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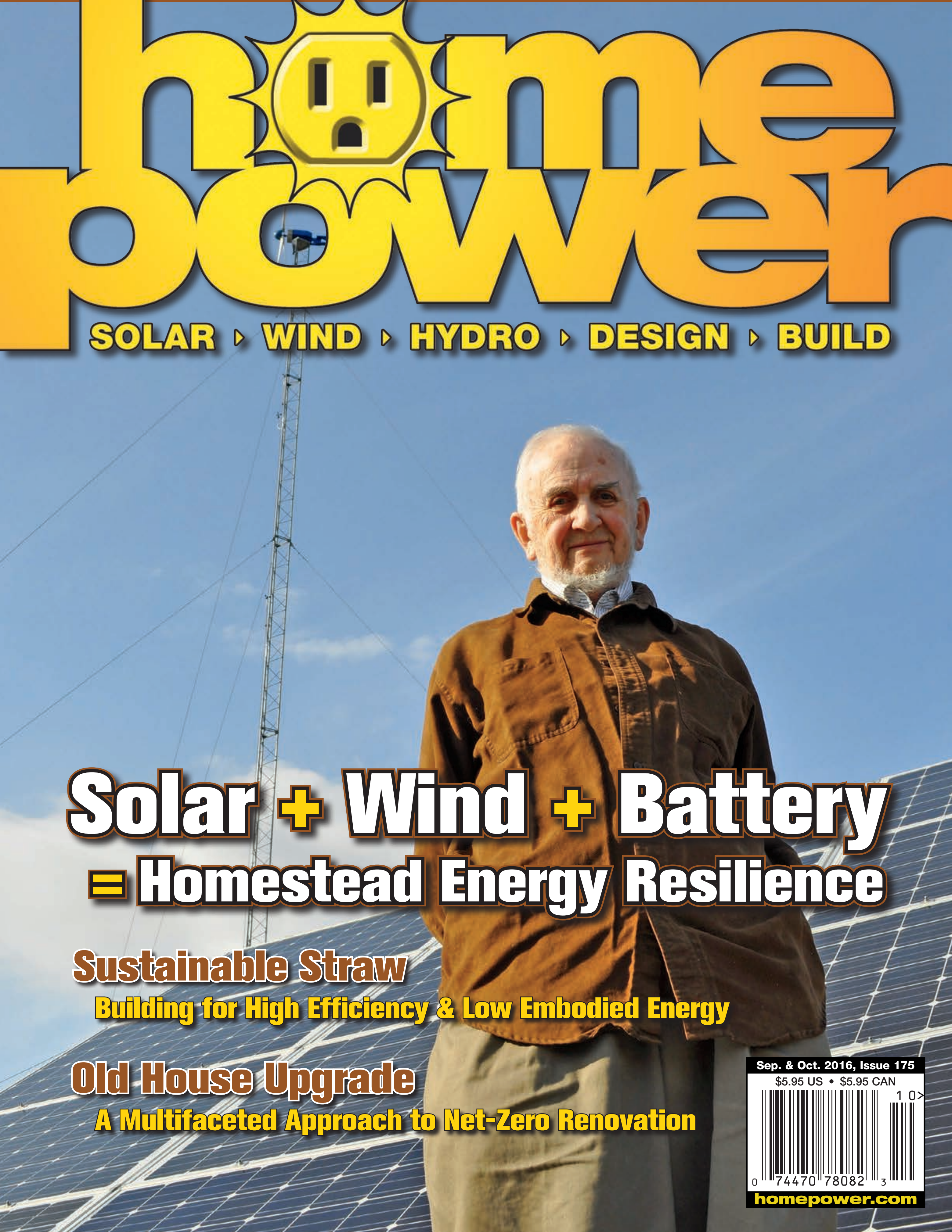

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Sustainable Straw

Building for High Efficiency & Low Embodied Energy

Old House Upgrade

A Multifaceted Approach to Net-Zero Renovation

Sep. & Oct. 2016, Issue 175
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contributors

this issue's experts

Home Power Managing Editor **Claire Anderson** lives in a passive solar, (almost) net-zero-energy home she and her husband designed. She and her family are developing their 4.6-acre homestead to incorporate more resilience in their energy, food, and water systems. Chickens were new additions this spring.

Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.

Brent Summerville is a Professional Engineer in North Carolina and president of his engineering firm, Summerville Wind & Sun. He started his career in graduate school at Appalachian State University (ASU), has worked in the wind industry for about decade, and is now teaching in the Sustainable Technology program at ASU.

William Bassett is Professor Emeritus in the Department of Earth and Atmospheric Sciences (EAS) at Cornell University, where he taught courses in mineralogy and crystallography. Since his retirement in 2000, he continues to serve Cornell as Curator of Geologic Collections.

Jim Reiland of Many Hands Builders is an Oregon general contractor and CASBA Advisory Board member.

Rebecca Tasker is a general contractor and co-owner of Simple Construct, a design-build construction company specializing in straw bale building and other forms of efficient, low-carbon building. Simple Construct has been involved in the construction of more than 12 straw bale buildings in San Diego.

Massey Burke is a San Francisco Bay Area natural materials specialist who works with the California Straw Building Association, The Ecological Building Network, and other organizations compiling technical information to support the use of natural materials in construction. She is also an active natural builder.

Justine Sanchez is *Home Power*'s principal technical editor. She's held NABCEP PV installer certification and is certified by IREC as a Master Trainer in Photovoltaics. An instructor with Solar Energy International since 1998, Justine leads PV design courses. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

Art Weaver has lived and worked in upstate New York for 17 years. A scientist by disposition and training, his current project is Weaver Wind Energy—whose mission is to create the world's most reliable small wind turbines. Art believes that catastrophes of climate change will focus our attention for generations to come.

Author and educator **Dan Fink** has lived off the grid in the Northern Colorado mountains since 1991, 11 miles from the nearest power pole or phone line. He started installing off-grid systems in 1994, and is an IREC Certified Instructor for both PV and small wind systems. His company, Buckville Energy Consulting, is an accredited continuing education provider for NABCEP, IREC, and ISPQ.

Formerly a builder, **Nehemiah Stone** is now the chief building official and special advisor to the Chair of the California Energy Commission. He also is a consultant with Stone Energy Associates, and a member of the CASBA advisory board.

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people-power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, and lecturing, teaching, and consulting with homeowners.

Brian Mehalic is a NABCEP-certified PV professional, with experience designing, installing, servicing, and inspecting all types and sizes of PV systems. He also is a curriculum developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.

Contact Our Contributors

Home Power works with a wide array of subject-matter experts and contributors. To get a message to one of them, locate their profile page in our Experts Directory at **homepower.com/experts**, then click on the Contact link.

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Straw Bales & Solar Energy

A Natural Partnership

by Rebecca Tasker

Building with straw can completely change how we use resources in construction, how we heat and cool our homes, and how we relate to the buildings we inhabit.

Straw bale building has unique and important answers to a few broad questions that help us get to the heart of sustainable building:

- What materials will have the lowest environmental impacts during and after construction?
- What materials and techniques will result in the most effective building—one that is durable, efficient, safe, healthy, and comfortable?
- What materials can be used together to make a building appealing over generations because of its resonant beauty, sense of solid shelter, and peaceful comfort?

Straw bale walls can be part of a whole-house plan to achieve high energy efficiency while keeping embodied energy low.

Jim Reiland

Low-Impact Building

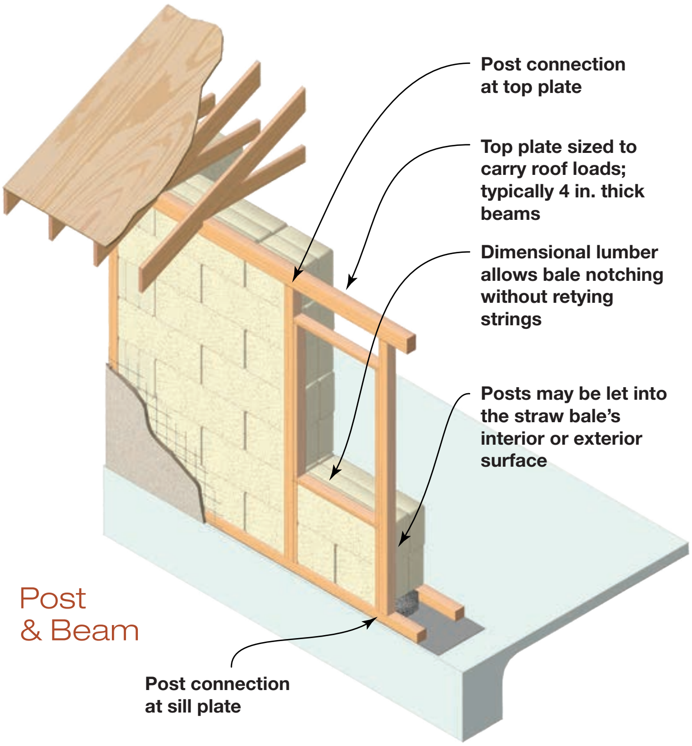
The straw in bales is left over from grain harvesting. Crops aren't grown just to make straw bales: the plants are being grown for rice, wheat, barley, or oats. Once the grain is harvested, the stalks are bundled together into bales.

