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# Efficient Agricultural Buildings: An Overview

FARM ENERGY SYSTEMS GUIDE

*Abstract: Efficiency-focused building designs reduce the use of materials and energy in building construction and operation. Planning for efficiency can help save money and improve building performance. This publication discusses several ways to improve the efficiency of agricultural buildings and provides further references for implementing those strategies. Topics covered include suiting a building to its site, using natural systems, using renewable energy, conserving energy, and conserving material resources in construction.*

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## Introduction

Efficient buildings can save money and improve comfort while reducing resource consumption. Designers and builders nationwide are creating new buildings that save energy and water, use fewer material resources, and create less waste. Through the U.S. Green Building Council's LEED rating system (1), the federal Energy Star® certification (2), and green building programs in states and communities, the building industry is developing standards that help measure and compare building efficiency. Several awards programs recognize green buildings, and professional organizations provide training for designing and constructing more efficient buildings (3). From architects to contractors to owners, more people are recognizing the benefits of efficient building and implementing efficiency strategies in their building projects. You don't have to participate in any special program to practice and enjoy the benefits of efficient building. Farmers and ranchers can join in the savings by incorporating efficiency in their plans for new buildings or renovations. Whether you are planning housing, barns, equipment sheds, greenhouses, storage spaces, or even specialized facilities for agritourism or product processing, efficiency is an important consideration.

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One of the challenges of efficient building is that there is no single solution that applies in every instance. Depending on where a building is located, what its purpose is, and how long it will be needed, the most efficient design and materials for a particular situation may be very different from the best options for other circumstances. An unheated storage building, a large barn, and a home all have different requirements for comfort, function, and efficiency. In general, the most efficient building is one that is responsive to its local climate, efficiently constructed of locally obtained materials, and requires minimal energy to operate and maintain. This publication discusses some of the strategies for efficient building, such as using natural systems for building comfort, using renewable energy in agricultural buildings, and conserving energy, materials, and water. Sources of detailed information are provided in the **Further Resources** section.

**Efficient building principles**

- Minimize operating energy.
- Incorporate renewable energy wherever possible.
- Optimize material use with the fewest, best materials.
- Design for local conditions; build with local materials.
- Conserve resources in design, construction, and operation.

## *Matching Building to Site*

In many parts of the country, buildings that predate the era of central heating and cooling often employ locally developed adaptations to climate. For example, buildings in extremely snowy regions are characterized by steep roofs, long roof overhangs, and tight construction. In hot climates, shading and ventilation are important design considerations (4). This vernacular architecture—designs and details developed for a specific local climate—has become rarer as relatively inexpensive energy and sophisticated technologies have made it possible to create artificial indoor climates. Yet climate creation comes at a high cost. The most efficient and least costly long-term solution is to design a building that is responsive to the location it will occupy. In some cases, this may require a sophisticated blending of local design wisdom with state-of-the art technology.

One of the first steps in building construction is site selection. Savvy designers recommend careful study of potential sites, to identify how they are affected seasonally by water, wind, and sun (5). Mapping or recording the incidence of these forces over the course of a year can help identify the best site for a building on a particular piece of property. Another important consideration for building is the substrate of the site. Some soil conditions make construction so expensive as to be impractical, while just a slight change in terrain can mark a completely different—and more suitable—soil type. Building on less-stable soil is often possible with specially designed foundations, but the difficulty of such construction can add significantly to the cost. It's best to seek a stable, well-drained soil that can support some type of standard foundation, whether that be pier, slab on grade, conventional poured footings, or a frost-protected shallow foundation.

Once you identify a building site, it's time to review your priorities for the building itself, to come up with the most efficient design for the location and situation.

- How big does the building need to be?
- How can the design work with the features of the site?
- Does the building need to be permanent, or will a temporary structure suit the purpose?
- Does the building need supplemental heating and cooling, or can natural processes maintain comfort?
- What materials are available locally?

**Related ATTRA Publications**

- *Learning More about Wind-powered Electric Systems for Homes, Farms, and Ranches*
- *Anaerobic Digestion of Animal Wastes*
- *Organic Alternatives to Treated Lumber*

