A demonstration project using affordable, energy-efficient construction techniques with an emphasis on materials produced near the building site and erected by local labor resources.

HOUSE *of* STRAW

STRAW BALE CONSTRUCTION COMES OF AGE

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Introduction

Americans want comfortable, attractive, functional, and durable housing. Yet, many increasingly find high quality housing beyond their means. Conventional building methods rely on plentiful resources. With some of these resources dwindling, housing costs are sky rocketing. The cost of a home includes materials, construction, financing, taxes, energy consumption, and insurance. This booklet explores recent attempts to reduce those costs. Construction techniques discussed in this booklet focus on building resource-efficient and energy-conserving homes, without sacrificing affordability or quality.

In a cooperative demonstration project between the U.S. Department of Energy (DOE), the U.S. Department of Housing and Urban Development (HUD), and the Navajo Nation, current home designs on the Navajo reservation were evaluated and recommendations were made to improve quality and lower the costs. The resulting design utilized straw-bale wall construction.

Straw-bale building is a practical and perhaps under utilized construction method. Initiated in the United States at the turn of the century, straw-bale building is showing new merit in today's marketplace. Walls of straw, easily constructed and structurally sound, promise to take some of the pressure off of limited forest resources.

Straw is a viable building alternative, plentiful and inexpensive. Straw-bale buildings boast superinsulated walls (R-50), simple construction, low costs, and the conversion of an agricultural byproduct into a valued building material. Properly constructed and maintained, the straw-bale walls, stucco exterior and plaster interior remain water proof, fire resistant, and pest free. Because only limited skill is required, a community house-raising effort can build most of a straw-bale house in a single day. This effort yields a low-cost, elegant, and energy-efficient living space for the owners, a graceful addition to the community, and a desirable boost to local farm income. This booklet offers an in-depth look at one such community house-raising, in addition to a general overview of straw-bale construction.

Straw-Bale Construction

History of Straw Bale Construction

People have built homes using straw, grass, or reed throughout history. These materials were used because they were reliable and easy to obtain. European houses built of straw or reed are now over two hundred years old. In the United States, too, people turned to straw houses, particularly after the hay/straw baler entered common usage in the 1890s. Homesteaders in the northwestern Nebraska "Sandhills"area, for example, turned to baled-hay construction, in response to a shortage of trees for lumber. Bale construction was used for homes, farm buildings, churches, schools, offices, and grocery stores.

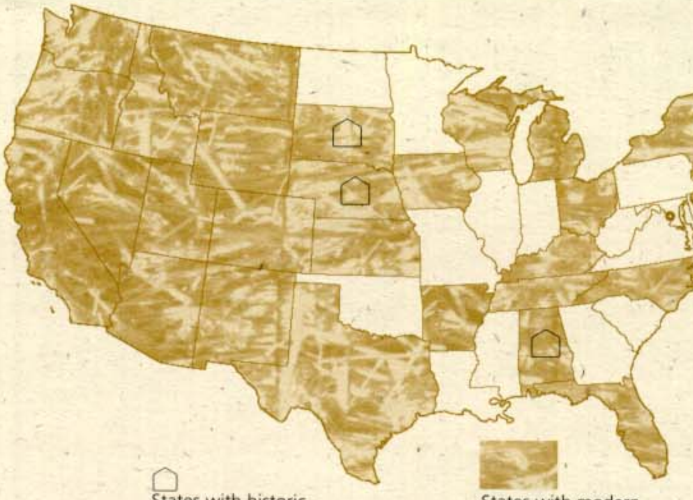
Nebraska historian Roger L. Welsch writes: "It was inevitable that some settler, desperate for a cheap, available building material, would eventually see the big, solid, hay blocks as a possibility. Soon, baled hay was indeed a significant construction material. The bales, about three to four feet long and one and one-half to two feet square, were stacked like bricks, one bale deep, with the joints staggered. About half used mortar between the bales; the others simply rested one bale directly on the other. Four to five wooden rods (in a few cases iron rods) were driven down through the bales to hold them firmly together. The roof plate and roof were also fastened to the top bales of the wall with rods or stakes. The most common roof configuration was some sort of hipped roof. . . .Window and door frames were set as the walls rose around them. . . .Walls were left to settle a few months before they were plastered and the windows installed."

Straw-bale house in Arthur, Nebraska, built 1925.

Matts Myhrman and Judy Knox, straw-bale construction consultants, have visited many of these "Nebraska-type" bale structures, built between 1900 and 1940. Myhrman rediscovered the area's oldest existing bale building, the Burke homestead, constructed in 1903 outside Alliance, Nebraska. Although abandoned in 1956, the Burke homestead continues to successfully withstand Nebraska's wide temperature swings and blizzard force winds. Long-time Nebraskan Lucille Cross recalls the hay-bale house of her childhood was so quiet that her family, not hearing a tornado outside, just sat there playing cards, while the tornado wrought havoc all around them.

In Wyoming, straw-bale structures have consistently withstood severe weather and earthquakes. "The earthquake was in the 1970s and it was either 5.3 or 5.8," Chuck Bruner, a resident of one of the houses told *The Mother Earth News*. "There wasn't a single crack in the house. You can live in this house comfortably during the summer. It stays nice and cool. We have never needed any air conditioning, and in summer we get days up in the 90s. Also, last winter, I only turned our small bedroom heater on twice. If I had to guess how our utility bills compare to those of our neighbors, I'd have to say our bill is about half."

The straw-bale building revival at a Glance (from *The Last Straw*, Fall, 1994).



Straw: A Renewable Resource

Straw, the stalks remaining after the harvest of grain, is a renewable resource, grown annually. Each year, 200 million tons of straw are under utilized or just wasted in this country alone. Wheat, oats, barley, rice, rye, and flax are all desirable straws for bale walls. Even though the early bale homes used hay for the bales, hay is not recommended because it is leafy and easily eaten by creatures great and small. Straw, tough and fibrous, lasts far longer. Straw-bale expert Matts Myhrman estimates that straw from the harvest of the United States' major grains could be used to construct five million, 2,000 square-foot houses every year! More conservative figures from the U.S. Department of Agriculture indicate that America's farmers annually harvest enough straw to build about four million, 2,000 square-foot homes each year, nearly four times the houses currently constructed.

Building a straw-bale house is relatively simple. A basic 2,000 square-foot house requires about 300 standard three-wire bales of straw (costing approximately $1,000). Placed on a foundation, the bales are skewered on rebar pins like giant shiskabobs. After wiring and plumbing, the walls are sealed and finished. Because grains are grown in almost every region of the country, straw bales are readily available, with minimal transportation costs. Lumber from trees, in addition to becoming more scarce and expensive, must be transported over longer distances.

TYPES OF STRAW BALES

Straw bales come in all shapes and sizes, from small two-string bales to larger three-string bales and massive cubical or round bales. The medium sized rectangular three-string bales are preferred for building construction. Three-string bales are better structurally, have higher R-value, and are often more compact. A typical medium-sized, three-wire bale may be 23" X 16" X 42" and may weigh from 75 to 85 pounds. The smaller two-wire bales, which are easier to handle, are roughly 18" X14" X 36" and weigh 50 to 60 pounds. If the current trend continues, it may not be long before "construction-grade" bales begin to appear.

Horse powered bale press around the turn of the century.

