of wall, roof, and floor insulation; 2) insulating value of doors and windows; and 3) rate at which air moves in and out of the building (air "exchange or infiltration"). Each of these three aspects of the envelope is responsible for about one-third of the thermal exchange between inside and outside temperatures" (Miller 1997).

Commercial insulation products include:

- Rock wool.
- Fiberglass.
- Cellulose, loose and spray on.
- Foam-in-place.

- Phenolic rigid foam.
- Plastic, nonwoven batting.

These insulators contain recovered material content, and fiberglass and cellulose contain post-consumer content. Silicon aerogel is another insulating material. It is made of silicon and air and is a very effective thermal and sound insulator.

DOE/NREL

The Environmental Protection Agency's Web site for Comprehensive Procurement Guidelines offers additional information regarding insulation products.[5] See figure 23.

Insulating Value and Air Infiltration

"**R-value** is a measure of how well a material resists the movement of heat. Air changes per hour (ACH) is a measurement of the rate of air infiltration and reflects not only the insulation value, but also how well a building is sealed" (Miller 1997). Insulated windows, specifically chosen for a certain climate, decrease heat loss, for example. Caulking around windows, doors, and under sill plates can significantly reduce air infiltration.

*Figure 23—***Structural insulated panel system (SIP) is** *made of an energy-efficient foam core (expanded polystyrene insulation) and sandwiched between recycled wood products.*

A well-insulated building minimizes the need for passive and active heating and cooling systems. The addition of rigid insulation on the outside walls reduces air infiltration and eliminates **thermal bridging**. Thermal bridging occurs at the studs, which are subject to **thermal transfer** when not insulated on the outside. See figure 24.

DOE/NREL

Figure 24—On this house, insulating sheathing is used to insulate and to block moisture.

DOE/NREL

Insulating sheathing and blown-in insulation are additional examples of products used to increase a building's thermal efficiency. See figure 25.

Figure 25—Soft foam insulation, Icynene, is sprayed into walls, floors and ceilings as a liquid and expands in seconds. This plastic insulation material, similar in chemical composition to the material used in pillows and mattresses, fills cracks and cervices. It is shown being trimmed.

Earth sheltering is another way to insulate a building. It is most effective at maintaining a comfortable interior temperature in hot, dry climates (Lechner 2001). See figure 26.


DOE/NREL

Figure 26—Earth-sheltered house for cooling, Tempe, Arizona.

BENEFITS OF USING PASSIVE ENERGY SYSTEMS

Better Working Environment

Employee productivity increases and the number of sick days taken decreases with the introduction of daylighting. Recent studies cited at the Department of Energy's Office of Energy Efficiency and Renewable Energy confirm these benefits.[6] [7]

Affordability

Passive solar design and construction do not have to cost significantly more. None of Miller's case studies showed an increase of more than 3 percent in housing construction costs. Costs need to be considered in light of another factor called "**payback.**" Payback is "the time it takes for energy cost savings to pay back the additional initial costs" (Miller 1997). See figure 27.


DOE/NREL

Figure 27—The south-facing roof of this house in coastal Maine incorporates an integrated array of solar thermal collectors and large-area PV modules to form a single, uniform glass pane. Space heating and domestic hot water are provided by the solar thermal system with space heating distributed in a multizone radiant floor system. The house also incorporates passive solar heating and cooling, super insulation, advanced R-8 windows, monolithic air and vapor barriers, air-lock vestibules, and a heat recovery ventilation system. Surplus energy is sold to the local utility company.

Intangible Benefits

Intangibles are natural lighting, less noise from mechanical systems, physical comfort, beauty, and an "alignment with ecologic values" (Miller 1997).

RENEWABLE ENERGY SYSTEMS

Renewable energy is energy that is generated using natural resources that are plentiful and regenerate or regrow themselves. Harvested wood, such as bamboo or cottonwood trees, are plentiful in certain regions and quickly regrow. The National Arbor Day Foundation, for example, heats and cools its entire convention facility with a biomass system that burns both cottonwood trees it grows on its farm and scrap wood from a local pallet maker. In addition, soot scrubbed from the chimney is used as fertilizer on site.