# Using Natural Systems

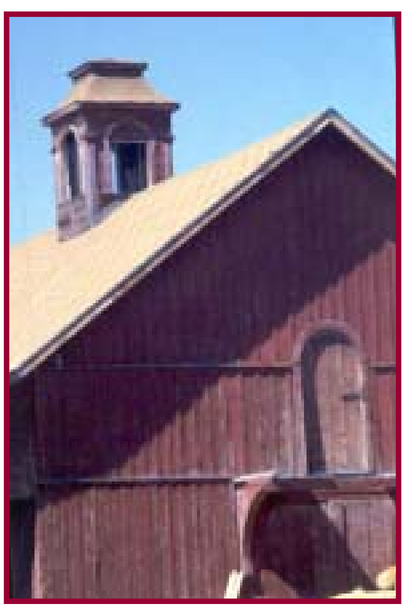
The more energy a building can capture passively from natural forces, the less the owner has to pay to operate it. In temperate climates there may be little challenge in keeping a building comfortable for people or animals without supplementary energy, but in more extreme climates it takes careful planning to put nature's energy to work heating or cooling your building. Fortunately, the savings potential is usually well worth the extra effort.

### Daylighting

Daylighting involves direct use of the sun to light the inside of a building. It may provide the sole light for a building that is used infrequently or only during the day. It can also be used in a self-adjusting or manually adjusted system that maintains a steady level of light by supplementing with artificial light when daylight is insufficient.

Windows are the most familiar way to let in daylight. In many climates, however, inefficient windows lose more heating and cooling energy than they gain in lighting energy (6). Consequently, it's important to budget for the most efficient windows possible and to place them where natural light is most needed and energy loss is held to a minimum. Looking at sun-angle charts for a particular latitude and season can help identify the optimum aspect and height for window placement. (For very detailed information on solar calculation, see the Solar Position and Intensity calculator available from the National Renewable Energy Laboratory at <http://rredc.nrel.gov/solar/codes_algs/solpos/> or consult the passive-solar design software cited below.)

The interior light gained from windows can be increased by beveling the window opening to allow more light to enter the room. This is particularly true for structures with thick walls, where incoming light can otherwise be severely limited by the depth of the opening.



For buildings without windows, for interior rooms, or for spaces in the middle of large open buildings, a skylight may offer the best daylighting option. There are several alternatives available, ranging from fixed or operable clear-glass skylights to diffused-tube skylights to translucent roofing material. Translucent roofing is a realistic option only in the relatively few areas where roof insulation isn't of greater value than the amount of light gained, such as in very temperate climates or in unheated buildings. Meanwhile, clear-glass skylights may actually provide too much lighting in some situations. Glare and overheating of the area directly below the skylight can be problems. Operable skylights can be valuable tools for ventilation as well as lighting, but they are expensive and can cause water damage if improperly installed.

In situations where a lot of light is needed, or where light must penetrate deep into a building, exterior appliances such as light shelves or reflectors can be applied to boost daylight's reach. This type of equipment can not only multiply the effect of daylighting, it can also improve the quality of the light by diffusing and redirecting it. Such appliances can help to improve the energy contribution of windows, in situations where the added investment is justified (7).

For information on daylighting and examples of its application, see the **Further Resources** section.

### Natural ventilation

Operable windows and/or skylights can aid in ventilation and provide cooling, especially in climates where the day and night temperatures differ significantly. Land forms and vegetation can also help to channel breezes for increased ventilation efficiency. In warmer areas, these simple measures may need to be augmented to provide adequate cooling.

One means of providing greater cooling for a building than simply opening the windows is a cooling tower that vents hot air out the top of the building and pulls in cooler air from the lowest level of the structure. The concept is generally familiar to farmers, many of whom have seen it at work in barn cupolas. For greatest efficiency the upper-level vents should be operable, to prevent undesirable heat loss in winter, and incoming air should be drawn from the lowest level through a "stack" design (8). In some desert climates, the effectiveness of cooling towers is increased by drawing incoming cool air over a pool or tank of water, to add evaporative cooling. Introducing moisture to the incoming air can help aid cooling in arid areas, although it doesn't work at all in humid climates.

Another idea that can be adapted from desert architecture is the wind catcher. These air collectors face into the prevailing wind, and funnel moving air into occupied spaces to provide a cooling breeze (9). The effectiveness of a wind catcher obviously depends on available air currents. The **Further Resources** section lists sources of information on natural ventilation strategies.

## Passive solar

In many locations the sun is the cheapest and most reliable heat source. By siting and designing a building for the best capture of solar gain, the owner can reap maximum energy gain from a minimal investment.

The best orientation for passive solar performance places the long axis of a building within 20 degrees of perpendicular to true south. This provides a building with solar gain from its southern exposure, while reducing the potential for overheating that comes from greater western exposure.