The Navajo Project

The Navajo Nation (located in parts of Arizona, New Mexico, and Utah) is the largest American Indian reservation in the United States. With a population of close to 200,000 people spread over 17 million rural acres, the Navajo community has a continuous need for adequate housing. This need for housing is complicated by the lack of affordable electricity to remote homesites, dwindling supplies of firewood, and increasing cost of building materials and labor. Navajo community leaders wanted housing that boosted the local economy, used local materials and labor, and maintained the integrity of their culture.

In 1991, the Navajo Nation asked the DOE for assistance in creating more energy-efficient, affordable housing. Under the proposal, DOE and HUD provides funds for technical assistance to review home designs and suggest alternatives, while the Navajo Nation provide funds for construction of a demonstration house. A team was assembled in December 1992 to discuss local housing construction, evaluate design options, identify the needs of home occupants, and inventory community sentiment. In architectural circles, this process is known as a "design charrette." Charrette participants were selected for expertise in energy, finance, indigenous materials, passive solar design, and knowledge of the Navajo community and traditions. The design charrette was conducted in Gallup, New Mexico and focused on the following design criteria for the prototype home:

- Energy efficiency;
- Affordability;
- Resource-efficient building technology;
- Use of local materials;
- Community involvement and use of local labor;
- Cultural compatibility; and
- Design simplicity, adaptability, and comfort.

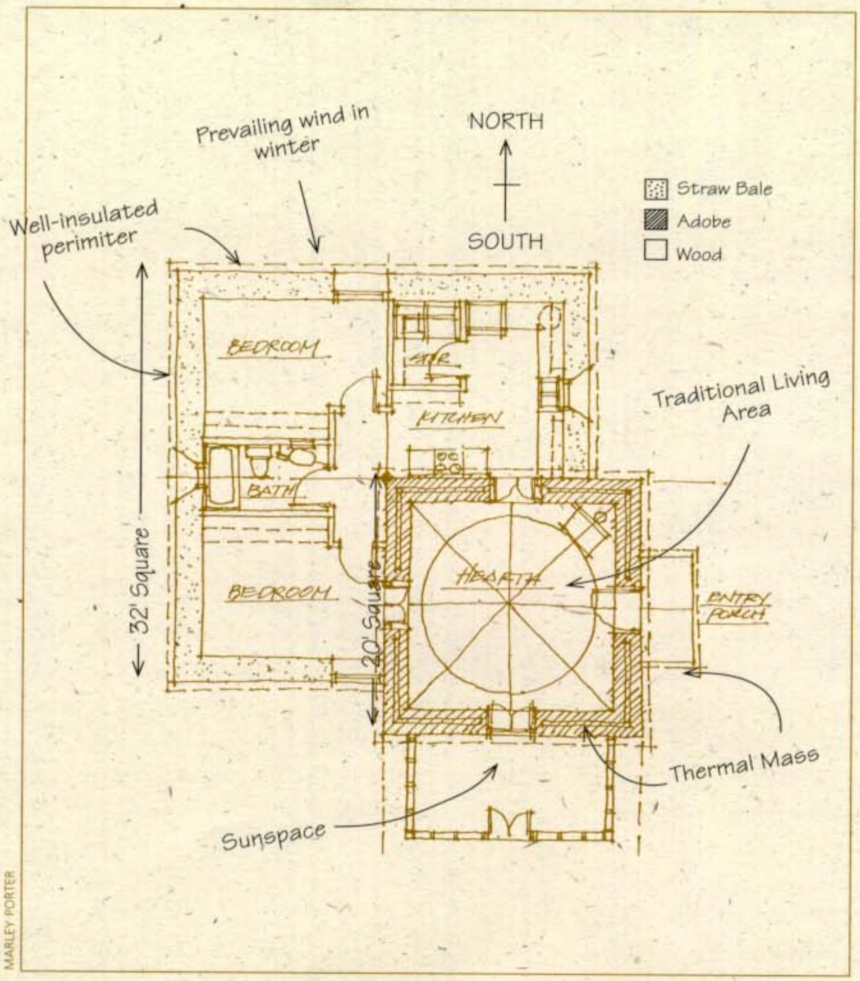
The final design that was agreed upon was a unique combination of "Nebraska-style" straw-bale walls and adobe walls with passive solar orientation. This combination has several benefits. Straw-bale and adobe are inexpensive, locally available materials that can be used for building by local unskilled labor after only minimal training. Straw-bale walls are superinsulated (about R-50), and adobe and passive solar orientation have been used for centuries by Native Americans in the southwest. Because of the two-foot thick bale walls, the resulting structure has approximately 1,000 square feet of living space.

LARRY AHASTEEN

Straw-bale/adobe prototype home under construction (southwest elevation).

Construction of the demonstration home began in July 1993 near Ganado, Arizona and was completed in December 1994. The home successfully met the design criteria in the following ways.

- **Energy Efficiency.** The high elevation desert climate of the Navajo Nation, characterized by wide daily temperature fluctuations, low humidity, plentiful sunshine, and cold winters, dictated the design



MARLEY PORTER

Ganado floor plan illustrates basic passive solar design principles at work; wrap the building with insulating straw bale exterior walls (except south, which is open to passive solar gain) and incorporate adobe into the house's interior. The insulating perimeter prevents the heat or cool stored in the thermal mass from being lost back to the outside.

parameters for the prototype home. Well-insulated walls, good air-leakage control, and taking advantage of the solar radiation were key to reducing the use and cost of space heating. Unlike a wood frame wall that has many pieces assembled at the site, bales provide an nearly monolithic layer of straw that is covered inside with plaster and outside with stucco. Coupled with a simple geometric design, the monolithic wall coverings result in very little air leakage.

Straw is a form of cellulose that has reasonably good insulating properties; and because a bale can be up to two feet thick, a straw-bale wall has extremely high thermal resistance. Recent tests following ASTM procedures resulted in bale R-values between R-2.4 and R-3.0 per inch, depending on the direction of the straw, and showed that thermal resistance is affected by moisture and density of the pack (Joseph McCabe, January 1993). Matts Myhrman, another straw-bale expert, suggests that R-2.4 per inch is representative of straw-bale thermal resistance in the field. Therefore, straw-bale homes should have lower heating and cooling costs than conventional homes.

The Department of Energy, interested in the magnitude of potential energy savings of the wall design options, asked building scientist Jim Hanford of Lawrence Berkeley Laboratory (LBL) to analyze the thermal characteristics of the various wall materials and project energy savings for the prototype home. The energy efficiency of various building design options was analyzed during the design charrette at Navajo and continued to be evaluated during the construction and testing phases of this project. Hanford's analysis, which follows, assumes R-2.4 per inch for a straw bale; with sensitivities conducted at R-1.8 and R-3.0 per inch. Table one compares thermal characteristics of the

METHODS OF BUILDING WITH STRAW

Straw has been used for centuries by builders who recognized its structural integrity. A piece of straw is simply a tube made of cellulose. Tubes are recognized as one of the strongest structural shapes. Straw was first used to reinforce mud against cracking. A lattice of straw criss-crossing a layer of mud produced a surface that remained crack free for decades, or in many cases, centuries. With the late 19th century invention of the baler, builders were given a convenient new building block, the rectangular bundle of straw. Straw-bale building in the United States has been mostly structural (Nebraska-style) and non-structural. Pliny Fisk III of the Center for Maximum Building Potential in Austin, Texas, describes the following five methods of building with straw.