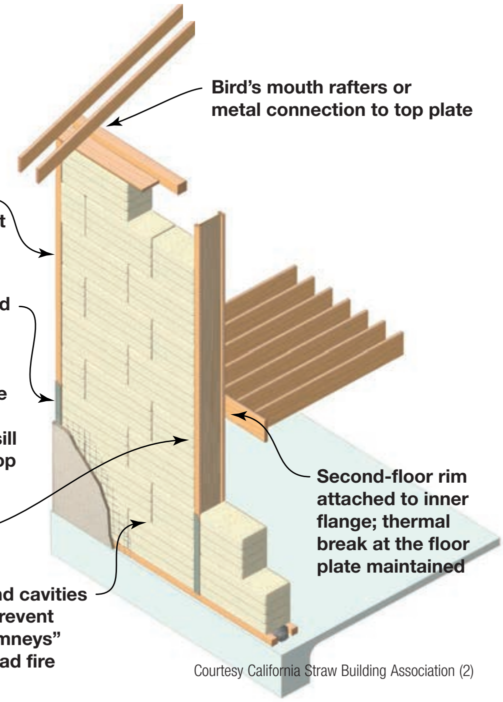
Straw is an abundant agricultural by-product with few uses, and using straw bales as a building material is a great example of upcycling. Unlike wood, straw is an annual crop and can often be sourced locally—frequently from less than 100 miles from a building site. That results in a small carbon footprint: other than the energy it takes to bale the leftover stalks and then deliver that bale to your job site, all of the other resources needed to produce that bale were used for the production of food.

The California Straw Building Association (CASBA) is currently studying how much carbon a straw bale wall sequesters. Plants draw carbon out of the air as they grow and lock it up, releasing it only when they decompose (or burn, which is what happens to many grain fields when the straw is not upcycled). By keeping the straw in the wall, the carbon is not released into the atmosphere (see "Carbon Sequestration" sidebar).

Plastered straw bales replace the insulation and drywall, and often the paint. They can reduce the amount of lumber needed for framing, and may even be part of the structure. Leftover straw can be used as fiber in the plaster, or used onsite as mulch without further processing. And at the end of a long life in a straw bale building, a straw bale is biodegradable.

Natural plasters used with straw bale construction also have lower impact than most wall finishes (such as cement stucco exterior or painted drywall interior), especially clay plaster. Clay is another abundant material, and can be found almost everywhere. Unlike cement—which uses a huge amount of energy during processing—clay requires little processing, so it has very low embodied energy.





Courtesy California Straw Building Association (2)

Straw Bale Walls

Bales are used flat or on edge. The terminology is simple, yet surprisingly hard to describe. "Laid flat" means that the bale is placed on its wider side so the bundled straws are horizontal and the strings that bind the bale face up and down. "On-edge" means that the bale is placed on its narrower edge, with the strings facing in and out, and the straws vertical.

In a load-bearing straw bale house, the bales are laid flat and stacked in a running bond. The combination of bales and their plaster skin resists shear forces. This building technique is well-suited for small buildings in low seismic areas with a reliably long period of dry weather, as the walls are exposed until the roof is on.

More commonly, straw bales are used to infill a post-and-beam wall system, usually made of 4-by dimensional lumber. The bales are again laid flat, notched around the posts, and stacked in a running bond.