Renewable energy systems include:

- Solar
  - o Solar panels – Solar panels trap heat for heating water.
  - o **Photovoltaic** – Solar cells convert solar energy (light) into electricity.[8]

o Wind – Turbines on wind farms or individual towers are turned by the wind to generate electricity.[9]

- Small hydropower – Run-of-the-river hydropower generates electricity using either small dams or no dams at all.
- Geothermal – Geothermal sources trap heat coming from deep in the Earth and use it to heat via heat pumps.[10]
- Cogeneration – This method captures and uses incidental heat and excess steam produced onsite.
- Methane – Methane gas is a renewable energy source. Gas from decaying landfills is captured and burned to create power.
- Biomass – Biomass systems involve heating organic materials at high temperatures to convert and reduce them to primarily permanent gases (CO, H_2, CH_4, etc.). Water, char, and condensables are minor byproducts. Alternatively, bacteria can be used to breakdown organic wastes (paper) into hydrocarbon gas. There are many other processes as well.

Renewable Energy Examples

DOE/NREL

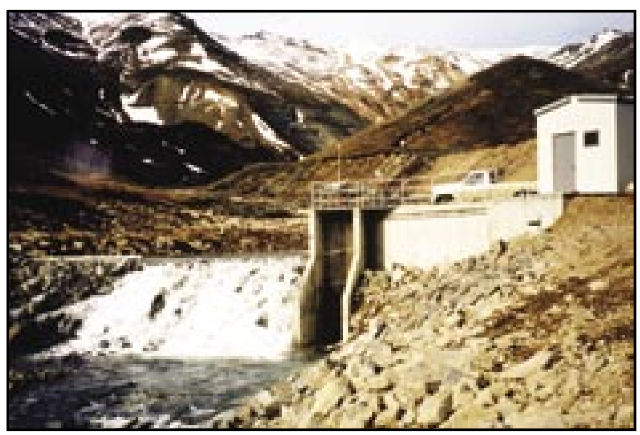
Figure 28—Photovoltaic or active solar . This photovoltaic system provides 6.5 kilowatts of electricity to power a general store in Canyonlands National Park, Utah. The electricity also heats water for hot showers for campers, melts snow for fresh water, and makes ice. Together with other energy saving measures, the system provides for roughly 85 percent of the store's power needs on an annual basis.

DOE/NREL

Figure 29—Photovoltaic panels. Photovoltaic panels at Oberlin College's Adam Joseph Lewis Center for Environmental Studies convert solar energy into electricity. The panes cover 4,682 square feet on the building's south-facing curved roof.

DOE/NREL

Figure 30—Wind Farms. Wind farm in Palm Springs, California. In 2005, wind plants have the capacity to produce 9,200 megawatts equivalent to 25 billion kilowatt-hours of electricity annually. This is enough to service 2.4 million average homes.



DOE/NREL

Figure 31—Hydropower. An 800-kilowatt micro-hydro-power station in King Cove, Alaska, went online in December 1994 to service the remote 700-resident town. This facility uses a run-of-the-river design in which water is drawn from two creeks and sent to a power house 250 vertical feet below the water intakes. The falling water turns a turbine, which generates electricity.

DOE/NREL

Figure 32—Geothermal. The Oregon Institute of Technology, Klamath Falls, Oregon, has been using a geothermal district heating system since 1964. Today the system heats 11 buildings, heats domestic hot water, melts snow on sidewalks, and even cools five buildings during the summer. The district heating system saves approximately $225,000 each year in heating costs as compared to the previous fuel burning system.

DOE/NREL

Figure 33—Cogeneration. Cogeneration is the coproduction of electrical and thermal energy, also called combined heat and power (CHP). Cogeneration systems use fuel to generate electricity. The heat generated from this process is captured and used to heat water, buildings, and so on.

DOE/NREL

Figure 34—Methane Gas Capture. Hornsby Bend wastewater treatment facility was built to treat solid sewage wastes from the city of Austin, Texas. It is also a bird sanctuary and a composting plant. Methane or "bio" gas, drawn from eight digesters, powers two 400 kilowatt piston-engine generators that supply electricity to Austin.

Figure 35—Biomass Energy. The Pacific International Center for High Technology Research (PICHTR) operates a biomass gasification demonstration project in Hawaii. This plant initially processed bagasse (a byproduct of sugarcane processing) from the neighboring sugarcane refineries; it was designed to receive a wide variety of biomass.

See figures 28-35. See pages 10-12.

SELECTING WINDOWS

Windows have evolved for use in all climates, and are enjoyed without jeopardizing indoor temperatures and energy efficiency. Added windows on the south exposure can actually save energy. The cost of double glazed, **low-emissivity** (low-e) windows is low enough that they should be standard except in the mildest climates. Benefits include "significant energy savings, increased thermal comfort, reduced noise transmission, reduced condensation (fogging), and reduced fading of fabrics from UV [ultra violet] radiation" (Lechner 2001). See figure 36.