1. In-fill or non-structural bale This building system, useful for construction of large structures, depends on a pole or post-and-beam building design. Post-and-beam construction employs a skeleton of vertical posts and horizontal beams to support the roof. The straw-bale walls have only themselves to support. The bales are attached to each other by piercing the bales with rebar or bamboo and attaching the bales to the pole or column. Fisk's Center has completed three buildings totaling 4,500 square-feet of space using this method.

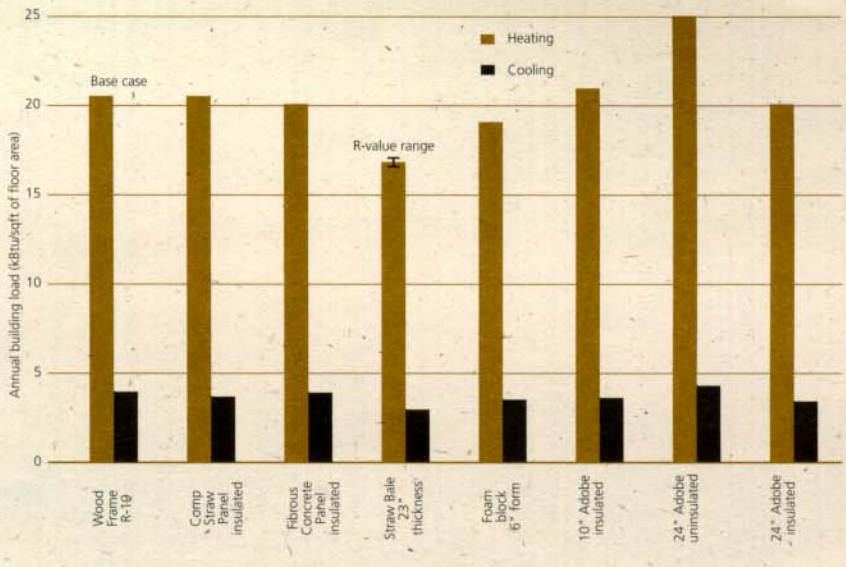
2. Structural bale Automatic straw balers create tight building blocks that are stacked up to one and one-half stories. The "Nebraska-style" buildings originated on the Great Plains where structural wood was not available. Bales are stuccoed on the exterior and plastered on the interior to protect them and provide an attractive finish. The stucco and plaster add to the structural integrity of the wall system.

3. Straw-clay building A pancake like batter of clay and water stirred into the loose straw produces a straw-reinforced clay mud. In the past, this mixture was packed into a double-sided wood form between the posts and beams of a timber-frame building. Today, a light weight wooden ladder like frame replaces the old heavy timber frame. European heavy timber structures using this method are still standing after more than 200 years. This method has passed the most stringent European fire codes.

4. Mortar bale Structural mortar, made of portland cement and sand, is applied between the straw bales. When dry, its lattice structure remains intact if the straw bales should ever fail. This method, developed in Canada, passes Canadian building codes. Bales are stuccoed on the exterior and plastered on the interior to protect them and provide an attractive finish. The mortered joints, stucco, and plaster also add to the structural integrity of the wall system.

5. Pressed straw panels Straw is compacted under certain temperatures. The resulting panels are 100 percent straw that can be used to build pre-fabricated structures, not only walls, but also roofs and floors.

Figure 1. Albuquerque, New Mexico Climate;
Building Performance with Alternative Wall Construction.



straw-bale wall with the other wall constructions considered at the Navajo design charrette.

The thermal performance for buildings using these wall constructions is compared in figures one and two. The data shown are simulation predictions of building heating and cooling loads per unit of floor area, using the DOE-2 building energy simulation program. The building size, shape, and other component characteristics are based on the Navajo straw-bale demonstration house. In the final case, straw-bale construction is combined with passive solar design. Weather data used in this analysis is from Cedar City, Utah representing the colder, mountainous areas of the reservation, and Albuquerque, New Mexico, representing the warmer climates.

The straw-bale wall has the best energy performance because it has the highest R-value by a wide margin, regardless of the assumed unit R-value for straw. For the entire building, changes in just the wall construction change the heating load by plus or minus twenty percent from the R-19 wood frame base case.

The results assume that the building infiltration rate is the same for all wall systems. All building components, including the roof, floors, windows, doors, and air infiltration need to be considered in the analysis of an energy-efficient dwelling.

The design team chose plastered straw-bale walls for their high R-value (approximately R-50) and adobe walls to absorb and radiate solar gain. The straw-bale walls face the northwest and join the adobe walls on the north and east sides of the building, exposing the adobe to the maximum solar radiation, yet shielding it from the prevailing winter wind. Both the adobe and straw bale walls are coated with three layers of stucco inside and out for protection. The attic, windows, and doors of the demonstration home are also well-insulated and sealed to minimize drafts. The resulting building is superinsulated, remaining cool on hot summer days and requiring minimal heating in winter.

Table One. Wall Section Thermal Characteristics

Wall Type	*R-value* (hr-sqft-F/Btu)	*U-value* (Btu/hr-sqft-F)	*weight* (lb/sqft)	*heat capacity* (Btu/sqft-F)
Wood Frame				
2x4 studs w/R11 batts	10.2	0.098	9.2	2.2
2x6 studs w/R19 batts	15.4	0.065	10.5	2.6
Compressed Straw Panel				
uninsulated 4.8" panel	10.1	0.099	13.4	4.9
insulated 4.8" panel	18.4	0.054	13.7	4.9
Fibrous Concrete Panel				
insulated 3" panel	16.7	0.060	16.9	4.7
insulated 4" panel	19.1	0.052	20.1	5.7
Straw Bale				
23" bale @ R-1.8/inch (-25%)	42.7	0.023		
23" bale @ R-2.4/inch	56.5	0.018	21.4	6.4
23" bale @ R-3.0/inch (+25%)	70.3	0.014		
Foam Blocks				
6" form w/ concrete/adobe fill	26.3	0.038	40.8	7.5
8" form w/ concrete/adobe fill	28.0	0.036	54.2	9.8
Adobe				
uninsulated 10"	3.5	0.284	95.0	17.9
insulated 10"	11.9	0.084	95.3	18.0
uninsulated 24"	6.8	0.147	183.4	34.2
exterior insulated 24"	15.1	0.066	183.6	34.3

Notes:

- All walls have stucco exterior and drywall interior, except adobe and straw walls have plaster.
- Wood frame walls have 25 percent (R-11) and 20 percent (R-19) stud areas. The R-19 batt compresses to R-18.
- Compressed straw panel, insulated case, has 2 inches polystyrene on exterior.
- Fibrous Concrete panel have 1 inch polystyrene inside and out.
- Straw bale wall R-value is calculated for 3 unit R-values for straw to cover potential variability.
- Average material thickness across foam block wall sections are as follows:
  6 inch foam has 2.9 inches polystryene each side and 3.4 inches of fill.
  8 inch foam has 3.1 inches polystryene each side and 4.8 inches of fill.
  Wall properties are based on 75 percent adobe and 23 percent concrete fill.
- Adobe walls , insulated case, have 2 inches of polystyrene on exterior.
  24 inch wall is two 10 inch layers with 4 inch air gap.