In a post-and-beam system that utilizes I-joists as posts, the bales are laid on-edge between the I-joists, with no notching needed. Post-and-beam systems have the advantages of being more familiar to building code officials, having a roof overhead to protect the walls from moisture, and having more shear-wall options.

All straw bale walls need to sit on a double-sill plate or curb to protect against ground moisture. At the top of a load-bearing wall, the roof loads are transferred to the wall via a roof bearing assembly, which could be a wall-width box beam, or a 4-by top plate.

In a post-and-beam structure, bales are notched around the structural uprights, preventing thermal bridging.

Jim Reiland (2)

In an I-joist structure, bales are fit between the joists, which reduces thermal bridging compared to a conventionally framed structure.

Jim Reiland

Left: A bale wall will rest on a raised and insulated double sill.

Rebecca Tasker

Right: Author and builder Rebecca Tasker (center) helps homeowners ceremonially set the first bale.

When tracking the energy a building consumes, we can't overlook the energy that's consumed during the mining and manufacturing processes for the building materials. This embodied energy can greatly exceed a building's operating energy. In their presentation, "The Carbon Elephants in the Room," builders Chris Magwood and Jacob Deva Racusin compare the energy requirements and carbon emissions of embodied versus 35-year operational data for four different houses in two different climates. While operational energy use has been reduced greatly in high-performance homes, if they are constructed with conventional materials (like polyurethane foam insulation), their embodied energy can still be high. They found that the carbon embodied in the materials used to build such a home was greater than half of the home's 35-year operational carbon emissions. Furthermore, compared to a high-performance home made of low embodied-energy (EE) materials (such as straw), the embodied carbon of the conventional home was higher than the *combined* 35-year operational carbon and the embodied carbon of a low EE high-performance home.

To make the best dent in total energy use and carbon emissions, we need to reduce both operational and embodied energy. The building industry is beginning to pay attention to embodied energy and carbon emissions through metrics like the Living Building Challenge and LEEDv4. We're realizing that the energy meter shouldn't start running after the building is built—the energy that went into making the building matters, too.

Carbon Sequestration with Straw

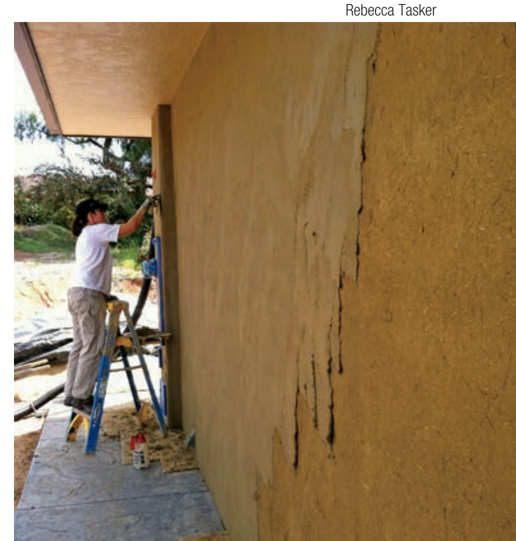
Until recently, the prevailing view for high-performance building has been to choose materials primarily to support performance, without much consideration for the materials' embodied energy and carbon footprint. But accord is growing within the green building community that the embodied carbon emissions of construction materials—how much carbon dioxide is emitted in the manufacture and transport of the materials—is becoming critical to making a truly greener home.

The carbon emissions (as well as other pollutants) associated with various building materials—especially manufactured materials—have a large impact. In contrast, natural, organic, or biomass-based materials are usually net carbon sinks when used in a building.

Calculating the carbon sequestration capacity of straw bale building depends upon several variables: the type of straw (wheat, rice, oat, etc.) and where and how it was grown. Many other aspects of straw bale construction need to be studied before we know how much carbon straw bale can sequester and for how long. But current evidence suggests that straw bale construction and other uses of straw in the building envelope is a powerful tool for reducing the total emissions of a building. CASBA and other organizations are continuing to pursue this research.

—Massey Burke

Rebecca Tasker



Exterior stucco can be lime-cement or, for reduced embodied energy, earthen-based, and any plaster used must be vapor-permeable.

Effective Building

A building with the lightest footprint would probably be a mud and grass hut, but in many places that is not the most effective building to shelter us, to keep us safe and healthy in the long term. Straw bale buildings are high-performance. Everyone knows that a straw bale building is “natural” and “green,” but fewer people know just how effective it is!

