Energy Implications of Straw Bale Construction

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INTRODUCTION

In the United States. buildings account for nearly 40% of the total annual energy consumption, which is about 10% of the world's total (Architects for Social Responsibility 1.3). Of this amount, 6.25% is used for the manufacture and installation of building materials, another 5% or so is used to create our infrastructure, and the remainder is used in building maintenance and operation (Stein et. al.). The necessity of reducing building energy consumption has received increased attention as of late after a lull of interest in energy efficiency. This renewed interest is supported by additional arguments that emphasize the importance of reducing the amount of energy we consume as a society. We are no longer only concerned with the inevitable depletion of non-renewable energy reserves and the volatility of our imported supply, which was first brought to our attention with the 1973 Oil Embargo, but we have begun to realize the consumption of fossil fuels is having adverse effects on the global environment. Because of the significant amount of energy consumed by the U.S. building industry, it is a logical choice for exploring efficiency options.

The materials chosen to construct a building have a large impact on the amount of energy a building consumes in its construction and operation. There are alternatives to standard construction practices that consume less energy during construction and result in reduced operational energy. The alternative explored in this paper is the use of straw bales as the primary material for the exterior walls'. One of the reasons for choosing to examine straw bale construction as opposed to other alternatives is its potential for a significant reduction in embodied energy. As buildings become more efficient to maintain due to higher insulation levels, more efficient windows and more efficient heating and cooling equipment, the embodied energy percentage of the lifetime energy costs of the building becomes greater. Embodied energy varies greatly between construction methods and even the design of specific details may have a great impact on the amount of embodied energy a building contains. Straw bale construction, which has enjoyed a revival of sorts in recent years, provides substantially higher insulation levels than wood framed construction at a lower embodied energy cost.

In addition to energy savings, straw bale buildings have other environmental benefits. Most people are aware of the often fierce debates over logging rights which is fueled by the building industry's voracious appetite for wood. The housing industry alone accounts for more than one-third of all lumber and structural panel products as well as one-quarter of all dimensional lumber (Adams 62). Straw bale construction offers significant savings in wood consumption. Straw is also a much more sustainable resource than wood because it may be grown again in less than a year compared to the minimum twenty to eighty years it takes to produce trees suitable for construction purposes.

Straw bale construction may also serve to reduce air pollution, both interior and exterior. Many construction materials in current use contain many chemicals that off-gas and pollute interior spaces. Once they have been plastered, straw bale walls are not problematic for most people with allergies or environmental illnesses. The reduced energy consumption of a straw bale house over its lifetime (from both the embodied energy of its materials and from its more efficient operational energy use) produces less pollution resulting from energy production. In addition, it will serve to reduce the amount of air pollution resulting from the disposal of straw. Straw is typically considered a waste product that is either burned or left to decompose in the field, both of which have detrimental environmental effects. The burning of straw produces carbon monoxide, particulates, nitrogen oxides as well as the greenhouse gases carbon dioxide and methane and the ozone depleting gas methyl bromide. More carbon monoxide and particulates are produced per year from the burning of rice straw in California (56,000 tons) than for all of the power generating plants in that state combined (25,000 tons) (Bainbridge 13). When rice straw is left to decompose in the field it releases methane, a gas that is a significant contributor to the greenhouse effect, thirty times more successful at trapping greenhouse gases than carbon dioxide. Worldwide flooded rice paddies contribute ten percent of all atmospheric methane (Neue). Even if the straw is tilled back into the soil the methane emissions are estimated to be up to twelve times higher than for soil without the added straw (Bainbridge 14).

This paper will investigate perhaps the most important environmental claim for using straw bales as a construction process by examining the energy consumption of building and maintaining a straw bale house.

Although this paper focuses on one specific material, the process could easily be utilized to examine the relative impact between any construction systems. The process could be used in a classroom situation to explore the energy implications of a variety of construction systems or individual building details. The only exposure that students typically have to energy consumption is in learning how to calculate whole building heat loss for purposes of mechanical system design. For reasons mentioned above, it is important for architects, and the building industry in general, to understand the environmental impacts of their decisions. This method primarily explores the impact our decisions have on energy consumption.

PROCESS OF ANALYSIS

The analysis made in this research project focuses on the energy consumed to produce and operate a "typical" single family suburban tract home. A "standard" California tract home was chosen for this comparison, because it represents more closely the majority of residences constructed in this state. This particular design was also chosen because it is suitable for either standard 2x4 framing or straw bale construction due to its simple footprint (the typical configuration for a load-bearing straw bale home). For the comparison the existing house design was modified by replacing the standard wood frame exterior walls with straw bales (see Fig. 1). Note that the standard concrete floors and roof trusses of the existing house needed to be modified only slightly to accommodate straw bale walls.

We have utilized several well established calculation methodologies in this study. These include standard construction industry estimating practices for the materials take-off, the embodied energy calculation methods developed by the Stein Partnership (Stein, et. al.), and the DOE-2 computer program for the thermal analysis. For the thermal properties of the straw bales we used figures calculated by Joe McCabe (McCabe) and the embodied energy figures developed by Paul Fritz (Fritz 47-48).

The conventionally framed house has a conditioned floor area of 1,689 ft^2, 3 bedrooms and two full baths (see Figs. 1 and 2). The construction is a standard 2x4 fir stud wall, framed at 16"o.c. with walls insulated to R-19 (fiberglass batts between studs and rigid insulation on the exterior), an engineered roof truss system with R-38 ceiling insulation and an uninsulated slab floor. The exterior is stucco and the roof is covered with concrete roof tiles. A typical load bearing straw bale wall section showing the top plate, window header and foundation may be seen in Fig. 3.