Notes for Figures 1 and 2:

- Prototype building is 1,050 square-feet (42 ft. X 25 ft.) with 120 square-feet of windows.
- Base house has R-30 roof, R-19 wood frame walls, slab-floor with 1 inch perimeter insulation, double glazed windows with aluminum frames, and medium infiltration levels (ELF=0.0005; ACH=0.52).
- Prototype has equal window area in four cardinal orientations (30 square-feet each).
- Prototype has concrete slab floor and wood-frame interior walls.
- Albuquerque, New Mexico represents Navajo Reservation climates (4186 heating degree days (HDD) @ 65° F base); Cedar City, Utah represents colder climates (5918 HDD).

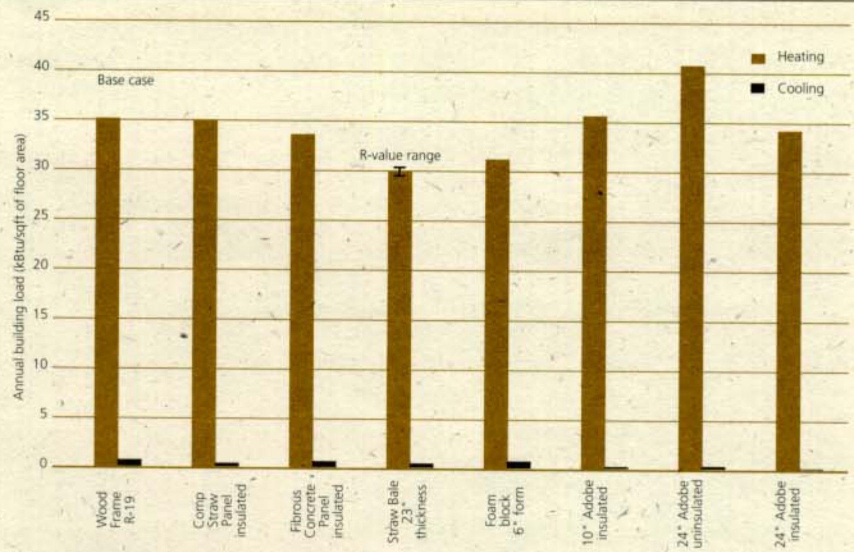


Figure 2. Cedar City, Utah Climate; Building Performance with Alternative Wall Construction.

Further computer simulations and other research summarized in Lawrence Berkeley Laboratory's forty-page final report show that the program currently undertaken by the Navajo Nation has the potential to improve the energy efficiency and thermal comfort of new residences when compared to those currently being built on the reservation.

LBL analyses show that (1) there are alternative construction technologies that provide equal or better energy performance than current practice, (2) the demonstration building, with a few modifications, could be substantially more energy efficient and comfortable than current practice, while meeting other program goals of architectural interest and long term environmental sustainability; and (3) straw-bale construction, along with appropriate building conservation technologies and simple passive solar design, could provide up to a 60 percent reduction in building heating loads over current practice.

Affordability. The Navajo project has demonstrated that straw-bale construction can be inexpensive compared to other materials. Table two details the costs of the project.

The cost of the finished 988 square-foot home equates to $58 per square foot, not including the cost of utility hookups (water, power, and sewage). A similar sized wood-frame house constructed in the same area would probably have cost about the same as the demonstration prototype. However, future straw-bale homes should cost considerably less than the prototype because of required changes and modifications during building of the prototype. In addition, the labor-intensive double adobe walls of the "hearth" area added more than $3,000 to the project. Had the exterior walls been entirely straw-bale, the overall costs would have been lower. Straw bales were supplied at a cost of $2.50 a bale, including transportation. Normally, the cost of a bale wall is about one-fourth the cost of a comparable, superinsulated wall built with conventional materials. Construction crews and volunteers with no straw-bale building experience erected the walls in a single day. Approximately 2,500 labor hours, a portion of which was donated, went into construction of the prototype house.

Table Two. Construction and Labor Costs for the Straw-bale Demonstration Project at Ganado

	Labor	*Material*	*Labor & Material*
Footing	$ 576	$1,022	$1,598
Foundation	2,500	2,938	5,438
Slab	720	3,435	4,155
Strawbale	540	1,032	1,572
Adobe	1,920	1,575	3,495
Bond Beam	576	1,022	1,598
Cripple Wall (Framing)	720	3,990	4,710
Insulation	576	664	1,240
Roof Structure	4,032	5,233	9,265
Stuccoing	1,440	3,430	4,870
Interior Walls	864	1,998	2,862
Interior Finishes	1,152	1,615	2,767
Ceiling Finishes	1,440	1,009	2,449
Rough Plumbing	576	621	1,197
Rough Wiring	576	490	1,066
Plumbing Trimming	384	1,041	1,425
Electrical Trimming	384	1,252	1,636
Cabinets	384	1,195	1,579
Floor Finishes	440	1,188	1,628
Fixed Equipment/Wood Stove	1,200	1,296	2,496
Totals	**$21,000**	**$36,046**	**$57,046**

SUMMARY OF LBL'S FINDINGS AND RECOMMENDATIONS

- Straw-bale building technology offers the best energy performance of any of the new construction typologies currently being considered, with 15 percent improvements in overall building energy-efficiency in heating for the climates on the Navajo reservation.
- The wall panel technologies that were part of this analysis, either straw or fibrous concrete, when insulated with an additional two inches of polystyrene insulation, perform about the same as an R-19 wood frame wall. Similarly, adobe should be insulated for better thermal performance.
- Small changes in the straw-bale/adobe prototype dwelling, specifically slab insulation, higher insulation in the vaulted ceiling, and either insulating or replacing the adobe walls with straw bales, would vastly improve the performance of this building.
- Energy-related testing of straw-bale buildings in the field is warranted. Infiltration characteristics and the effects of moisture on energy performance need further evaluation.
- Future design and building programs on the Navajo reservation should consider using better technologies for all building components, including increased roof insulation, advanced window features, and infiltration reduction details.

Construction details, demonstration house at Ganado.

Resource-Efficient Building Technology. Resource efficiency was one of the important elements considered during the four-day Navajo design charrette. For a house to be truly efficient, the energy expended in the extraction, refinement, and transportation of building materials to the site, and the total resources used during construction, should also be included in the calculation of the structure's efficiency. The integration of resource-efficiency concepts into design, materials, and building practices can reduce the environmental impacts associated with home construction. In the same way that the occupant's habits and conservation consciousness affect the home's operating efficiency, the selection of building materials and techniques also reflects the resource-efficiency consciousness of the architect, builder, and homeowner.

These considerations led to the selection of straw bale and adobe as building materials for the demonstration house at Ganado. Straw bales were available not far from the building site and adobe blocks were manufactured from soil taken from the site. Plastered straw-bale building was just one component the resource-efficient strategy employed in the Navajo demonstration project. Passive solar design and the use of adobe as the thermal mass were also used to save energy and lower heating and cooling costs.

