



## #9 WHOLE SYSTEM DESIGN

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### PUTTING IT ALL TOGETHER

Building and operating a green home does not have to cost more than building and operating a conventional one; in fact it can—and should—cost less. The key is whole system design (which goes by a variety of names, including “green design,” “integrated design,” etc.). Whole system or integrated building design actively considers the interconnections between systems, occupants, and the environment; and uses these connections to develop single solutions to multiple problems (shelter, energy savings, aesthetics, natural daylight, indoor environmental quality, affordability, etc.). While whole system design can produce many desirable environmental, health, and financial outcomes, potential energy savings perhaps illustrate the concept best. The previous eight *Home Energy Briefs* focus on individual home retrofit and purchase opportunities. This ninth Brief “puts it all together” and introduces the reader to a design

ideal that should be overarching in all green building projects. While reading this Brief, think about applying the concepts to your own projects and make note of synergies that can reduce your energy bill.

To guide you through a whole system way of thinking, we have chosen the building envelope as our key focus for energy savings. In a typical home, 45 percent of the total energy bill goes to heating and cooling indoor spaces. Considering that the average bill is about \$1,500, this is almost \$700 every year! While efficiency gains in heating and cooling equipment alone can produce incremental savings (see *Home Energy Briefs No. 3: Space Cooling* and *No. 4: Space Heating* for more details), applying the principles of whole system design compounds energy savings in heating, cooling, and lighting, which leads to a healthier indoor environment that costs less to build.

This Brief will cover the following topics:

- **Whole system design** and its application to the building envelope;
- Additional ideas for **reducing heat gain** in summer;
- **The right building materials** for your building envelope; and
- **Cost and financing** of whole system design.

### WHOLE SYSTEM DESIGN AND ITS APPLICATION

There are many ways to conceptualize whole system design. Consider the following guidelines a roadmap:

**Think of the purpose (application before equipment):** Technology such as lighting, heating and cooling, or insulation equipment does not exist for its own sake. Its aim is to provide illumination and thermal comfort. Think about your project in terms of what you want to achieve and then consider the “passive” and “active” options (see below).

**Size your requirements appropriately (demand before supply):** When purchasing new equipment, such as a heating and cooling system or a clothes dryer, think about actual use (demand) and size your equipment accordingly (supply). Too large a system will be expensive to operate and inefficient because, like most household devices, they are designed to operate at full capacity.

Other titles in Rocky Mountain Institute's *Home Energy Briefs* include:

- No. 1 Building Envelope
- No. 2 Lighting
- No. 3 Space Cooling
- No. 4 Space Heating
- No. 5 Water Heating
- No. 6 Cleaning Appliances
- No. 7 Electronics
- No. 8 Kitchen Appliances
- No. 9 Whole System Design



For additional information, as well as a downloadable version of this document, please see our website: [www.rmi.org](http://www.rmi.org)

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**Consider whole systems (means before ends):** By seeing your home as a series of interconnected systems, you will learn to pinpoint problems. For example, your high water-heating bill might have nothing to do with the price of gas or electricity, or even how much energy you consume; it might be high due to leaky water pipes that are not insulated properly, or due to inefficient equipment.

**Choose passive options first (passive before active):** Take actions and choose technology that circumvent the need for artificial and/or energy-intensive systems and devices. Letting sunlight into your home in winter is a passive (and free) way to light and heat your home while gas and electric heaters are an active (and expensive) way of achieving the same thing.

### What does applying whole system design to the building envelope look like?

As discussed in *Home Energy Brief No. 1: Building Envelope*, the building envelope is a very important component of any home.