R-value. Straw bale walls have a relatively high R-value—the measure of a material’s ability to resist the flow of heat. In the summer when it’s hot outside and cool inside, the heat will work its way through the walls. The higher the R-value of the wall, the longer it will keep that heat out.

The accepted rating for straw bales is R-1.45 per inch, and bales are 18 to 23 inches thick when laid flat. The accepted rating when the bales are on edge is R-1.76 per inch, and the bales are around 15 inches thick. The result is a wall with an insulation value between R-26 and R-33 (see “Thermal Performance” sidebar). If you ask your local energy specialist about an R-30 wall, they will probably tell you is it’s well-suited for most climates.

Thermal bridging is when a relatively non-insulating material, like wood, interrupts the insulation layer and bridges from one side of the wall to the other, more easily letting heat pass through. Because straw bale walls are so thick, penetrations are relatively shallow: the framing is on one side of the bales, usually only 4 inches deep, and electrical boxes penetrate only 4 inches. In an on-edge wall system, I-joists bridge the wall surfaces, but the wood webbing member is so thin and non-conductive that little heat is transferred.

Air leakage. Straw bale walls are pretty good at preventing air leakage, too. Because plastered straw bale walls have fewer edges than materials like plywood and sheetrock, there are fewer seams to seal. Well-built straw bale homes have reached Passive House standards for air-tightness—a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50). As with any tight building envelope, attention must be paid to getting fresh air through natural or mechanical ventilation.

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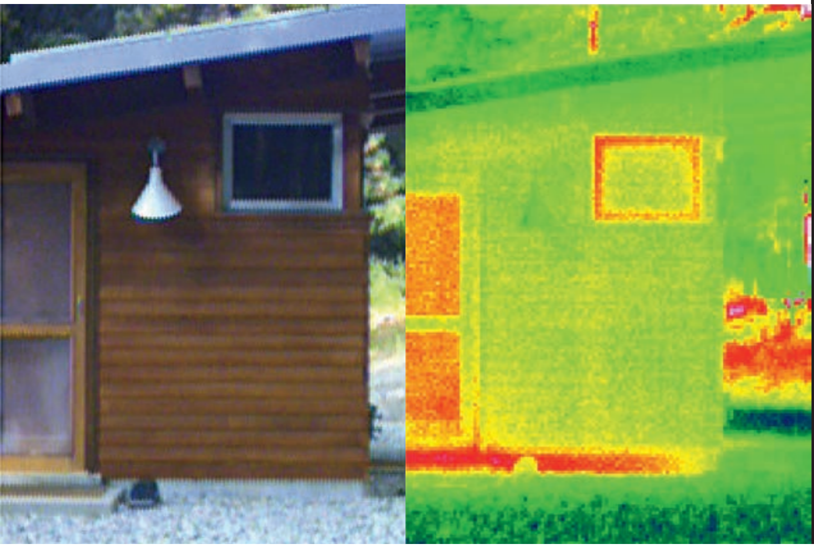
Bale wall systems have fewer thermal bridges that cause heat flow across the assembly.



Courtesy Arkin Tilt Architects (2)

Thermal Performance

Thermal resistance (R-value) of straw bale (SB) walls has been tested for 20 years, with the most reliable tests indicating R-values ranging from R-33 to R-50 (R per inch values of 1.46 to 2.25) for walls with three-string (22.5 by 16 in.) bales. The range results from variations in bale orientation, bale density, construction practices, and moisture content.

Standard stud-framed walls with R-19 insulation have an actual R-value of only about R-14 due to the lower R-value of the framing members (R-5.5 for 2 by 6 studs). Because straw bale walls do not have significant framing members to introduce thermal bridging, wall R-values are not similarly reduced.

In most climates, “thermal lag” increases the effective R-value of straw bale walls. Thermal lag is the time it takes heat to travel through a material. For straw bale walls, that’s 12 to 15 hours. In temperate climates, this closely matches the daily change in outdoor temperatures (diurnal swing), so on cold days, the heat never escapes the exterior before daytime warming drives it back toward the interior. However, it takes weeks of simulated 0°F exterior conditions for straw bale walls to reach the steady-state heat flow that the official test—ASTM-236 (now replaced by ASTM C1363)—requires.