For best passive solar performance, the highest concentration of windows should be on the building's southern face, although generally the total window area should not exceed 15% of the building's total floor area. Southern windows provide the best opportunity for solar heat gain in winter. Through careful placement and shading, these windows can capture the heat from a low-angle winter sun, while excluding much of the heat from the summer sun high in the sky. The optimal height of windows from the ground and the size of overhang needed to shade them from the summer sun can be calculated for different latitudes in the United States by using sun-angle tables or software (see the **Further Resources** section). The right amount of window area and the correct configuration of shading can make the difference between a comfortable naturally-heated building and a space that feels like an oven.

In a structure with passive solar heat, capturing heat from the sun is only part of the battle. Storing it to help moderate night-time temperature swings is also a key element in a passive solar design. Storage capacity is provided by thermal mass within the structure. There are many options for providing thermal mass, ranging from special interior walls containing barrels of water to dark-colored stone flooring. When energy-efficient windows are used in conjunction with a thermally efficient and well-sealed building envelope, however, the mass of ordinary flooring and interior walls may be enough to modulate building temperature and help provide for occupant comfort. In northern climates it is critical to include night insulation measures for windows in passive solar designs. Otherwise, in climates with over 6000 heating degree days—the cumulative number of degrees in a year by which the mean temperature falls below 65°F.—windows that are supposed to provide heat gain can actually cause a net heat loss. (Maps showing heating degree days and cooling degree days for the United States are available from The National Climatic Data Center, viewable online at <http://lwf.ncdc.noaa.gov/oa/documentlibrary/clim81supp3/clim81.html>.)

There are many good references on passive solar design details, some of which are listed in the **Further Resources** section at the end of this publication. There are also many experienced solar design professionals who can be of service.

## Shading

Often in agricultural buildings there is less concern with capturing enough solar heat than with preventing overheating. In warm climates and seasonally used buildings, preventing heat gain may be the more important strategy, and shading is a key means of avoiding unwanted heat buildup.

Shade can be provided by vegetation, constructions, or a combination of the two. Quick-growing deciduous trees are often chosen because they can provide summer shade for a structure, yet when their leaves have fallen they allow the sun to reach the building and boost solar gain during the winter. Trellises can also provide window shading, especially when covered with vines or other vegetation during the growing season. Awnings and slatted above-window shades are other means of protecting windows from heat gain during the months when the sun is high in the sky. Information on shading strategies is included in the **Further Resources** section.

### Earth berms

Another natural force that can significantly contribute to reducing energy use in buildings is the temperature-moderating thermal mass of the earth itself. When a building is set into a slope or simply set deeper than usual into the ground of a level site, the surrounding earth helps shelter the structure from heat loss or gain. The surrounding earth acts as a thermal reservoir, moderating the indoor temperature of the building as the outside air temperature changes. There are two important considerations when earth-berming buildings: the structure must be designed to support the pressure of the surrounding earth, and the building system must be protected from moisture in the soil. It is also worth checking the average annual ground temperature of the building site, to assess whether the difference between air and soil temperature provides a bermed building with a significant thermal advantage.

## Renewable Energy for Agricultural Buildings

### Photovoltaics

Solar electric energy systems, or photovoltaics, can supply power for any number of remote agricultural applications, including pumping and electric fencing. See the related ATTRA publications *Solar-powered Livestock Watering Systems* and *Freeze Protection for Solar-powered Livestock Watering Systems*. Photovoltaics can also be used to generate electricity for lighting buildings or operating equipment and appliances. There are several options for solar electric systems. They can be designed to tie into the power grid as utilities allow, feeding any excess power back into the grid to run the meter backwards, and drawing power from the grid when they aren't generating. At remote sites, photovoltaics team with storage batteries to provide a reliable power supply at any time. The solar panels can be mounted on a building rooftop that provides the right aspect and angle, or mounted in a freestanding array.

One recent development in solar panel technology may be especially relevant to agricultural buildings. Manufacturers are now offering several roofing products that combine roofing material and photovoltaic electricity-generating capacity in a single unit. Both slate-styleand standing-seam-style panels are available from Uni-Solar products <http://www.uni-solar.com/bipv_resid.html>. Although these products are expensive, they can be economical for new roofs at sites that are far from the power grid. When the cost of roofing and the cost of power generation are both weighed in the balance, *building-integrated photovoltaics* (BIPV) can come out the winner for some locations (10).

### Solar Hot Water

Solar water-heating systems range from the simple and homemade to the complex and expensive. Generally they serve to preheat water before it reaches a conventional water heater, minimizing the energy that the water heater then uses to boost the water to its final temperature. In some climates and seasons, the solar water heater may bring the water to full temperature without supplementary heating. The use of most solar water-heating systems is seasonal in cold climates, where systems must be drained during winter to prevent water in the system from freez-

ing. More complex systems that heat an anti-freeze liquid and then transfer that heat to water inside a heated space can be used throughout the year (11). For seasonally occupied or warm-climate agricultural buildings, even a simple solar hot-water system can offer energy savings at minimal cost. See the **Further Resources** section for additional sources of information.