DOE/NREL

Figure 36—A Building America Program Consortium installed double-paned, low-emissivity, vinyl-framed windows in their test home in Las Vegas, Nevada. Compared to standard windows, the high-performance model reduces heat losses and heat gains through the windows by 30 to 50 percent.

Windows have two rating systems. The American Architectural Manufacturers Association prints “voluntary” specifications for glass windows, doors, and framing materials. This organization uses a **U-factor.** The lower the U-factor, the higher the insulation value. Another organization, the Efficient Windows Collaborative, uses a system based on R-value. The higher the R-value, the less heat lost.

There are a number of ways to increase R-values. The space between panes and the low-e coating provides **thermal resistance** or less heat loss. In large windows most heat is lost through the pane. In smaller windows, the frame material enters into the heat loss equation. In double- and triple-paned windows, the **edge spacers** can be contributors to heat loss (Lechner 2001). Edge spacers should have thermal breaks to lessen heat exchange.


DOE/NREL

Figure 37—Double-paned window.

A double-paned storm window has an R-value of 2. Switching to a window with an R-value of 4 is like changing a wall’s insulation from R-19 to R-100. This is why it is now possible to use windows in very cold and very hot climates. Argon and krypton gases between the panes measurably improve the insulation value. See figure 37.

Energy-efficient windows block heat coming in through a window and inside heat that might escape through the window. Low-e reduces heat flow and allows light through. A spectral coated window blocks even more heat. “In the near future, electrically switchable coatings will become available. A building’s operating computer will then select which radiation and how much will be transmitted or reflected from the glazing at a particular time” (Lechner 2001).[11]

Window frames can be made out of wood, aluminum, plastic, or a combination of these materials. Wood is the best insulator and, when covered with aluminum or vinyl, is low maintenance.

The North American Fenestration Standard or NAFS has produced structural classifications for windows. They are commercial (C), heavy commercial (HC), and architectural (AW). These classifications indicate the frame depth from 2 ¼ to 4 ½ inches and the **extrusion** thickness. (A window’s extrusion forms its frame’s walls.) Commercial windows are ideal for one- to two-story buildings. Architectural windows are reproductions of historic windows or specific replacement windows.

Both Lawrence Berkeley National Laboratory and the U.S. Department of Energy’s Efficient and Renewable Energy official Web sites offer helpful information about selecting windows.[12] [13]

AUXILIARY ENERGY SYSTEMS

Passive solar designs usually cannot meet all heating needs. Energy-efficient mechanical systems are generally required as well. Such systems may include ground-coupled heat pumps, natural-gas-fired furnaces, boilers, biomass burners, and wood burning stoves. Passive cooling definitely will lessen the need for air conditioning and may eliminate the need for it altogether.

Passive solar systems may eliminate the need for cooling in cool dry climates, but probably will never do so in hot, humid climates. In tropical and sub-tropical climates, the opposite may occur - it is heating equipment that may be eliminated instead.

Integrated Electrical and Mechanical Systems
Sustainable buildings need to "integrate electrical lighting and control systems with their daylighting design to optimize energy savings. Sensors throughout the buildings adjust electric lighting levels depending on the amount of daylight entering each particular space.

"[Each sustainable building] has a controlled mechanical ventilation system, typically integrated with the conventional heating and cooling system. In most cases, because daylighting design reduced cooling loads, the mechanical systems are smaller than they would otherwise be… . This 'downsizing' can mean sizable initial cost savings, which significantly offsets the additional cost of the daylighting features" (Miller 1997).

Ventilation is critical to occupants' health. Proper ventilation prevents the buildup of carbon monoxide, radon gas, formaldehyde, cigarette smoke, and harmful gasses given off by volatile organic compounds or **VOCs** in manufactured products and in cleaning and maintenance supplies. See figure 38.

DOE/NREL

Figure 38—Shown is the air handler for a controlled ventilation system. The system ensures that there is fresh air in the building. A ventilation system is necessary because well-insulated buildings do not "breathe" on their own.

DOE/NREL

Figure 39—Reception desk at the Chesapeake Bay Foundation's Philip Merrill Environmental Center, Annapolis, Maryland. Bamboo and cork flooring are used through the building.

NATURAL BUILDING METHODS
There are many long-standing **natural building** methods. In *Alternative Construction: Contemporary Natural Building Methods*, Lynne Elizabeth and Cassandra Adams cover the building techniques for these methods, which have been modernized to lessen construction time and the amount of hand labor. Inexpensive earthquake adaptations have been added to some of these methods, though most were already surprisingly earthquake resistant.