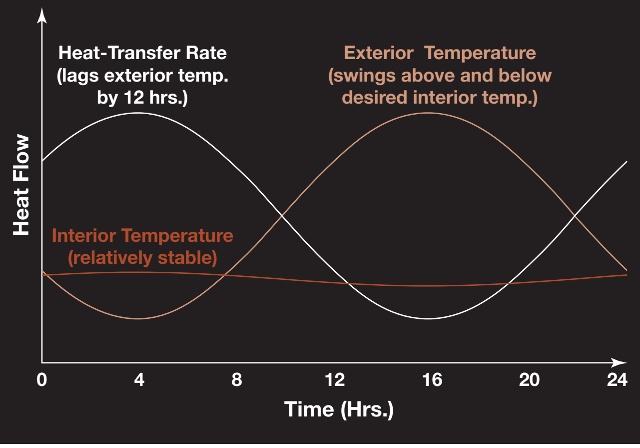
In the “hot box” test, one side of the wall is held as close to 70°F as possible with a small electric heater and small fan. The other side of the wall is held close to 0°F with a constant 15 mph fan-generated air current directed at it. Thermocouples across the surfaces of both the interior and exterior wall measure small fluctuations in temperature. Steady-state heat flow is defined as the point at which none of the thermocouples’ readings change by more than 0.5°F in a five-minute period, and none of them change in the same direction during two consecutive 5-minute periods.

For an aluminum-framed window, steady-state heat flow is usually reached in less than 20 minutes. For a conventional framed and insulated wall, it takes an hour or two. For a straw bale wall, it takes two to three *weeks*. In climates where the temperature can stay at or below freezing for weeks, straw-bale walls perform closer to the tested R-values.

Our sense of thermal comfort depends more on mean radiant temperature (MRT, the average temperature of everything around us) than it does on air temperature. Straw bale walls have high thermal mass, which results in a very stable MRT. Combined with their other properties, they result in a very comfortable home.

—Nehemiah Stone

Thermal Lag Benefits



Well-sized roof overhangs protect the walls, and shade south-facing walls and windows from the intense summer sun.

Southern (Oregon) Comfort

Guided by images of thick-walled buildings in books and childhood memories growing up in Portugal's Azores Islands, John and Marie Galego set out to build their dream retirement home on rural land outside of Jacksonville, Oregon. They sold their 2,300-square-foot home in Boise, Idaho, moved to southern Oregon, and lived temporarily in two 200-square-foot straw bale buildings—one a kitchen and living space, the other with a bedroom and bath. This experience convinced them a small house would satisfy their needs and budget.

A double airlock entry reduces air exchanges by stopping blow-through when the outer door is opened.

Claire Anderson (2)

Home designer Anna Bjernfalk enthusiastically embraced the challenges posed by creating a small home that doesn't feel small. Ceilings in the main room and kitchen soar to a functional loft over the bedroom, bath, and pantry areas. South-facing clerestory windows illuminate both the loft and main living space. A large east-facing porch offers protected outdoor living space adjacent to the kitchen, and affords sweeping views of meadows and forested mountains. A south-facing double folding door opens onto what will one day be a garden patio, easing the boundary between inside and out.

Wood posts and beams hold up the roof; prefabricated steel bracing resists shear forces; and the plastered straw bales supply insulation and thermal mass. This structural system allowed John and Marie to use their abundant clay-rich site soil for base-coat interior plaster and for the earthen floor. Lime-plastered exterior walls offer durability in wind-driven rain. Locally sourced Douglas fir posts and beams support the loft floor, and make up the loft railings and access ladder. Kitchen counters and window stools are made of locally harvested walnut.

The house is set up for both rainwater collection and greywater use; the couple plans to develop these systems as time and budget allow. The orientation and design of the home allow winter solar gain and passive summer cooling. A 6 kW batteryless grid-tied system was designed to offset all of their electricity needs.

The Galego home received an Energy Trust of Oregon New Homes EPS (Energy Performance Score) score of 9, on a scale that ranges from 0 (best) to 200 (worst). For comparison, a similarly sized home in Oregon, built to minimum code standards, typically has a score of 60. The building's continuous plaster skin, combined with careful detailing at windows, doors, floor, and ceiling joints, inhibits air movement—the house had a blower-door test of 2 at ACH50.