Whole system design encourages us to think of the building envelope in terms of the service that it provides: shelter from wind, rain, heat, and cold. Knowing the building envelope's role in the building system motivates us to maximize the quality of its service through our choice of passive solar design and building materials. A well constructed, properly insulated, and adequately ventilated building envelope reduces heat loss/gain and saves you money by allowing you to reduce heating and cooling energy consumption. Such "passive" design translates into utility bill savings for the homeowner, as well as a cleaner environment (less air pollution from power plants). In addition, it allows you to downsize or even eliminate heating and cooling systems. Smaller equipment should cost less, allowing you to purchase the most efficient equipment available (the technologies are described in *Home Energy Brief No. 3: Space Cooling* and *No. 4: Space Heating*). These savings can then contribute to paying for additional improvements to the overall efficiency of your house (such as better windows). The remainder of this Brief will go into further detail on the whole system design choices that one would consider when using the building envelope to save energy.

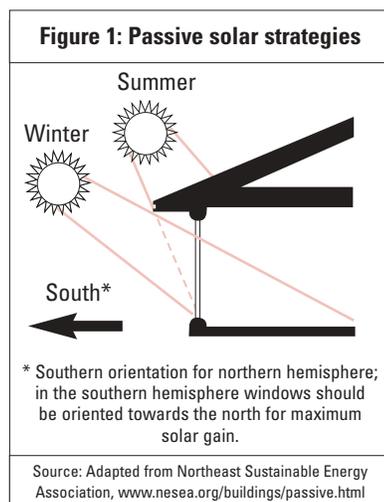
### PASSIVE SOLAR DESIGN IN THE BUILDING ENVELOPE

By harnessing the free energy of the sun to naturally heat, cool, ventilate, and light your home, resource consumption is reduced (e.g., fossil fuels to power air conditioners and furnaces), and money saved. Passive solar concepts can be applied throughout a

building's life cycle; however, the most effective passive solar designs are usually realized with new construction via proper building orientation, living space arrangement, fenestration, and use of solar mass.

### What is the best way to orient a living space to encourage natural heating and cooling?

Proper building orientation in a new home or addition requires no additional cost, but it ensures that your new living space can take advantage of year-round energy savings by minimizing the need for air conditioning and heating. Simply facing your home in the right direction can save up to 30 percent on your energy bill.<sup>2</sup> In the northern hemisphere the new living spaces should be oriented along an east–west axis so that their longest walls and largest windows face south. This provides the maximum benefits and best control of solar heat gain and lighting in the home as the sun travels across the sky (in the southern hemisphere, the reverse is the case). For more information on building heat loss/gain, refer to *Home Energy Briefs No. 1: Building Envelope*, *No. 4: Space Heating*, and *No. 5: Space Cooling*. Locate living and working spaces requiring lighting, heating, or cooling along the south side of the building with garages, workshops, utility rooms, and storage areas on the north side (or east and west ends). Due to the sun's lower path during the winter months, south facing windows and rooms will receive direct winter sunshine (see Figure 1). Use overhangs or deciduous trees to prevent glare and summer overheating. If a home has minimum southern exposure (e.g., its short-side



faces south), an open-plan interior is one option to transfer heat and light to the northern zones.

In warm climates, orientation is equally important. Minimize east and west facing wall areas to reduce hard-to-manage heat gain and consequent loading on your air conditioning system. Shading west walls and windows with trees and/or window treatments is also recommended. On the north side of your home, either minimize window size or use high-performance windows for greater insulation. However, remember that good north facing windows can provide consistent natural daylighting, free of glare, that minimizes demands on your heating system. Finally, determine the directions of prevailing breezes and storms. Orient and design your home to capture the benefits of desirable breezes, and protect you from storms.

### **What are the benefits of south facing windows for providing thermal comfort?**

North of the equator, south facing glass is a key component of passive solar design. If you live in a cold climate, you can specify energy-efficient window technologies that allow sunlight in during the day and retain most or all of the daytime heat gained at night. In hot climates you can select windows that admit light with minimum heat gain during the day. For more information on energy-efficient, high performance windows and their selection, see *Home Energy Brief No. 1: Building Envelope*. South facing windows should be designed so that heat is gained during the winter without compromising cooling performance during the summer. The rec-

ommended maximum amount of south facing glazing (window area) is 7 percent of the home's total square footage. For example, a 2,000-square-foot conventional home with carpeted or wood floors would ideally have 140 square feet of south facing windows. Increasing glazed areas to greater than 7 percent will require additional thermal mass in the walls and floors (see below) to maintain thermal balance. When windows are perpendicular to the sun or oriented vertically, their effectiveness as solar collectors increases. However, this must be done very carefully, because without proper design they can admit too much heat in the summer.