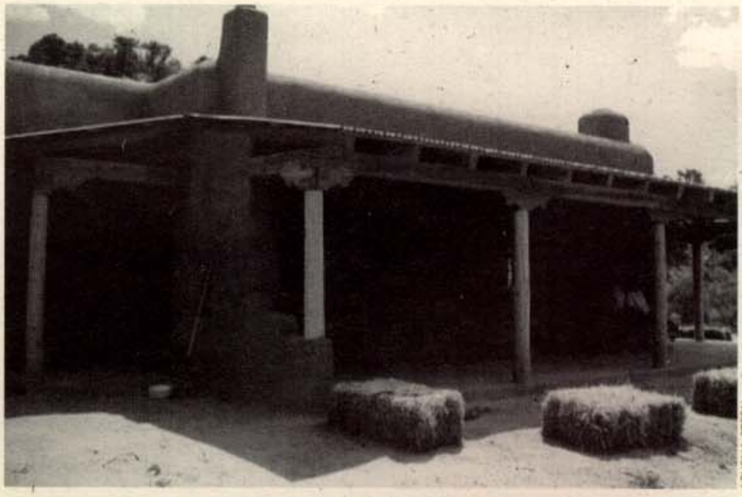
Solar Energy. In the Navajo area, the daytime average solar radiation is 1200 Btus per hour during the six winter months and 1800 during the six summer months. This ample sunshine makes solar energy a good strategy for winter space heating. Solar heat, however, needs to be controlled during the summer months to prevent overheating.

At the Navajo demonstration project, the home's design oriented the windows to use passive solar heating and passive cooling. Due to the width of straw bales, the windows are naturally shaded from the high, hot summer sun, while the lower, winter sun is allowed to enter. Most of the passive solar heat is provided by the wood-frame and glass sunspace on the south side. The concrete floor and adobe walls within the sunspace provide heat storage of daytime heat for nighttime use. During winter, solar heat collected in the sunspace is vented into the home. For back-up heating, the Navajo demonstration home utilizes a wood pellet stove and two electric baseboard heaters. During summer, the sunspace is shaded and vented to prevent overheating.

Adobe Walls and Thermal Mass. Adobe and rammed earth construction are two of the oldest and most commonly used building materials. Adobe has been used to shelter the Navajo people for centuries and, consequently, was integrated into the demonstration project. Exterior adobe walls are appropriate in a desert climate with wide day-to-night temperature swings. Adobe walls stabilize the home's interior by moderating the indoor effects of high and low outdoor temperatures. Adobe walls absorb solar heat during the day, and at night radiate their heat back into the cool night sky leaving the home at a comfortable temperature. Exterior and interior adobe walls provide excellent thermal mass. In the Navajo demonstration project, adobe serves as thermal mass in the common wall between the solar sunspace and main house, and also in interior house walls.

Other Contemporary Straw-Bale Homes

Although the straw-bale method has a long history, official recognition of straw-bale construction is just beginning. In the last decade, modern straw-bale construction pioneers have braved reluctant contractors and hesitant local building officials. The result has been a slow, but continuous, growth in construction of straw-bale houses. Straw-bale dwellings range from small owner-built units to large, contractor-built luxury homes. Costs vary from $5 to more than $100 a square-foot depending on a number of variables, as discussed in the next section. Photos on the opposite page depict the variety of styles of contemporary straw-bale buildings.



ATHENA STEEN

Virginia Carabelli House, New Mexico

The 1,400 square-foot home of Virginia Carabelli near Santa Fe, New Mexico was designed by local architect, Ken Figuerado. The Carabelli house cost $60 a square-foot, which included radiant floor heating, three fireplaces, and other custom features.

The home of Catherine Wells in Santa Fe, New Mexico, measuring 1,224 square-feet (exterior measurement), was built by Ted Varney at $56 a square-foot. The width of the straw-bale walls (ranging from 14 inches to to 24 inches) reduces the interior square footage dimensions when compared with the exterior measurements. The cost includes interior features such as radiant floor heating supplied by solar panels located on the roof and flooring laid with tile pavers. The main interior wall was also constructed of straw bales to increase sound insulation.

The pottery studio of Kate Brown (720 square-feet), in Mimbres, New Mexico, could be used as a small home. It was owner-built for $12 a square-foot. In Corrales, New Mexico, the private chapel of Dykeman Vermian, 215 square-feet, was built by Cadmun Whitty for $18 a square-foot. The chapel is an example of straw bales used in a pueblo-style building.

The straw-bale home of Mark Hawes is located in the Sangre De Cristo mountains of northern New Mexico. The house is post-and-beam construction with straw bales used as fill for the walls. Because it is in a remote location and off-the-grid, a photovoltaic system provides the electricity. The 1,400 square-foot structure was engineered by DeLapp Engineering of Santa Fe and built to code in 1992 by Hawes, a building contractor. The interior of the house contains custom southwestern features that added to the cost, which was approximately $46 a square-foot.

The first legal building in California constructed primarily of straw bales was completed in 1992. The Noland project, a 2,500 square-foot ranch headquarters and residence, is located in the Owens Valley in eastern California. Designed by architects Ken Haggard and Polly Cooper with Pliny Fisk and built by contractor Greg McMillan, the passive solar structure used straw bales for the walls on the north and east sides of the building.

In Arizona, straw-bale construction is steadily increasing. Pima County and the City of Tucson are expected to adopt straw-bale construction into their building codes in the near future. The straw-bale demonstration home of Mary Diamond, approximately 1,200 square-feet (exterior measurement), is in southeast Arizona. The house is off-the-grid, using photovoltaic power. It has a wind cooling tower, a composting toilet, and a greywater system. Built for approximately $50 per square-foot, the demonstration house is open to the public for overnight visits.

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ATHENA STEEN

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DAVID BAINBRIDGE

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KEN HAGGARD

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ATHENA STEEN

1. Straw Bale Demonstration Home of Mary Diamond, southeast Arizona
2. Pottery Studio of Kate Brown, New Mexico
3. Home of Catherine Wells, New Mexico
4. Home of Mark Hawes, northern New Mexico
5. Noland House, Lone Pine California
6. Private Chapel of Dykeman Vermian, New Mexico

Affordability

How Affordable is a Straw-Bale House?

A straw-bale house may cost the same as a conventional wood frame house. However, there are many factors that can make a straw-bale house less expensive; and, there are additional benefits to building with straw. According to a 1982 *Housing* magazine cost guide, exterior and interior wall systems comprise approximately 30 percent of the cost of construction for a typical wood frame, slab on grade house in Albuquerque, New Mexico. With the recent increases in the costs of materials, particularly lumber, this cost is presently estimated to be considerably higher. For example, lumber prices rose 70 percent during the last six months of 1993. This hefty increase added approximately $4,000 to the cost of a typical 2,000 square-foot house.

A 2,000 square-foot straw-bale house requires about 300 standard, three-wire bales at a cost of approximately $1,000. The cost of a "Nebraska-style" (structural) bale wall is about one-fourth that of a comparable superinsulated wall. Of course, there are many other variables that go into building a house such as the cost of labor, choice of finishes such as siding, roofing, flooring, and other amenities. Unique to straw-bale construction is the broad range of costs associated with different levels of quality available to builders. Table three compares the range of straw-bale construction costs based on a number of variables.

Table 3. Outline Range of Straw Bale Construction Costs Per Square Foot (sf)*

Very Low: 120-1000 sf @ $5-$20
a-scavenging, salvaging materials
b-material costs only, owner-builder labor throughout
c-initial start-up costs, ongoing improvements, pay as-you-go
d-Nebraska-style, timber frame, and post and beam
Low: 1000-1500 sf @ $30-$50
a-contractor-built, owner-built wall, finishes
b-subcontract foundations, plumbing, mechanical, roof
c-experienced job-site supervisor
d-materials at market cost
e-typically post-and-beam or Nebraska-style
Moderate: 1500-2500 sf @ $50-$80
a-standard, contractor-built
b-production housing
c-speculative development
d-typically post-and-beam
High: 2500-4000 sf @ $80-$120
a-luxury homes
b-custom design
c-site specific
d-marginally less than conventional construction
e-typically post-and-beam with custom features

**The Last Straw*, Spring 1994. Prices do not include land costs, site development, or utility interface. Compiled with data from Hofmeister, Kemble, Macdonald, Perry, and Myhrman.