Natural building refers to using at-hand or locally produced materials such as earth, straw, and bamboo. See figure 39. Local materials should be easy to acquire and their use should cause little environmental damage.

Many long-standing natural building methods, for example adobe, cob, and light clay, rely on the abundance of local materials such as earth, water, and straw.

The use of earth for buildings is quite ancient. The technique of compacting moist soil to form walls, for example, can be traced back to 7000 B.C.E. This is essentially the rammed-earth method. It is estimated that today between one-third and one-half of the world's population lives in earthen dwellings.

Earthen buildings last hundreds of years. In hot climates, they are cool in the summer and warm in the winter. In cool climates, they are always cool and use great amounts of nonrenewable energy for heating unless passive and/or active solar systems are included in the designs. Generally earthen buildings have a much smaller environmental impact than do traditional building methods. For instance, adobe-block production takes only 1 percent of the energy required to produce fired bricks or Portland cement. (Elizabeth 2000).

Adobe is a sun-dried mud brick that can be found worldwide. Adobe, generally, has an insulation R-value of 20. See figures 40 and 41. Cob is similar to adobe with the R-value varying depending on the exact mixture of sand, clay, straw, and water, while light clay's R-value is approximately 25 (Elizabeth 2000). See figure 42. These building materials are constituted and formed in slightly different ways around the world. They are nontoxic and recyclable.

Richard D. Pieper

Figure 40—This adobe house in Geneva, New York, was built around 1843. Over 20 adobe buildings were built in Geneva between 1841 and 1850, and nearly 40 Statewide in the same period. More than 20 exist in New York State today.

C. E. Laird

Figure 41—Tall windows in this house in Albuquerque, New Mexico, (designed by C. E. Laird) allow for daylighting to light the room and for heat gain to be stored in the brick floor. The windows open for ventilation, and the shutters were made of local tamarisk.

Frank Meyer

Figure 42—This contemporary mantel was fashioned out of cob and finished with a simple earthen plaster to create this handsome Southwest-style hearth (Elizabeth 2000).

Straw-bale construction is another environmentally and human friendly construction method. The walls are sealed using waterproof plaster so bales do not decay. Straw-bale buildings, generally, have an insulation R-value between 40 and 57 and are very fire resistant (Elizabeth 2000). See figure 43.

Figure 43—This classroom building is made of straw bales, Claremont, California.

Simón Vélez

Figure 44—Bamboo livestock shelter.

Bamboo is another very good building material. It is an economical and environmentally responsible method of building in climates where bamboo is plentiful and naturally occurring, such as the Southern United States and Puerto Rico. See figure 44.

OTHER ASPECTS OF SUSTAINABLE DESIGN

Indoor Environmental Quality

Occupant health is also affected by the choice of indoor materials for floors, walls, cabinets, furniture, and by products used for cleaning and maintenance. Avoid products that offgas.

Purchase and use building materials and products that contain low levels or no volatile organic compounds.[14]

Interior materials are also made of native materials. Construction particleboard made from wheat straw, a more renewable product than particleboard made of wood fibers, is an example of a natural building material. Wood products are also available for cabinets that do not contain urea-formaldehyde (UF) resin or toxic glues that give off toxic fumes or offgas. See figure 45.

DOE/NREL

Figure 45—Wheat-straw particle board. It contains no formaldehyde or other emissions, reduces forest exploitation, and supports the use of an agricultural byproduct.

Energy Efficient Appliances and Mechanical Systems

To implement a sustainable design project successfully, use the most energy efficient appliances, lighting, and HVAC systems. The Energy Star® label was developed by the U.S. Department of Energy and the U.S. Environmental Protection Agency to indicate products that meet energy efficiency standards. When an energy-efficiency label designation is not available, an appliance should be at least 20 percent more efficient than the average one on the market. Energy Star-approved appliances can be found at its official Web site.[15] See figure 46.

DOE/NREL

Figure 46—ENERGY STAR® r-labeled lighting fits every need. A wide variety of light bulbs are available. Energy Star-compliant light bulbs last up to 10,000 hours or an average of 7 years of normal, daily household use.

In 1992, the Federal Government established minimum efficiency requirements for all heating and air conditioning equipment. There are three rating systems for HVAC systems. They are:

- Seasonal Energy Efficiency Ratio (**SEER**).
- Energy Efficiency Ratio (**EER**).
- Heating Season Performance Factor (**HSPF**).