### **How can thermal mass heat and cool a home?**

Energy admitted into the home through south facing windows can be collected and stored by materials with high thermal mass, such as masonry floors and walls. Masonry, stone, concrete, adobe, water, and other materials are effective as thermal mass—meaning they absorb and store warmth and “coolth,” and release it slowly.

#### **Glass to mass ratios<sup>3</sup>**

Each design starts with 7 percent south glazing. To increase beyond 7 percent we must also add thermal mass, usually starting with floor mass and then walls. The recommended maximum amount of south facing glass for direct gain is 12–15%. An additional 1 sq. ft. of south facing glass may be added for every:

- 5.5 sq. ft. of sunlit thermal mass floor (1.5 times the south facing window area);
- 40 sq. ft. of floor not in direct sunshine; and
- 8.3 sq. ft. of thermal mass wall.

They can be used as floors, walls, fireplaces, etc. These materials have a much better storage capacity for heat and coolth than the surrounding air. You have probably experienced the thermal mass effect when leaning against a sun-warmed brick wall in winter, or sheltered beside a cool stone in summer. Thermal mass helps to regulate temperature inside the home as outdoor temperatures rise and fall. A well-designed passive solar home can hold a constant interior temperature of 68–70°F with minimal supplemental heating and cooling. In the summer, thermal mass should be shaded so it pulls warmth out of the surrounding air and cools the room. To optimize the ratio of south facing glass (solar collectors) to thermal mass, consider *Trombe* walls and *tube* walls:

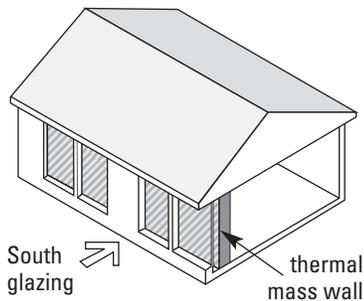
**Trombe** walls (named for Professor Felix Trombe, who helped develop them in the 1960's) offer one method of using thermal mass to offset heating and cooling bills. Trombe walls (see Figure 2) generally consist of an 8- to 16-inch thick masonry wall, coated with a dark, heat absorbing material. These surfaces are then faced with a layer of glazing (windows) separated from the dark wall by three-quarters to two inches, creating an airspace. The thermal mass of the wall is heated by the sun and warms the air in the airspace, causing it to rise. Openings in the bottom and top of the Trombe wall allow air to circulate and heat the interior of the building. It is possible to adapt some existing sun-facing masonry walls by painting the exterior surface with an absorptive coating and installing glazing. However, during summers in hot climates, Trombe walls must be shaded.

**Tube** walls use water drums or columns as heat stores. Water is more efficient than masonry for thermal storage but is very heavy and needs regular maintenance to prevent leaks and the growth of algae. To help you choose the best thermal mass option for your home, contact a green architect or builder. Issues to keep in mind include:

- Thermal mass is only effective in certain climates (see below);
- In winter these surfaces can be cold until they are “recharged” by the sun; and
- If glass-to-mass ratio is not optimal, supplementary mechanical heating and cooling might be required.

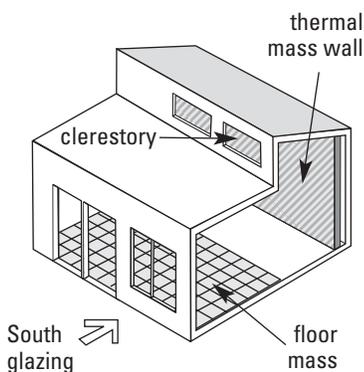
**Figure 2a: Thermal storage walls**

A thermal storage wall is an effective passive solar system, especially to provide nighttime heating.