### Other Renewable Power Sources for Buildings

In addition to the sun, many other renewable power sources exist, and a number of them may be particularly well-suited to rural sites. Small-scale wind power, biomass generation, micro-hydro power, and methane digesters are all potential sources of renewable power for agricultural buildings. More information is available in the ATTRA publications *Learning More about Wind-powered Electric Systems for Homes, Farms, and Ranches* and *Anaerobic Digestion of Animal Wastes*.

## Energy Conservation in Agricultural Buildings

Before investing in renewable energy generation systems for any building, it pays to make sure that the building is as energy efficient as possible. Improving energy efficiency is generally a minimal investment compared to the expense of solar panels or a wind generator. The level of energy efficiency appropriate for a given building differs according to its use characteristics. If a building is rarely occupied or heated, energy efficiency investments won't be as cost effective. For occupied buildings, however, the payback time for most investments in energy efficiency is relatively short, making conservation measures an easy choice for building owners (12).

### Insulation

Insulation is the first line of defense for heated or cooled buildings. Insulation increases the resistance of the building to heat flow, helping to keep heated or cooled air from escaping. Insulation also provides sound-deadening properties. Today the most common types of building insulation are fiberglass, cellulose, or petroleum-based foam, though many specialty types of insulation are commercially available, including cementitious foam, straw, and mineral fiber. Historically, a wide range of materials, including cattle hair and shaved wood fiber, were used for insulation. Important concerns for any insulation material are that it be fire and insect resistant, as well as thermally efficient. Labels on commercially available insulation materials generally provide evidence of compliance with recognized safety standards. Documentation for alternative insulation materials may be more difficult to obtain or assess.

Recommended insulation levels differ by climate. While information on residential insulation is readily available, information for other types of buildings may be more difficult to come by. However, there are several building-energy calculators that can be used to extrapolate energy performance, and many utility companies offer energy audits for both their residential and commercial customers. These audits can be a good way to identify potential for improvement, and participating in audit programs may qualify the owner for rebates or technical assistance in undertaking energy improvements.

As amazing as insulation is, it can't stand alone as a building's thermal defense. It's important to team insulation with other energy-efficient components to achieve good *system* performance, the same way you combine a hat, coat, and boots to outfit yourself for winter weather. Once basic levels of insulation have been achieved in the walls, roof, and floor, it's time to turn attention to preventing energy loss from the other parts of the building.

### Windows/doors

It's relatively easy to add insulation to walls, roofs, and even floors, but when it comes to doors and windows, high prices often frighten consumers away from the most energy-efficient options. However, eliminating leaky, inefficient doors and windows can significantly improve a building's energy performance and comfort. It's essentially like getting rid of a large hole in the wall, since many doors and windows have extremely low thermal resistance compared to solid walls and roofs. Investing in the most energy-efficient doors and windows you can afford is a good choice for your building.

Although there are state-of-the-art "superwindows" available that are nearly as insulative as most walls, they are very expensive and probably aren't warranted, except for very specialized applications where exceptional thermal performance is necessary (e.g., coolers). In most cases a double-pane window with low-e coating will provide adequate energy performance. The energy rating of windows is higher when they have an argon or krypton gas fill between the panes, but there is some controversy about how rapidly the gas fill escapes when the window is exposed to the low air pressure of high altitudes (13). Building owners at high altitudes may decide not to opt for gas-filled windows, given the uncertainty of their long-term performance at altitude.

### Air sealing

Once a building has efficient walls, roof, windows, and doors, what's left to improve its energy performance? Studies show that most buildings have air leaks that provide escape routes for conditioned (heated and cooled) air (14). Blocking air leaks with gaskets, caulk, or expanding foam can move a building's energy performance up a notch. The most common sources of air leaks include the sill plate; window and door openings; and wall, floor, and ceiling penetrations such as electrical boxes, plumbing lines, and recessed light fixtures.

Ducts should also be sealed, particularly if they pass through an unconditioned airspace. Making sure that all of these areas are detailed and sealed eliminates most major air leaks.