The home and outbuildings—assembled in a clearing on a forested hillside, and surrounded by gardens and orchards—resemble the cheerful, ageless villages of their native country and make sensible use of the sun and abundant local resources—a good model to follow.

—Jim Reiland

Clerestory windows let in natural light and admit solar heat during winter.

Thick walls make deep windowsills, for an old-world feel.

High ceilings paired with well-placed windows promote convective cooling.

in a Solar Straw Bale Home

Overview

Dwelling: 960 sq. ft. straw bale home (895 sq. ft. heated)

Location: Jacksonville, Oregon

Owners: John and Marie Galego

Designer: Anna Bjernfalk, AB Design

Engineering: Snyder Engineers

General Contractor: Jim Reiland, Many Hands Builders

Energy

Passive solar: Long façade oriented east-west. Eaves sized to maximize winter heat gain and minimize direct summer sun. Thermal mass from 1.5-inch-thick interior earth plaster on straw bale walls and 1-inch earthen floor over compacted gravel.

Space heating: Hydronic floor, wood heater, heat-recovery ventilator

Cooling: Thermal siphon, with operable clerestory and gable-end windows.

Renewable energy: 6 kW grid-tied PV system

Other Features

Insulation: 18-inch-wide straw bales (R-26); R-15 rigid foam under slab and along foundation wall; R-50+ rock wool and rigid foam gable and clerestory walls; R-50+ rock wool ceiling

Envelope: Blower door test is 2 at ACH50

Windows: Double-pane, U-0.29

Lighting: LEDs

Water

Household: Well

Greywater (future): Collected from sinks, laundry, and shower; gravity flow to orchard

Rainwater (future): Collected from 1,700 sq. ft. steel roof; gravity flow to irrigation storage tanks

Materials

Roof: Standing-seam metal

Exterior wall finish: Lime plaster

Interior wall finish: Straw bale walls used site-dug earth-plaster base coats with locally sourced clay-plaster finish

Floors: Site-dug earth and locally sourced gravel

Claire Anderson (4)

A natural earthen floor covers R-15 insulation and provides thermal mass for storing passive solar gain.

Rebecca Tasker (2)

Multiple layers of natural plaster, both interior and exterior, mitigate diurnal temperature swings inside the building.

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Thermal mass provides heat storage. Imagine a rock sitting in the sun all day—the rock stays warm after the sun sets and the air temperature drops, because the rock has a lot of thermal mass and air has very little. The plaster on straw bale walls is 1-inch-thick evenly distributed thermal mass. This helps slow the transfer of heat through the wall and also slows changes in temperature, so a warm room stays warm longer.

Fire & seismic resistance. Plastered straw bale walls have a high fire-resistance rating: 1 hour for clay plaster and 2 hours for lime-cement, which both compare favorably to conventional building. Straw bales are so dense, it's like trying to burn a phone book—there isn't enough oxygen available for combustion: they just smolder, allowing a lot of time before the walls are compromised. For comparison, 0.5-inch-thick gypsum wallboard has a 15-minute rating. To achieve a two-hour fire-resistance rating for a conventionally framed exterior wall, you'd need an assembly with 1 inch of exterior cement stucco over 5/8-inch-thick fire-retardant sheathing over retardant-treated 2-by-6 wood studs, with two layers of 5/8-inch-thick fire-resistant gypsum wallboard on the interior.

Earthquakes are an important consideration in some locations. Seismic testing on straw bale wall assemblies demonstrate that they're up to the challenge. Because both the natural plasters and straw bales are flexible, they do well in earthquakes because they "bend" more than conventional materials before they break.

Vapor permeability. Straw bale walls are also vapor-permeable, which means that they allow water vapor to pass through them, though they don't allow air or liquid water to enter. People are damp—a family of four can produce as much as 2 gallons of moisture a day from breathing, showering, and cooking. If we choose a wall system that traps that moisture, we get moldy, sick buildings. If a building can't deal passively with moisture, we have to mechanically vent it.