**Figure 2b: Direct gain**

Direct gain is the most common passive solar system in residential applications.



Source: Adapted from *Whole Building Design Guide*, [www.wbdg.org/design/resource.php?cn=0&rp=22](http://www.wbdg.org/design/resource.php?cn=0&rp=22)

### **What is the difference between thermal mass and insulation for a building's exterior walls?**

Using thermal mass to passively cool a building is most effective in climates that have high daytime temperatures and low nighttime temperatures. Such areas include the sunny Southwestern United States, particularly the high elevation areas of Arizona, New Mexico, and Colorado. In Northern regions, where the winter temperatures are normally well below the indoor temperature, exterior walls with high thermal mass offer almost no heat storage or insulation benefit. Consequently, people who live in areas that experience outdoor temperatures that consistently remain lower than the desired indoor temperature should select instead a super-insulated wall system with a high R-value (see *Home Energy Brief No. 1: Building Envelope* for more details).

### **What are the benefits of sunrooms or greenhouses?**

Sunspaces have become popular energy-saving architectural features in recent years. They are particularly effective in areas that have year-round sunshine. Often they can be easily added to an existing home. Known also as a conservatory, a solar greenhouse, a solarium, or a sunroom, a sunspace can make an ideal family room, and can function as a solar heat collector—all at the same time. A sunspace is a tightly constructed, windowed enclosure that provides heat, light, and controlled ventilation for the home. A sunspace should have as much south facing glass as possible and will work best when combined with

thermal mass using a thick slab floor and a high-mass northern wall. The most effective sunspaces integrate natural and/or forced convection to distribute heat throughout the home and offset heating loads. The heat generated in the sunspace can be ventilated into rooms that are used during the day, such as the kitchen, playroom, or living room. The sunspace should also have vents to the outdoors located both high and low in the space; these can be used to create a natural draft to ventilate your house in the summer.

### **ADDITIONAL IDEAS FOR REDUCING HEAT GAIN IN SUMMER**

#### **How can a roof provide additional passive cooling benefits?**

In summer, traditional dark roofing materials can reach temperatures of 150–190°F, adding to the cooling load of your home. However, there are simple and effective design solutions to reduce this heat gain—“cool roof systems,” for example. Cool roof systems have two characteristics: high reflectance (also called *albedo*) and a high thermal emittance. Lawrence Berkeley National Laboratory (LBNL) researches and promotes the benefits of “cool roof systems.” LBNL found that buildings that used light-colored, reflective roofs needed 40 percent less energy for cooling than buildings with dark roofs.<sup>4</sup> The choice you make for a lighter, more reflective roof depends on the type of roof you have and the extent of your re-roofing.

Here are some tips:

- The best options are materials that are smooth and white and can be applied as a coating (like paint). Cool roof coatings cost \$0.75–1.50 per square foot for materials and labor.<sup>5</sup>
- Conventional white asphalt shingles typically reflect about 25 percent of sunlight while premium white asphalt shingles reflect up to 35 percent.
- If you have a low-angled or flat roof, you can buy solar-reflective white roofing at almost the same price as standard dark roofing. If you have a gently sloped roof, you need to purchase the more expensive white clay, concrete, or fiber cement tiles—or painted metal roofing.
- White roof coatings wear with time and regular cleaning and maintenance may be required.