## HVAC and Other Systems

Insulation, efficient windows and doors, and air sealing all contribute to making the building envelope energy efficient, but mechanical systems also have a role to play. Functions that aren't furnished by the natural systems described above will need to be provided by mechanical and electrical systems and appliances. Choosing efficient systems for heating, cooling, ventilation, and lighting helps to cut energy costs and minimize pollution, and can help support the use of renewable energy on site by cutting loads. Useful guidelines are available for evaluating the relative efficiency of many appliances and of equipment like furnaces and light fixtures. One standard is the Energy Star certification, which applies to a wide range of products. Qualified products and their manufacturers are listed on the Energy Star website <http://www.energystar.gov>. Another directory of energy-efficient products, which is updated regularly, is the *Consumer Guide to Home Energy Savings* from the American Council for an Energy-Efficient Economy, and its companion listing, *The Most Energy-Efficient Appliances*, available through <http://www.aceee.org/consumerguide/index.htm>. These inexpensive references can be useful aids in finding and selecting energy-efficient equipment.

In buildings where lights are used infrequently, standard incandescent lighting will suffice, but where lights are used for more than a few hours each day, fluorescent lighting is more energy efficient. Either fluorescent tubes or compact fluorescent lighting can be used, depending on the amount of light needed. In situations where lighting is used in temperatures below freezing, it's important to select a ballast that is rated for low-temperature conditions. The most efficient choice for lighting large areas is a high-intensity discharge lamp, typically a metal halide lamp.

## *Resource Conservation in Agricultural Building Construction*

There are many different strategies that can help produce efficient agricultural buildings. With many types of buildings and many different materials, the possibilities are almost endless. A few guidelines can help the builder navigate the available choices.

### Efficient systems

One of the basic tenets of resource-efficient construction is to employ building systems that use minimal material. Engineered and pre-assembled building components can use material very efficiently, and they also help to eliminate waste at the job site and speed construction. Although engineered systems may be more expensive than conventional frame construction, there are situations where assured performance, quick assembly, and minimal on-site labor are exactly what the owner needs, and can offset any added cost.

Pre-assembled panels may be conventional wood-framed wall panels that are delivered to the site with insulation already installed, or *structural insulated panels* that can be used for walls, floors, or roofs. Structural insulated panels sandwich a layer of foam between two faces, usually made of oriented strand board. They offer excellent energy performance, because they greatly reduce the number of thermal bridges—uninterrupted paths of heat loss—across the wall from inside to outside. They also provide good sound attenuation, and an experienced crew can assemble them quickly. An inexperienced crew will take longer to assemble the panels, and may be reluctant to work with them at all, so it's important to coordinate the building crew with the material that's going to be used.

Trusses for roofs are another efficient component for buildings. Using roof trusses instead of building a roof system on-site can save material and labor costs, although setting trusses often requires a crane.

A comparatively efficient building system that has recently grown in popularity is *insulating concrete forms*. These permanent foam forms provide an insulative framework into which reinforced concrete is poured to form below- or above-grade walls. Foam forms come in either interlocking blocks or large panels, depending on the particular system. Although some systems claim to be owner-friendly enough for beginners to assemble, many companies require a certified applicator on site, to help make sure that the forms are properly braced and leveled, and that the concrete pour goes smoothly. Insulating concrete form systems are more expensive than wood framing, but they provide an extremely durable building that offers thermal performance, sound attenuation, and fire resistance.

Turning to foundations, an especially resource-efficient system that reduces both excavation costs and cement use is the frost-protected shallow foundation. This system, long in use in Scandinavia and used by a few builders in the United States for decades, relies on insulation around the foundation perimeter to stabilize a heated building, rather than extending footings below the frost line. Information on designing and installing a frost-protected shallow foundation is available from the National Association of Home Builders via their website <http://www.nahb.com/builders/frost.htm>.

## Recycled materials

Another approach to resource-efficient building is to use recycled materials. These are materials that have been removed from the waste stream and reprocessed to make another product. Although recycled products are seldom less expensive than conventional materials, they do divert waste and conserve resources and energy in their manufacture. Also, some recycled materials have performance attributes that make them the best choice for a particular application.

Cellulose insulation is typically made from recycled newsprint, treated with borate additives to provide fire and insect resistance. Cellulose can be blown loose into ceilings, wet-sprayed into wall cavities, or mixed with adhesives and sprayed onto the interior of industrial buildings. Cellulose insulation is renowned for its ability to prevent air infiltration in addition to furnishing thermal resistance. There are many cellulose insulation manufacturers located in rural areas. These manufacturers often rely on local newspaper recycling to provide their raw material.