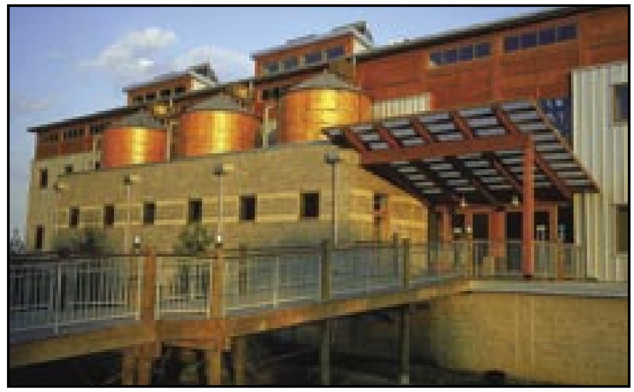
A higher number in each of these rating systems equates to higher energy efficiency.

Seasonal Energy Efficiency Ratio is a measure of cooling efficiency for air conditioning products. An Energy Efficiency Ratio is calculated by dividing the cooling capacity in Btu per hour by the power input in watts at a given set of rating conditions, expressed in Btu per hour per watt. The Heating Season Performance Factor is used typically when referring to heat pumps.

Water Conservation and Wastewater Treatment
Sustainability also includes water conservation, waste treatment, and recycling. Water systems can be made more efficient by using low-flush toilets, waterless urinals, aerators on faucets and showerheads, and drip irrigation for native plants and fire-safe landscaping.

Sustainability also calls for storing caught rainwater in cisterns in low rainfall areas for indoor graywater use and for irrigation. See figure 47. Graywater created from potable water also can be use for irrigation.

Treat wastewater onsite if possible and practical. In certain areas, constructed wetlands are appropriate for sewage treatment.



DOE/NREL

Figure 47—To decrease municipal water use and runoff, a rainwater collecting system, on the roof of the Chesapeake Bay Foundation, Philip Merrill Environmental Center, Annapolis, Maryland, captures rainwater for use in fire suppression and in the building's sinks.

Reduce, Reuse, Recycle
It is important to reduce the amount of waste generated as a sustainable project is built, to reuse old building materials such as wood or steel in a new building, and to plan for the recycling of waste generated by the work at the facility and by workers. A significant part of any recycling program is reducing the amount of waste imported into a facility or generated by the facility.

Figure 48—Wayne National Forest Headquarters, Nelsonville, Ohio, building.

A sustainable project should include recycled products in new construction. For example, elements of local history were incorporated into the unique design of the Wayne National Forest Headquarters. See figure 48. The reclaimed bricks used on this project came from several surrounding communities that once had their own brick and tile manufacturing plants or clay quarries. The stone flooring and native hardwoods were also from the local area. Many of the materials used in the building, such as the steel siding and roofing, carpeting, insulation, ceiling tiles, and wallboard, were made with recycled products.

Recycling procedures also should be designed into the building by planning for the flow of recyclables and their storage. The structure itself should have reusable parts. During a building's life the interior may be reconfigured several times for different uses. This flexibility of design should be taken into account during the planning. At the end of the building's planned life, its parts should be reused and recycled.

SUMMARY

The LEED Silver certification requirement for new construction, implemented in 2005, moves the Forest Service into the sphere of sustainable building. Remodeled, leased, and new buildings can, at no great cost, be made into sustainable buildings. Operations and maintenance costs are less over time, and occupants and visitors benefit as well.

LEED is a tool to use as a checklist for integrated design methodology and team approach. Whole-site/whole-building design and three-tiered design use team approaches, as well, to ensure that all aspects of sustainability and building use are considered during siting and design phases. Commissioning is an important tool in determining that systems are working as designed.

Sustainable building design uses passive energy systems, especially passive solar systems. This approach encompasses such different, yet interconnected, aspects as building orientation, daylighting, heat gain, thermal mass storage, thermal efficiency, cooling strategies, and the proper selection of windows.

Finally, sustainable building design means integrating electrical and mechanical systems, taking advantage, whenever possible, of other renewable energy sources such as photovoltaic, wind, geothermal, etc. The use of native building materials, energy-efficient appliances, as well as reusing and recycling materials (including the building at the end of its planned life) are all facets of sustainable building design principles.

Former Forest Service Chief Dale Bosworth wrote, “When we build our facilities to respect the natural systems in which they reside, be durable, and emphasize efficiency in energy and materials consumption, we not only use less ourselves, but send a message to all about what we value and what everyone can do to conserve resources” (Built Environment Image Guide 2002).