**Figure 3a: Green roofing**



**Figure 3b: Semi-annual maintenance**



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Green or living roofs (roofs substantially covered by vegetation) are well established in Europe as a functional and aesthetically pleasing passive cooling strategy. Although green roofs can be modularly prepared in movable, interlocking squares, they are typically attached via a special waterproof and root-repellent membrane, as well as a drainage and filter system, and plants. In addition to their aesthetic appeal, green roofs provide many environmental and economic benefits. A green roof cools a building through plant respiration and lowers rooftop temperatures. Consequently, less heat is radiated into the building and the surrounding environment. This helps to reduce the “heat island effect.” Rooftop plants also absorb pollution and purify air while providing a natural barrier to street noise. Additionally, vegetated roofs filter water, reduce the load on stormwater infrastructure, and prevent run-off from polluting streams and lakes. Green roofs typically last much longer than conventional roofs, reducing maintenance and replacement costs. Currently, the up-front cost of a green roof that is less than six inches in depth starts at about \$8 per square foot, which includes materials, preparation work, and installation. Extensive green roofs weigh no more than commercial ballasted roofs. In comparison, the cost of a traditional roof starts at about \$1.25 per square foot, including materials and labor.

## BUILDING MATERIALS AND THE BUILDING ENVELOPE

### *How does one choose the right building material to save on energy bills?*

When applying whole system design you can select materials that maintain thermal comfort, make a positive contribution to indoor environmental quality (see below), are affordable, can be obtained locally, and are reusable and recyclable. Your final decision will be based on the criteria most important to your needs. In our example we would place contributions to passive heating and cooling (thermal performance) at the top of our list. We have created a table (see Table 1) that illustrates how to weigh different wall materials using a whole system approach.

#### **Did you know?**

Photovoltaic (PV) roof shingles are new roofing systems coated with a film that converts sunlight to electricity. These are designed to look similar to traditional roofing. Each 100 square feet of PV roof will generate 1 kW of electricity. These are most effective on south facing roofs (in the northern hemisphere) although they can be used on east and west facing roofs. PV shingles are available from some roofing suppliers such as the United Solar Ovonic Corporation ([www.uni-solar.com](http://www.uni-solar.com)). Additional links to manufacturers and suppliers can be found at: [www.solartoday.org/links.htm](http://www.solartoday.org/links.htm).

Table 1: General properties of available building materials

Building material for walls*	Thermal performance (higher R-value means better insulation)	Toxicity (off-gassing and ability to neutralize toxins)	Renewable and recyclable	End of life	Cost (whole system design benefits)
<b>concrete (block or solid)</b>	Low R-value but an effective thermal mass material for moderating indoor temperatures in mixed climates (climates that experience daytime temperatures above and nighttime temperatures below the desired indoor temperature)	Low	Choose products supplemented with recycled fly ash or slag from steel manufacture	Can be crushed for road base	Inexpensive but poor insulation can lead to high heating bills in cold climates
<b>wood</b>	Super-insulated wood walls with staggered double studs can be effective in cold climates. However, wood frames are often a thermal "weak link," causing "thermal bridging" that lowers the effective R-value of the entire wall system (for example, a wood framed wall with R-19 insulation has an actual insulation value of R-16)	Low but can be toxic if formaldehyde is used as the binding agent in engineered wood systems	Choose renewable products that are sustainably harvested. Check for Forest Steward Council (FSC) endorsement	Non-toxic and can be re-used in buildings or down-cycled for mulch	FSC lumber can be expensive. Wall cavities need to be insulated
<b>straw bale</b>	Very high R-value and when combined with an earthen plaster can provide a substantial thermal mass	Low when built with earthen plaster	Renewable, and instead of crop-burning, farmers can profitably divert otherwise wasted straw to a productive use	Non-toxic and can be used for mulch	Cost-effective if sourced locally, and no additional insulation costs
<b>adobe (earth)</b>	Low R-value, but great source of thermal mass material in warm or mixed climates	Low	Not renewable, earth is not easily replaced but is plentiful	Returns to earth	Cost-effective if sourced locally, and can be part of good passive solar design. Requires insulation in extreme climates
<b>masonry</b>	Masonry is not a good insulator, but it is a very effective thermal mass material, capable of storing heat or coolth	Low	Not renewable, but the raw materials are abundant	Non-toxic and can be crushed for fill or reused	Price dependent on design and level of expertise required. Requires insulation in extreme climates
<b>structural insulation panels (SIPs: foam insulation or compressed straw sandwiched between sheathing)</b>	SIPs can provide very high insulating values and reduce air infiltration by minimizing joints	Low to high depending on materials used	Most are made using recycled wood chips in the sheathing and are manufactured to size, which minimizes waste	Depends on core material: straw can be ground for mulch and foam can be recycled	Material is expensive but does not require framing or extra insulation, and requires less labor

\* Note that if installed and preserved correctly all these materials are durable.