In addition, there are many recycled plastic products used in building construction for many different applications. Recycled plastic panels are popular in some livestock barns because they are easier to clean than wooden panels. Center Industries (880 1st Ave. NW, Sioux Center, IA 51250, 712-722-4049, http://www.center-industries.com/Window.html) makes windows with a recycled plastic frame specifically for agricultural use. Meanwhile, recycled plastic lumber manufacturers offer a variety of posts and dimensional products useful for farm applications, including fencing, boardwalks, bridge decks, retaining walls, and raised beds. See the ATTRA publication *Organic Alternatives to Treated Lumber* for more information on recycled plastic lumber products. The American Plastics Council's Recycled Plastic Products Directory includes a section of products for Farming and Agriculture, online at <http://sourcebook.plasticsresource.com/category.asp?/Farming+&+Agriculture>.

### Reused building materials

Unlike recycled products, which are reprocessed into a new form, reused products are salvaged and reapplied in the same form. Most farmers and ranchers are old hands at reusing building materials time and again, in one application after another, and in remodeling existing buildings to serve new uses.

There is a market for vintage buildings, including agricultural buildings, in reasonably good condition. Even if the whole building is not salvageable for resale, individual components may be. A number of companies specialize in remilling old beams to make flooring, or selling antique beams intact for reuse. If a farm building project involves demolition of an existing structure, it may be worth checking with a professional building-salvage operation to see whether there is market value for the materials.

Conversely, it may be worth considering reused materials for new farm structures. The possibilities are endless, ranging from old windows for cold frames or greenhouses to salvaged and reused metal roofing (15). (Some landowners have even accepted clean gypsum drywall scrap from building contractors to use as a weed suppressant and soil amendment in orchards and fields. Although the effects of gypsum drywall waste as a soil amendment have been studied in controlled settings, on a few crops, widespread field application experiences are still lacking (16).)

There are also important cautions to observe in reusing some types of building materials. Old paint on wood is likely to contain lead, so it's important to consider how this wood can be safely handled and where it can be applied or disposed of properly. Other salvaged wood may be treated with preservatives that are not desirable for residential or organic agricultural applications. Also, note that wood that is reused for structural uses in residences or commercial buildings will need to be regraded by a certified lumber grader in most jurisdictions.

Finally, beware of asbestos contamination in used building materials. Asbestos fibers as used in insulation are a hazardous material because they can become airborne and be breathed in. The removal and handling of this type of asbestos is regulated by law (17). Non-friable forms of asbestos, which are less apt to become airborne because they are bound in composite materials, may appear in unexpected building materials, such as old fiber-cement siding, floor tiles, or sheet flooring. Although not classified as hazardous materials, these asbestos-containing materials are not desirable for reuse.

### Alternative technologies

In much of the world, building technologies that we might consider alternative in the United States are widely accepted and practiced. Some of these traditional material technologies may be viable and effective options for agricultural buildings in the United States, providing they are adapted to meet safety requirements such as fire and seismic codes.

The majority of buildings on Earth are actually built of earth. Earth is obviously a widely available, low-cost building material, although it has some drawbacks in its high maintenance requirements and seismic instability, as well as its comparatively low insulation value. In regions of the world where earthen building is commonplace, there is some concern about soil depletion that could have a negative impact on agriculture, but this seems unlikely in the United States. By adapting ancient technologies, today's earth builders are overcoming many of the disadvantages associated with earthen construction and making earth a relevant and useful building material for the present day.

Typically massive and thick, earthen walls have good thermal performance because their mass slows the rate at which the temperature inside the building changes. In milder climates, with cool nights and warm days, this thermal mass factor alone may be adequate to maintain a comfortable temperature. Designs with thick walls require special considerations, since thick walls reduce usable interior space compared to the building's footprint, and can make door and window installation challenging, as well as complicating daylighting.

Earthen building systems include traditional adobe block and rammed earth, and systems that mix earth and fiber. Modern adaptations of these techniques include equipment that fabricates earth blocks mechanically at the building site and Pneumatically Impacted Stabilized Earth (PISE) that is sprayed onto walls with a hose at high pressure. To help earthen buildings better withstand the weather, systems have been invented that combine earth with asphalt or gypsum (18). There is even a system developed by architect Nader Khalili of the Cal-Earth Institute <http://www.calearth.org> that uses bags of sand bonded with barbed wire to build domed structures. Modern earth-building can make use of equipment that reduces labor requirements, additives that improve weather resistance, and engineered support structures that enhance seismic performance. For examples of modern earth-building in the United States, see the **Further Resources** section.