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Simón Vélez, leader of modern use of bamboo in architecture, Colombia, South America.

GLOSSARY

Commissioning:	A plan that verifies and ensures that building elements and systems are designated, installed and calibrated to operate as intended.
Daylighting:	Daylighting is the use of direct, diffuse, or reflected sunlight to provide full or supplemental lighting for building interiors.
Direct gain:	Radiant heat resulting from sunlight admitted directly to the interior spaces.
Earth shelter:	Part or all of a structure is covered with earth. It is best used in climates with extreme outdoor temperatures and low humidity.
Edge spacers:	Double- and triple-paned windows use spacers to keep the panes separated.
EER:	Energy efficiency ratio is calculated by dividing the cooling capacity in Btu per hour (Btu/h) by the power input in watts at a given set of rating conditions, expressed in Btu/h per watt.
Extrusion:	A window's extrusion forms its frame's walls that hold the glass in place.
Heat gain:	Inside heat generated from internal heat sources such as lights, appliances, machinery, and human bodies, thermal mass, and air temperature (sun).
HSPF:	Heating Seasonal Performance Factor is typically used with reference to heat pumps. The higher the HSPF rating, the more efficient a heat pump is at heating a building.
Indirect gain:	Solar heat that is absorbed by a Trombe wall or a space. The heat is absorbed before it heats the room and can be transferred then or later.
Low-emissivity:	Emissivity is a measure of an object's ability to emit long-wave infrared radiation or room temperature radiant heat energy. Surfaces with low-emissivity reduce heat flow and allow light through.
Natural building:	A building approach that uses at-hand or locally produced materials including earth, straw, and bamboo.
Payback:	The time it takes for energy cost savings to pay back the additional cost of using more costly, energy-efficient products.
Passive solar:	The use of solar energy to heat and cool a building with no assistance from mechanized equipment.
Photovoltaic:	Photovoltaic (or PV) systems convert light energy into electricity. Also commonly known as "solar cells." The simplest systems power many small calculators and wrist watches. More complicated systems can provide electricity for pumping water, powering communications equipment, and

	lighting homes, and running appliances.
R-value:	Standard rating system used to label insulation value of materials. Also, an energy efficiency rating designed by the Efficient Windows Collaborative system. The higher the r-value, the less heat loss.
SEER:	Seasonal Energy Efficiency Ratio is a measure of cooling efficiency for air conditioning products. The higher the SEER rating number, the more energy efficient the unit.
Solar contribution:	The percent of the total heating load that is met through a combination of direct gain, indirect gain, and thermal mass storage.
Solar gain:	Heat from the sun.
Sustainable development:	The ability to meet "today's energy needs without compromising the ability of future generations to meet theirs." The use of energy-efficient designs, building materials, appliances, as well as reusing and recycling materials, including the building at the end of its life.
Thermal bridging:	Thermal bridging is a characteristic of some materials, such as steel studs, to transmit temperature differences through a wall assembly, short-circuiting the insulation that abuts it.
Thermal mass:	Material within the building that absorbs heat.
Thermal mass storage:	A floor, wall, or other type of structure specifically built to absorbs solar radiation. This uses indirect gain.
Thermal resistance:	The opposition of materials and air spaces to the flow of heat conduction, convection, and radiation (Lechner2001).
Thermal transfer:	Transfer of an outside temperature, for example, to the inside of a building along the building components.
Trombe wall:	A glass-fronted, south-facing concrete wall heated by sunlight during the day. The wall radiates heat inside the building as it cools at night.
U-factor:	The American Architectural Manufacturers Association (AAMA) specifications for glass windows, doors, and framing materials. The lower the u-factor, the higher the insulation value.
VOCs:	Volatile organic compounds.
Whole-site design:	An approach to building design that looks at the entire site and how it interacts with adjacent land, its effect on the ecosystem, etc. before deciding to build. It relies on using the natural amenities of the location when siting the building and on the use of a team of professionals and stakeholders.

Whole-building team:	A group of interacting building professionals (and stakeholders) working together during the entire building process. It is marked by the attitude that no one profession knows it all and the recognition that building tenants can also contribute because they will be using the completed facility.

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http://fsweb.sdtdc.wo.fs.fed.us/

For additional information on sustainable design principles, contact Ellen Eubanks at SDTDC. Phone: 909–599–1267 ext 225. E-mail: eeubanks@fs.fed.us

(Footnotes)

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