The cost of a straw-bale house depends on the size of the building, the cost of materials including bales, the design of the house, and the amount of "sweat-equity" donated by the owner and friends. Straw-bale costs range from fifty cents each when purchased from the fields of Montana to $3.50 to $5.00 for three-wire bales delivered to a site in Arizona. Homes have been build for as little as $5,000 to well above $200,000. Construction costs range from $5 to $120 per square-foot. ($53 per square-foot is the national average for conventional construction.) Straw-bale houses come in a variety of shapes and sizes from A-frames to tipis to two-story custom homes. Simple, owner-built structures tend to be less expensive.

Long-lasting, low maintenance building materials and protection from the elements are key for a long-term, maintenance-free house. Providing proper site drainage is the most important factor for the home's longevity. If the ground around the house remains dry and the house is sufficiently maintained, the life-span could be hundreds of years. The roof is another crucial component. Leaky roofs damage many homes each year. Steeper roofs constructed of more permanent roofing materials are preferred. Properly built and maintained, straw-bale walls can last hundreds of years.

Table four compares the life-cycle costs of a conventional house with a straw-bale house. The Plastered Straw Bale Working Group (September, 1993) estimated that the straw-bale homes use half as much energy as conventional houses do for heating and cooling. This could translate to a savings of several hundred dollars a year over the life of a home.

Table 4. Life cycle cost estimate for conventional vs straw-bale houses

	Construction	*Finance*	*Energy*	*Total*	*Savings*
Conventional	$82,500	396,000	120,000	532,500	———
Straw bale	$78,375	376,000	60,000	451,675	83,875
Straw Bale*	$40,000	192,000	60,000	260,000	272,500

*owner-built walls, finishing, roofing

Notes:
- Life cycle = 100 years.
- Finance cost = construction cost minus down payment of twenty percent at an annual interest rate of six percent over the one hundred year life cycle (does not include closing costs when the house is sold).
- Energy = the average cost for heating and cooling a conventional home for this analysis to be $100 per month.
- Total = Amount of down payment plus energy and finance.

Source: *Working Group Reports*, Plastered Straw Bale Conference, "Roots and Revival," Arthur Nebraska, September, 1993.

Frequently Asked Questions About Straw-Bale

HOW TO BUY A BALE

Straw-bale construction consultant Judy Knox from Out on Bale (un)Ltd. raises the following considerations about selecting bales.

1. Purchase bales following the harvest when they are usually inexpensive and abundant. Make sure the bales are stored high and dry.

2. Obtain the bales from feed stores and other retail outlets, wholesale brokers, or directly from the farmer. Retail outlets are the easiest and most expensive sources. Wholesale brokers offer direct access to the bale supplier and often offer commercial transportation. Dealing directly with farmers may give you more say about bale quality and consistency, but you will likely have to address bale transportation.

3. Don't rely on hearsay concerning the size and condition of any bales you might buy. Check out the bales yourself.

4. Bales must be tightly tied with durable material preferably polypropylene string or baling wire. Avoid bales tied with traditional natural fiber baling twine. When you lift the bale, it should not twist or sag.

5. Make sure the bales are uniformly well-compacted.

6. Look for thick, long-stemmed straw that is mostly free of seed heads. Wheat, oats, rye, barley, rice, or flax are all good.

7. Test most bales to make sure they have always been dry. Bale moisture content should be 14 percent or less.

8. An ideal bale size proportion is twice as long as it is wide. This simplifies maintaining a running bond in courses.

9. Try to get bales of equal size and length. If they do vary in length (as many will), lay ten bales end-to-end. Measure this entire length. Then, divide by ten. This is the average bale length to use for planning.

This section answers some of the most commonly asked questions about straw-bale construction.

Will the bales rot? Without adequate safeguards, rot can occur. The most important safeguard is to buy dry bales. Fungi and mites can live in wet straw, so it's best to buy the straw when it's dry and keep it dry until it is safely sealed into the walls. Paint for interior and exterior wall surfaces should be permeable to water vapor so that moisture doesn't get trapped inside the wall. Construction design must prevent water from gathering where the first course of bales meets the foundation. Even if straw bales are plastered, the foundation upon which the bales rest should be elevated above outside ground level by at least six inches or more. This protects bales from rain water splashing off the roof.

Will pests destroy the walls? Straw bales provide fewer havens for pests such as insects and vermin than conventional wood framing. Once plastered, any chance of access is eliminated.

Are straw-bale buildings a fire hazard? The National Research Council of Canada tested plastered straw bales for fire safety and found them to perform better than conventional building materials. In fact, the plaster surface withstood temperatures of about 1,850° F for two hours before any cracks developed. According to the Canada Mortgage and Housing Corporation, "The straw-bales/mortar structure wall has proven to be exceptionally resistant to fire. The straw bales hold enough air to provide good insulation value, but because they are compacted firmly, they don't hold enough air to permit combustion."

Are straw-bale buildings acceptable to my local building code? Most cities and counties have adopted one of three or four model building codes. City, county, and state building codes may be different. Straw bale is acceptable to some codes, and not acceptable to other codes.

ESTELA ROMO

HINTS ON OBTAINING A PERMIT TO BUILD A STRAW-BALE HOUSE

If your community has adopted a building code, you will need a building permit before beginning construction. The local government's building official is the community's designated expert and enforcer. He or she has the responsibility of interpreting the codes, inspecting homes under construction, and making exceptions to the code, if requested. As a first step, identify local building officials and code requirements. *Out on Bale (un)Ltd.* recommends the following steps to help you obtain a straw-bale house building permit.

1. Obtain and read a copy of the current building codes for your area.

2. Gather as much information as you can about straw bale construction. *See page 14 for a list of selected resources.*

3. Talk with straw-bale experts and others interested in straw bale building.

4. Before drawing up specific house plans, meet with local building code officials. If they are not familiar with straw-bale construction, you may want to take along a knowledgeable architect or builder. Give the building officials copies of supportive information; allow them to digest the information, then meet with them again. Develop a rapport with them during the planning and building process.

5. Become familiar enough with the code and straw bale to be able to discuss and defend your design decisions as they relate to the code. If necessary, you might suggest a small straw-bale demonstration structure, perhaps a small storage shed. This will allow building officials to become familiar with the materials and construction methods.

Resources

FOR MORE INFORMATION ABOUT STRAW-BALE CONSTRUCTION, CONTACT THE FOLLOWING RESOURCES.

STRAW BALE CONSTRUCTION

Black Range Films. *A Straw Bale Workshop* and *A Straw Bale Home Tour*, two videos by Catherine Wanek. Star Route 2, Box 119, Kingston, NM 88042.

The Canelo Project. Basic information on straw-bale building. *Plastered Straw Bale Construction*, 1992, by David A. Bainbridge with Athena and Bill Steen and *The Straw Bale House*, January 1995 by David Bainbridge, Athena and Bill Steen, and David Eisenberg. HCR Box 324, Canelo, AZ 85611, (520) 455-5548.