Earth buildings are worth considering for some agricultural applications, particularly in mild climates with good building soil. The best building soil contains coarse sand or aggregate, fine sand, silt, and clay. Although the proportions of these constituents can vary somewhat, the ideal building soil mix based on averages has been offered as 23% coarse sand or aggregate, 30% fine sand, 32% silt, and 15% clay (19). Soils that differ substantially from this composition will most likely require additives for successful earth building. A careful assessment of the soil at the site and local sources of soil amendments can help determine the suitability of a particular location for an earthen building. A common way to roughly assess soil composition is the "jar test" in which a soil sample is placed in a glass jar, covered with water, vigorously shaken, and then allowed to settle until the water is clear. Coarse aggregates will settle in a band at the bottom, sand and silt in the middle, and clay on top.

Farmers may be particularly interested in building technologies based on agricultural fiber. There are several manufactured building materials made from straw, including ceiling panels, a variant of the structural insulated panel, and a number of medium-density fiberboards. The fiberboard products, which are commonly used for flooring underlayment, cabinets, and shelving, can also be made from other agricultural fibers such as bagasse, rice hulls, and hemp. Agricultural fiberboard manufacture is a capital-intensive and expensive process, and many manufacturers, including some farmer-owned cooperatives, have struggled to establish themselves in the marketplace. In areas where strawboard manufacturing facilities are able to operate successfully, they provide a strong market for straw, as well as a useful building product derived from agricultural fiber.

Another building technology based on agricultural fiber, although in a less-processed form, is straw-bale building. Originating in Nebraska more than 70 years ago, the building system uses a running bond of straw bales as walls and has enjoyed a revival during the past ten years. Straw bales have been used to build homes in at least 38 states, as well as countless non-residential buildings ranging from chicken coops and storage sheds to camp dining halls. Straw-bale buildings may be either load-bearing, in which the bale walls support their own weight and the weight of the roof, or non-load-bearing, in which a conventional wood or steel structural framework is infilled with bales that provide the wall insulation. Straw-bale residences are often finished with a cementitious stucco, although it is possible to finish interiors with gypsum wallboard and exteriors with different siding options. In some agricultural buildings owners have left bale walls unfinished, recognizing that this leaves them vulnerable to damage from livestock and weather.

Some farmers have used bales to construct winter livestock shelters, and intentionally left the bales exposed to serve as emergency food for the animals. In these applications the roof would need to be supported by a separate framework, and the walls themselves well supported, to prevent their collapse. The weathered bales are then removed in the spring, allowing the roof to serve as a shade shelter during summer.

Straw-bale construction's recent rise in popularity can be partly attributed to its intuitive, easily grasped assembly process. Many owners have reduced building costs by investing their own sweat equity or employing work parties of unskilled labor. However, it is important to recognize that the wall system is typically less than 15% of a building's cost, so the savings provided by a homegrown wall system are limited. Also note that subcontractors (i.e., electrical, cabinetry, drywall, etc.) may charge more when working with an unfamiliar construction system that forces them to modify their standard installation practices.

When straw-bale walls are well protected from moisture by a good foundation, a sound roof, and a good exterior covering, they offer a durable structure with good thermal performance. Few buildings can be as resource efficient, or as locally derived, as a straw bale building.

## Other Efficiency Strategies for Agricultural Buildings

Energy and material are the primary resources used in buildings. When the use of these resources during construction and operation is reduced, the cost of a building and its impact on the environment are both lessened. There are additional opportunities to make buildings more efficient, as well.

Installing water-conserving fixtures and appliances usually saves costs in building operation, for both water and the energy needed to heat and move it. There are also several options for treating used water, ranging from complex closed-loop treatment systems based on the ecological structure of a marsh (20) to less-involved constructed wetlands (21) or sand filters. In some jurisdictions greywater (as opposed to blackwater, or sewage) can be stored and used for irrigation of trees or nonfood vegetation. (See the Greywater website at <http://www.greywater.com/> for additional information.)

Buildings can also play a role in capturing rainwater for either drinking or irrigation. Rooftop water-catchment systems vary in complexity from simple rain barrels placed at the bottom of gutters to systems that collect runoff that is stored in a cistern and treated for drinking. For more information on designing and installing rainwater collection systems, see the **Further Resources** section.

## Summary

Designing and constructing agricultural buildings with efficiency in mind saves money, energy, and resources. Employing strategies such as natural ventilation, passive solar heating, and daylighting are some of the ways that building owners can put natural systems to work for them. By combining energy efficiency and renewable energy options, agricultural buildings can move toward energy independence. And finally, agricultural buildings can be built from a range of resource-efficient materials geared to meet almost any need, whether that be for a temporary structure or a high-performance specialty building.