Source: RMI compilation

Although the list is not comprehensive, it shows that the cheapest wall system does not necessarily provide the best alternative when the additional benefits of other systems are considered.

**What is Indoor Environmental Quality and why is it an important consideration for choosing building materials?**

Indoor Environmental Quality (IEQ) refers to the quality of the environment inside a building. Factors that affect IEQ include indoor thermal comfort, air quality, moisture management, noise and lighting—characteristics that individually or in combination can make a building healthy or unhealthy.

Therefore, in terms of thermal performance, whole system design encourages us to choose a wall system that offers auxiliary benefits, such as adequate ventilation. Building or renovating a home so that it only provides thermal comfort would not support a whole system design approach. A combination of passive and efficient, active space conditioning and ventilation strategies (mechanical equipment), will properly maintain indoor humidity levels and air circulation, air filtration, retard the growth of mold and mildew, and maintain thermal comfort. For more information, see climate specific literature, such as the *Builder's Guide* for vapor and thermal barrier strategies.<sup>6</sup> Also, *Home Energy Brief No. 3: Space Cooling* and *No. 4: Space Heating* offer information on space conditioning solutions.

**WHOLE SYSTEM DESIGN: COST, SAVING, AND FINANCING**

***Does green building cost more?***

Utilizing whole system design can lead to substantial savings by minimizing or reducing some building systems. No matter what green building strategies you choose, the key to realizing maximum benefit is following a well-defined plan—the planning phase of a home project determines 80–90 percent of what you will pay in energy bills. If you plan carefully, the savings should offset the cost increases, providing you with a highly efficient house for the same cost to build as an inefficient one. Factor in additional benefits such as good indoor environmental quality (e.g., healthy air, high quality natural light, better acoustics, elimination of drafts, etc.) and attractiveness to future buyers.

***Are financing options available?***

Aside from traditional mortgages and home improvement loans, you can fund whole system design improvements by using an Energy Efficient Mortgage (EEM) to buy an efficient home or remodel your home for efficiency. EEMs work in various ways; most commonly, they either increase the amount you can borrow against your house because of reduced operating costs, or they provide borrowers with point reductions on their mortgage interest when purchasing an energy-efficient home, or when making energy-efficient improvements to a home. An EEM is granted by a participating lender upon completion of a Home Energy Rating Systems (HERS) report that

is prepared by a certified Home Energy Rater. Factors such as amount of insulation, appliance and window characteristics, and local climate are used to rate the home and calculate energy costs. An energy rating of 3 or better on a scale of 1–5, or a rating of 85 or better on a scale of 0–100 is usually needed for EEM qualification; however, some communities simply certify that your home meets minimum HERS requirements. A HERS report usually costs \$100–300 and can be paid for by the buyer, seller, lender, or real estate agent. Refer to the Residential Energy Services Network for more information and to determine if there is a HERS/EEM program in your area (see [www.natresnet.org](http://www.natresnet.org)).

***I am interested in whole-system and green design. What should I do?***

Once you are familiar with the basic principles described in this Brief you can start researching the best choices for your budget and needs. For large projects, ask a green architect or green builder for guidance. Find listings for professionals in your area on websites such as [www.greenbuilder.com](http://www.greenbuilder.com). For smaller projects, refer to the resources section at the end of this Brief for ideas, as well as our website: [www.rmi.org](http://www.rmi.org). Before signing on with these professionals, however, satisfy yourself that they understand whole system thinking by questioning them about the concepts discussed in this Brief.