Development Center for Appropriate Technology. Consulting, education, testing and research, networking. *Straw Bale Construction and Building Codes, A Working Paper* and *Draft Prescriptive Standard for Structural and Non-Structural Straw Bale Construction for Pima County and the City of Tucson, Arizona*. P.O. Box 41144, Tucson, AZ 85717, (520) 326-1418.

Lawrence Berkeley Laboratory. *Energy-Efficient Building Technologies for the Navajo Reservation and Analysis of A Straw-Bale/ Adobe Dwelling Prototype*, November 1994, by Jim Hanford and Joe Huang. (LBL-36320, UC 1600). Energy Analysis Program, Berkeley, CA 94720, (510) 486-7438.

Out on Bale (un)Ltd. A general resource, education, and information center with written material and videos available on straw-bale construction. *The Last Straw* newsletter published quarterly. *Build It With Bales*, January 1995, a construction guide by S.O. Mac Donald and Matts Myhrman. *Summary of Results of a Structural Straw-Bale Testing Program*, based on a Master's thesis by Ghailene Bou-Ali. June, 1993. 1037 East Linden Street, Tucson, AZ 85719, (520) 624-1673.

Resourceful Nest. *Come Home to Straw Bale Construction*, 1993, by Jim Peterson. A construction manual. P.O. Box 641, Livingston, MT 59047, (406) 222-0557.

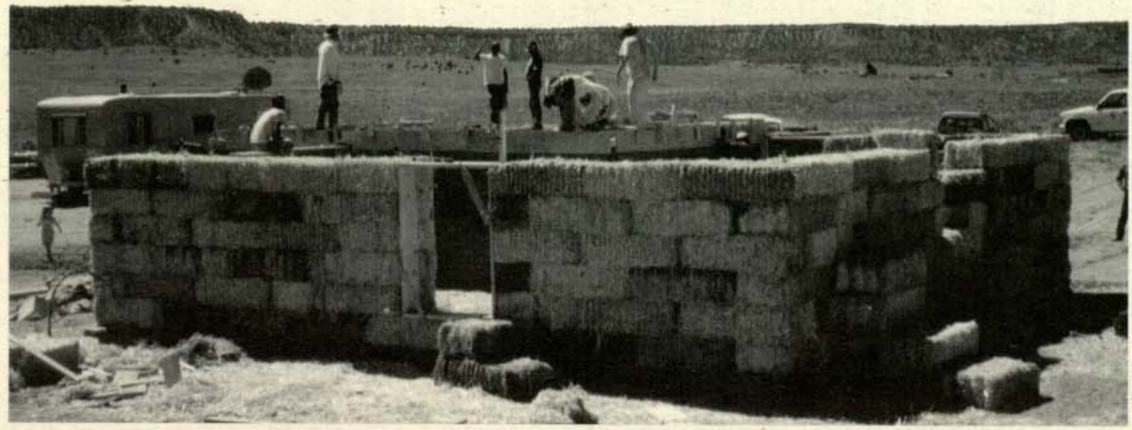
Straw Bale Construction Association. Association of architects, designers, engineers, general contractors, and subcontractors interested in straw-bale, testing, and methods inclusion into code. Forum for sharing technical information. 31 Old Arroyo Chamiso, Santa Fe, NM 87505.

Sustainable Systems Support. Consultation, design, workshops and informational materials. Videos: *How To Build Your Elegant Home with Straw Bales* and *Straw Bale Construction: The Elegant Solution,* produced by Carol Escott & Steve Kemble. P.O. Box 318, Bisbee, AZ 85603.

ENVIRONMENTALLY SUSTAINABLE CONSTRUCTION

Center for Maximum Potential Building Systems. Alternative building and design center, normally works on large projects. Rewriting the alternative building codes for Texas. 8604 FM 969, Austin, TX 78724, (512) 928-4786.

Center for Renewable Energy and Sustainable Technology (CREST), 777 N. Capitol St., NW, Ste. 805, Washington, D.C. 20002 (202) 289-5365; email: info@crest.org www: http://solstice.crest.org/



CAROLE GATES

Center for Resourceful Building Technology. Information about resource-efficient building materials. *GREBE: Guide to Resource Efficient Building Elements* and *ReCraft 90: The Construction of a Resource-Efficient House* both by Steve Loken, P.O. Box 3866, Missoula, MT 59805, (406) 549-7678.

EOS Institute. Non-profit education and resource center for ecological building design. Regional straw-bale resources, referrals. Quarterly publication, *Earthword*. 580 Broadway, Ste 200, Laguna Beach, CA 92651.

Energy Efficiency and Renewable Energy Network (EREN). Multimedia, Internet-based information system developed by the U.S. Department of Energy for world-wide information sources that contain maps, images, video, sound, text, and information on energy efficiency and renewable technologies. World Wide Web site on the Internet. P.O. Box 3048, Merrifield, VA 22116, 800-363-3732, ENERGYINFO@delphi.com.

Environmental Building News. A bimonthly newletter on environmentally sustainable design and construction. RR 1 Box 161, Brattleboro, VT 05301, (802) 257-7300.

Home Energy**.** Bimonthly magazine of residential energy conservation. 2124 Kittridge Street, No. 95, Berkeley, CA 94704, (510) 524-5405.

Rocky Mountain Institute. International outreach and technical exchange programs focusing on seven areas including energy, water, and green development. Numerous publications including: *The Efficient House Sourcebook, Homemade Money: How to Save Energy and Dollars in Your Home, A Primer on Sustainable Building,* and the RMI *Newsletter.* 1739 Old Snowmass Road, Snowmass, CO 81654-9199, (303) 927-3851.

U.S. Department of Housing and Urban Development. *OUR HOME: Buildings of the Land*, March 1994, HUD-1410-CPD. Energy-efficiency design guide for Indian housing. HUD Office of Native American Programs, 451 - 7th Street, SW, Room B133, Washington, DC 20410-7000, (202) 755-0032.

GENERAL CONSTRUCTION AND BUILDING CODES

Building Officials Conference of America. *Basic Building Code.* 1313 East 60th Street, Chicago, IL 60637.

Contractor's Guide to the Building Code, by Jack Hageman. Craftsman Book Co., 1991, (800) 829-8123.

Council of American Building Code Officials (CABO). *One and Two Family Dwelling Code.* Only national residential building code, comprised of other three code organizations. 5203 Leesburg Pike, Falls Church, VA 22041.

International Conference of Building Code Officials. *Uniform Building Code*. 5360 South Workman Mill Road, Whittier, CA 90601.

Southern Building Code Congress International. *Standard Building Code*. 3617 - 8th Avenue, South, Birmingham, AL 35222.

Journal of Light Construction. Construction management, building techniques, and energy issues. R2, Box 146, Richmond, VT 05477, (802) 434-4747.