## References

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1015 18th St. NW, Suite 805
Washington, DC 20036
(202) 82-USGBC
info@usgbc.org
<http://www.usgbc.org>

2) Energy Star
(888) STAR YES
http://www.energystar.gov

3) National Association of Home Builders Research Center
(National Green Building Conference, Green Building Awards and Energy Value Housing Awards)
400 Prince George's Boulevard
Upper Marlboro, MD 20774
(301) 249-4000
(800) 638-8556
<http://www.nahbrc.org>

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125 La Posta Road
8018 NDCBU
Taos, New Mexico 87571
(505) 751-4448
<http://www.livingmachines.com>

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## Further Resources

**Builder's Guide.** 2000. By Joseph Lstiburek. Building Science Corporation, Westford, MA.

*The Builder's Guide series from the Energy and Environmental Building Association presents a systems approach to designing and building healthy, comfortable, durable, energy efficient, and environmentally responsible homes. Separate versions are available for each climate type: Cold, Mixed, Hot/Humid and Hot/Dry. $40 each from EEBA, <http://www.eeba.org>.*

**Climatic Building Design**. 1983. By Donald Watson and Kenneth Labs. McGraw Hill Book Company, New York, NY. 288 p.

*This comprehensive reference presents principles of climatic design related to ventilation, cooling, solar gain, and more, as well as practices and supplemental climatic data.*

**Serious Straw Bale.** 2000. By Paul Lacinski and Michel Bergeron. Chelsea Green Publishing, White River Junction, VT. 371 p.

*Billed as "A Home Construction Guide for All Climates," this reference addresses different elements of straw-bale structures, as well as finish options, moisture studies, and experimental constructions.*

**Sun, Wind & Light: Architectural Design Strategies**, second edition. 2001. By G.Z. Brown and Mark DeKay. John Wiley and Sons, New York, NY. 382 p.

*An in-depth technical reference addressing analysis techniques, design strategies, and strategies for supplementing passive systems.*

## Web-based Resources

**Adobe International**
http://www.adobe-block.com/

*Portable equipment for mechanically manufacturing earthen blocks at the building site.*

**Daylighting Collaborative**
http://www.daylighting.org

*Information on daylighting buildings, including benefits of daylighting and an extensive how-to section with interactive online worksheets. Case-study buildings are also featured.*

**Design Recommendations for Natural Ventilation Systems**
http://www.ae.iastate.edu/design_recommendations.htm

*An electronic publication on natural ventilation for livestock facilities from the Department of Agricultural and Biosystems Engineering at Iowa State University that provides guidelines for placing buildings and sizing ventilation openings.*

**Designing with the Pilkington Sun Angle Calculator**
http://www.sbse.org/resources/sac/pnasac.htm#thesac

*Detailed online information on how sun angle calculations are performed and applied in building design. Includes discussions of solar orientation, designing overhangs, daylighting, and solar heat gain.*

**Landscaping for Energy Efficiency**
http://www.eren.doe.gov/erec/factsheets/landscape.pdf

*A factsheet available as a PDF file from the Energy Efficiency and Renewable Energy Clearinghouse on using trees and other landscaping to help mitigate hot and cool temperatures in different climates and micro-climates.*

**Lawrence Berkeley National Laboratory—Windows & Daylighting Group**
http://windows.lbl.gov/

*Information on daylighting products and controls.*

**NCAT Center for Resourceful Building Technology**
http://www.crbt.ncat.org

*Information on resource conservation in buildings, including a searchable database of manufacturers of efficient systems, recycled and reused building materials, as well as alternative building technologies.*

**Passive Solar Design for the Home**
http://www.eren.doe.gov/erec/factsheets/passive_solar.html

*A fact sheet from the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy that explains the basic principles of how passive solar strategies can help heat and cool homes.*

**Rainwater Harvesting Wizard**
http://www.captured-rainwater.com/

*A fee-based information website where consultation on rainwater harvesting system design and equipment is provided to answer online inquiries.*

**Rammed Earth Works**
http://www.rammedearthworks.com/

*Founded by David Easton, this is a leading company in the research and development of modern earth construction technologies, including rammed earth and variations such as PISE.*

**Solar Water Heating**
http://www.eren.doe.gov/erec/factsheets/solrwatr.html

*A basic factsheet on residential solar water-heating technology, from the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.*

**SunAngle calculator**
http://www.susdesign.com/sunangle/

*Online shareware that can be used to calculate optimal angles for solar design, for a fee of $10 for individuals, or $25 for professionals.*

**Texas Water Development Board's page on Rainwater Harvesting**
http://www.twdb.state.tx.us/assistance/conservation/Rain.htm

*Offers the PDF version of the Texas Guide to Rainwater Harvesting and a list of rainwater catchment systems, services, and equipment providers.*

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