## SUMMARY

This *Home Energy Brief* has introduced the powerful tool of whole system design within the context of the building envelope—introducing the synergies that exist between thermal mass, windows, and other components of passive solar design. Mechanical or energy-intensive options were only considered as supplementary options once the loads were significantly reduced through integrated design. This process of working through whole system design can be applied to most projects. For further advice on how to make the best design and purchase decisions for your building and budget, be sure to refer to the various information resources available (starting from the list below) or ask a green architect or builder for advice. Your investment decisions will be enjoyed today and appreciated by generations to come.

## ADDITIONAL RESOURCES

For a complete and frequently updated free list of resources, download "Green Building Sources" (RMI publication #D03-17) at [www.rmi.org](http://www.rmi.org) in the Library's Buildings & Land section.

**BuildingGreen.com** — Provides a collection of well-researched articles that address the most important green building issues ([www.buildinggreen.com](http://www.buildinggreen.com)).

**GreenHomeBuilding.com** — Contains basic background information on several natural building materials, techniques, and overall holistic living ([www.greenhomebuilding.com](http://www.greenhomebuilding.com)).

**Home Energy Online** — Has links to several publications and articles about all elements of green building drawn from the archives of *Home Energy Magazine* ([www.homeenergy.org](http://www.homeenergy.org)).

**A Primer on Sustainable Building**, Dianna Barnett and William Browning, Snowmass, CO: Rocky Mountain Institute, 1995 (updated 2004). Provides an easy-to-digest overview of sustainable building from proper site selection to building operation.

**Living Homes: Sustainable Architecture and Design**, Suzi McGregor and Nora Trulsson, San Francisco, CA: Chronicle Books, 2001. Description and photographs of homes constructed with adobe, rammed earth, straw bale, and recycled and high-tech materials.

**Good Green Homes**, Jennifer Roberts, Layton, UT: Gibbs Smith Publisher, 2003. A guide to creating beautiful homes that are healthier to live in and easier on the environment.

**Climatic Building Design: Energy-Efficient Building Principles and Practices**, David Watson and Kenneth Labs, Columbus, OH: McGraw-Hill Book Company, 1993. Introduces the art and the science of using the beneficial elements of nature to create environmentally sensitive buildings.

**GreenSpec® Directory: Product Directory with Guideline Specifications** — has information on more than 1,750 green building products in over 250 categories ([www.BuildingGreen.com](http://www.BuildingGreen.com)).

**Environmental Design & Construction** — A bimonthly publication that covers all aspects of environmentally sound building design and construction ([www.edcmag.com](http://www.edcmag.com)).

**Natural Home** — This bi-monthly magazine offers information on earth-friendly dwellings. The premier issue included articles such as "25 Water-Wise Tips," and "The Art of Living Green" ([www.naturalhomemagazine.com](http://www.naturalhomemagazine.com)).

## NOTES

1. EIA (Energy Information Administration), "Residential Energy Consumption Survey 2001," (Washington DC: EIA, 2001), [www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html#total](http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html#total).
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3. El Paso Solar Energy Association, "Passive Solar Design – Thermal Mass," (Undated), [www.txses.org/epsea/mass.html](http://www.txses.org/epsea/mass.html).
4. Lawrence Berkeley National Laboratory, "Cool Roofs," (Berkeley, CA: LBNL, 27 April 2000), <http://eetd.lbl.gov/HeatIsland/CoolRoofs/>.
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6. Joseph Lstiburek, *Builder's Guide*, (Westford, MA: Building Science Corporation, 1998), [www.buildingscience.com](http://www.buildingscience.com).

Contact your local utility or energy office for information on rebates that may be available in your area on the purchase of new energy-efficient appliances. This publication is intended to help you improve the resource efficiency of your home. You should use your best judgment about your home, and seek expert advice when appropriate. Rocky Mountain Institute does not endorse any products mentioned and does not assume any responsibility for the accuracy or completeness of the information in this Brief. Written by Ramola Yardi, Tomakin Archambault, Katherine Wang, and Huston Eubank. © Rocky Mountain Institute 2004.

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