The old adage about moisture was that "buildings have to breathe," but that's misleading because breathing entails air moving in and out—and we don't want air leaks. A better way to put it is that "buildings need to transpire." Clay or lime-plastered straw bale walls allow moisture to pass through without allowing air to pass through.

Clay plaster also has hygric mass, which is like thermal mass but for moisture—it "stores" moisture like a rock stores heat. Clay plasters can draw excess moisture out of the air when it is humid and store it until the air dries, then re-release it. This evens out spikes in humidity, making people feel more comfortable, and it reduces the risk of condensation and mold. Better indoor air quality is achieved using these nontoxic, zero-VOC materials that don't trap moisture, reduce the risk of mold, and balance humidity.

Pair this super-insulated, low embodied energy, thermally massive wall system with passive solar design, and you get a structure that has relatively small heating and cooling loads. Climate-appropriate glazing on the south side; roof overhangs to limit summer heat gain; and reduced glazing, where summer sun or winter wind impacts interior temperatures, are important. Windows that encourage a thermal siphon for nighttime cooling can help moderate interior temperatures, too. A well-designed straw bale building can be comfortable year-round with little energy used for heating and cooling.

Other Considerations

One potential drawback to straw bale building is the thickness of the wall, which can be significant. Matts Myhrman, one of the straw bale building revival's early leaders, famously quipped, "You can have anything you want in a straw bale house, except skinny walls."

Another disadvantage is that straw bale building often has a higher up-front cost, and unfamiliarity of designers and builders with this system can add to costs. A well-designed and well-managed straw bale project can cost 10% to 15% more per square foot to build than a conventional home.

web extras

See a load-bearing shake-table test at **youtube.com/watch?v=x8Uz-2PonEk**

Rebecca Tasker (3)

Thick walls make for deep door and window openings. There are several structural and aesthetic ways to approach this.

Straw bale building owners care about their buildings because they're charismatic. As soon as you start putting straw bales into a wall, people notice. People also notice a difference when they enter a straw bale home. Perhaps it's the thick walls that offer a sense of security, or the hand-applied finishes that harken to a time when buildings were crafted, instead of manufactured.

Straw bale buildings invite participation. Because the materials are nontoxic, there is a tradition of getting friends and family involved in the process with work parties—days when volunteers come to help stack bales or plaster walls, not unlike an Amish barn raising. Work parties don't make sense on every project, but can advance the construction process while engaging the community. Most people feel alienated from construction, and working on your own building is empowering: a foot in the door to further engagement. This leads to a feeling of commitment and stewardship for the building, which can lead to greater longevity.

Of course, straw bale is just the wall. For a truly healthy, high-performance building, attention must be paid to the rest of the building system, such as minimizing its overall size and its loads; incorporating renewable energy systems; selecting high-performance HVAC, electrical, and plumbing systems; and choosing nontoxic finishes throughout the building. With straw bale's Appendix S added to the *International Residential Code* in 2015, and the California Straw Building Association's (CASBA, strawbuilding.org) *Detail Book* soon to be published, this form of building will receive the acceptance and recognition it deserves.

But be sure to compare apples to apples. If you compare straw bale to other well-insulated wall systems that can achieve R-30—such as double-stud and cellulose—the costs are very similar. And the main difference between a well-insulated wall system and conventional wall is that the energy bills will be significantly less over the building's life, making up for the higher up-front cost. If you consider the embodied energy "cost" of building an R-30 wall with bales versus other materials, straw bale is less. In his book, *Making Better Buildings*, Chris Magwood compares the embodied energy (EE) of various wall systems of a sample house. A wood-framed wall insulated to R-30 with cellulose, with drywall on the interior and OSB and lime-cement stucco on the exterior adds up to 40,497 megajoules (MJ). The EE of a bale-laid-flat, post-and-beam straw-bale wall with 2-by-4 framing at doors and windows, and lime-cement plaster on the interior and exterior, was about half, at 19,145 MJ.

Appealing Building

Approaching sustainability requires longevity: we take care of things we love and the longer something lasts, the lower its environmental impact. Unloved buildings get knocked down; then there's additional environmental cost to build new ones.

There's no longevity without durability. Most conventional buildings are built to last 30 or 40 years. Compare this to straw bale structures built in the late 1890s that are still in use today.

The relatively simple, but labor-intensive, aspect of building with bales fosters community involvement with "bale raising" parties.