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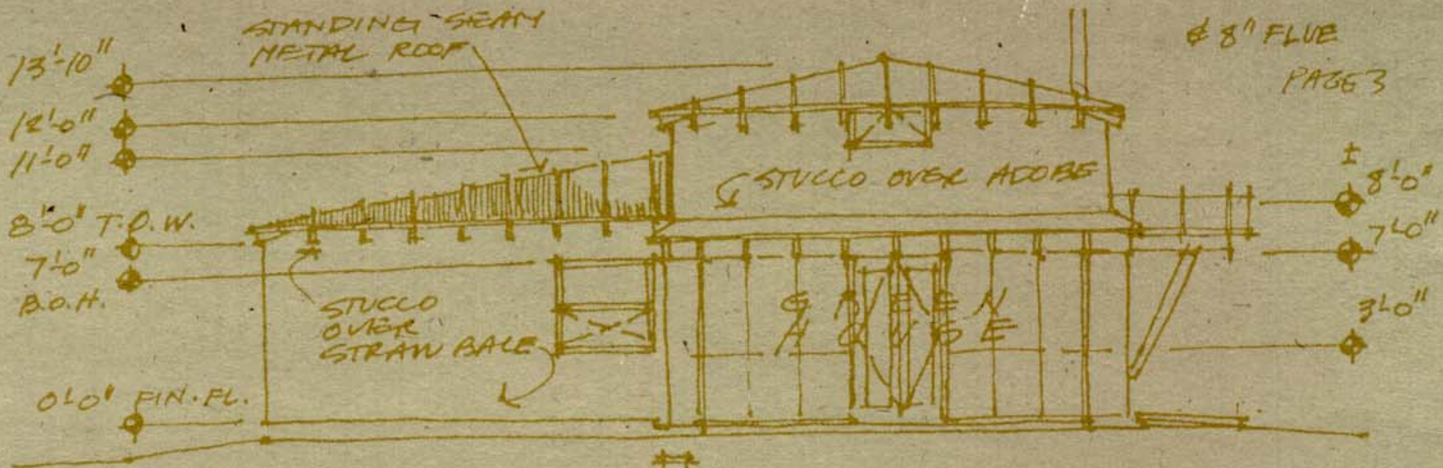

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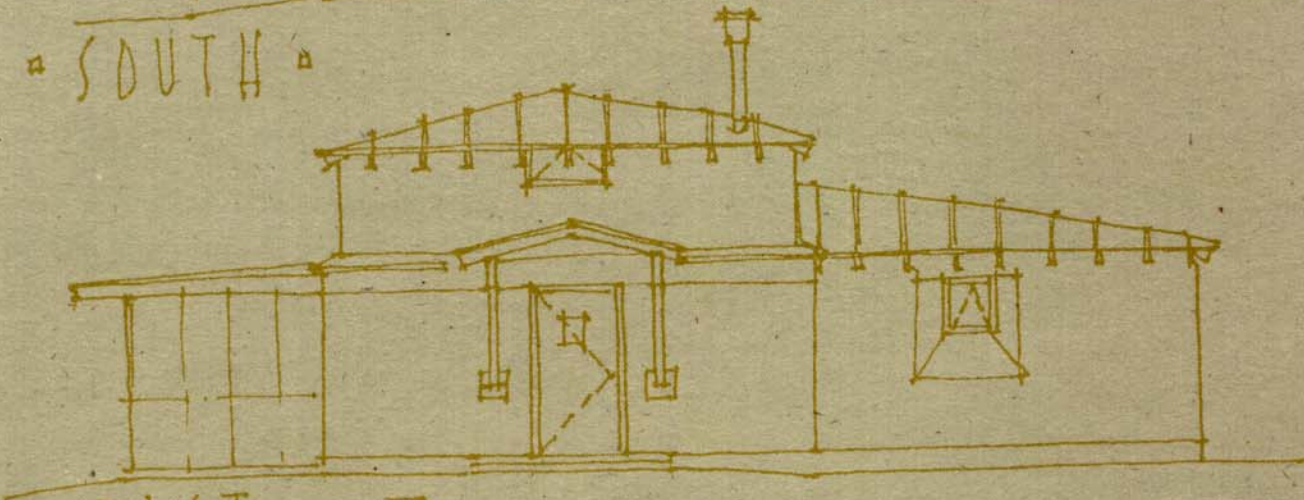

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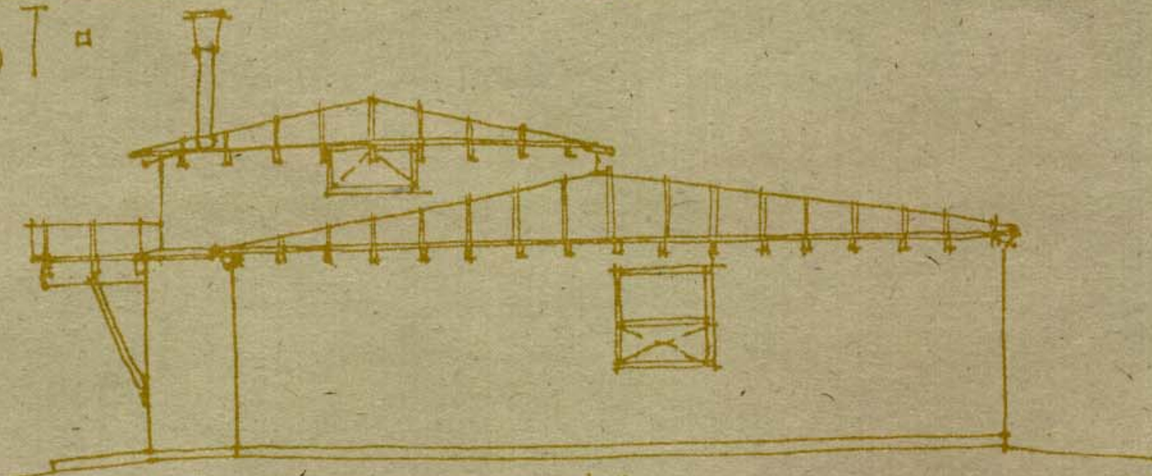

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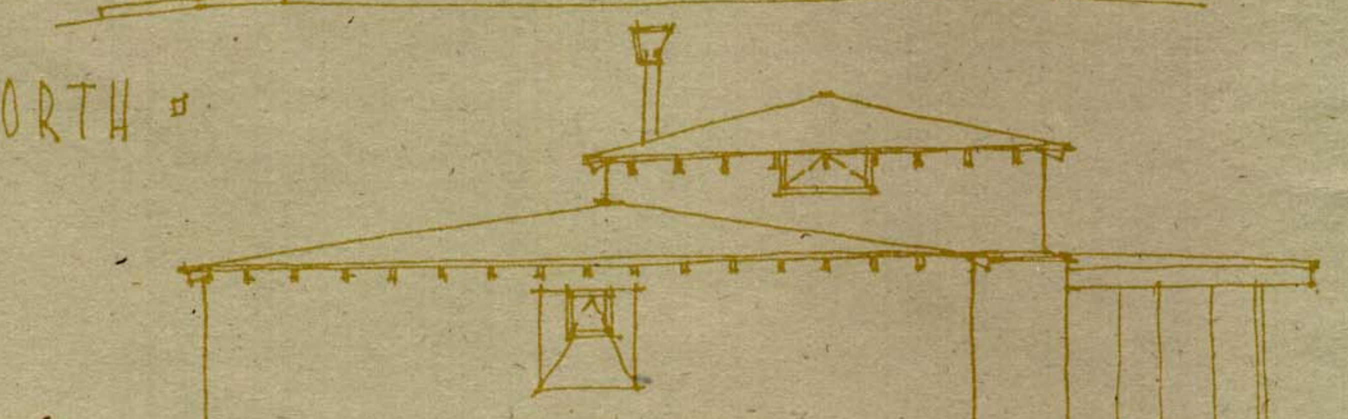

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