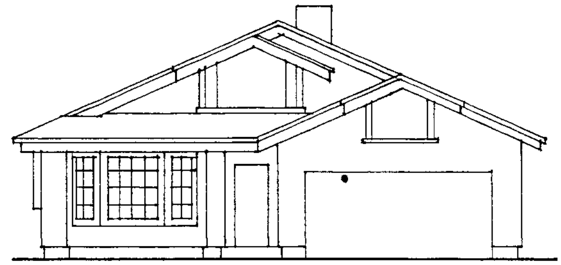

Fig. 1. Front Elevation

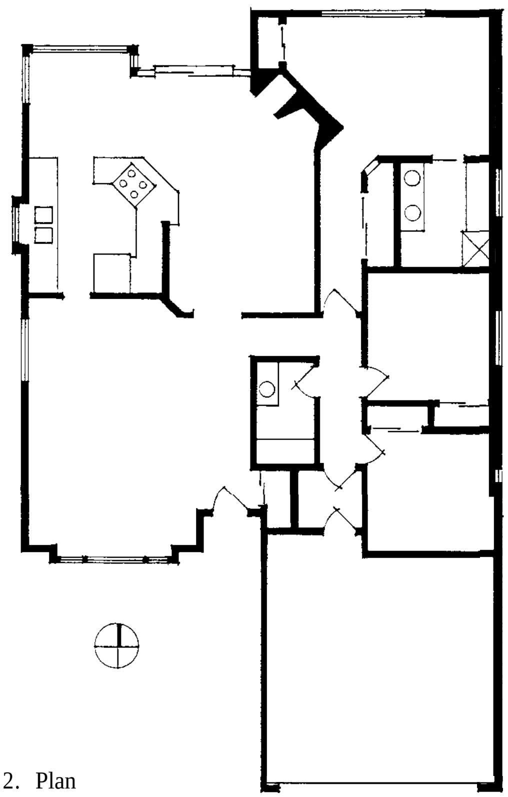

Fig. 2. Plan

EMBODIED ENERGY ANALYSIS

Being a waste product, it was difficult to find facts and figures on straw production. Because straw is an agricultural by-product, its embodied energy includes only the amount of energy required to bale the straw and transport it between the field and a building site. Vaclav Smil has calculated the amount of energy required to harvest various crop residues. The values ranged from around 1,000-5,000 Btu/bale (Smil 217). For the purposes of this study a conservative value of 5,000 Btu/bale was used[2].

Because there are a variety of methods of straw bale construction a number of possibilities for the design of specific details are being used around the country. This paper explores the embodied energy of two detail options for headers, as a comparison. This process could be applied to other details as well to determine the most efficient in terms of energy and materials used.

Table 1 is a summary of the amount of embodied energy

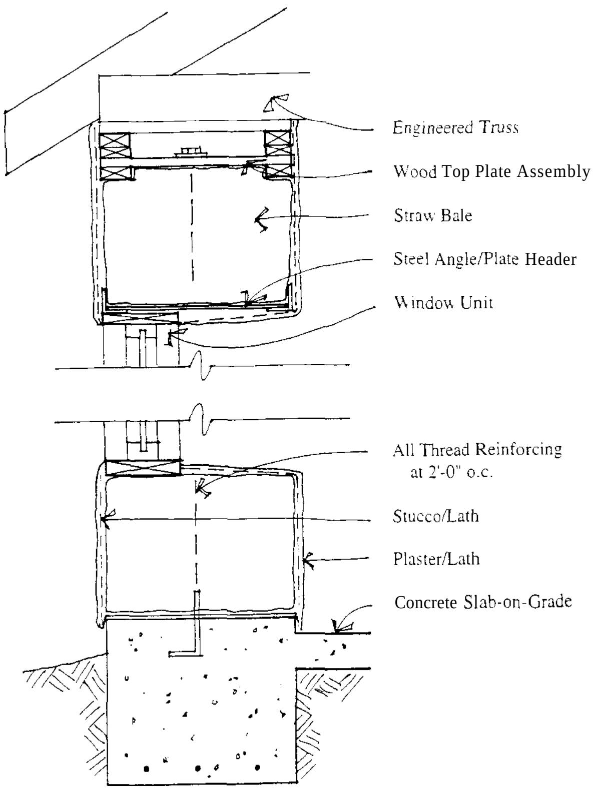

Fig. 3. Typical Wall Section

	Standard	Standard	Straw	Straw
	Embodied Energy	% of Total	Embodied Energy	% of Total
Slab	203,135	22	203,169	23
Interior Walls	47,323	5	45,070	5
Exterior Walls	108,152	12	100,334	11
Roofs	106,399	12	110,713	12
Ceilings	43,990	5	43,590	5
Finishes	57,097	6	57,097	6
Windows	22,740	2	16,813	2
Doors	2,476	<1	2,476	<1
Hardware	7,769	1	7,769	1
Plumbing	48,981	5	48,981	5
Electrical	33,780	4	33,780	4
Mechanical	84,450	9	84,450	9
Specialties	45,603	5	45,603	5
Direct Energy	62,493	7	62,493	7
Overhead	38,847	4	38,847	4
Total	913,237		**901,586**	

Table 1. Embodied Energy of Components (kBtu)

for different components of each house along with its percent of the total embodied energy.

It can be seen that the home built using standard construction practices requires only a little over 1 percent more energy (11,651 kBtu) to construct than the home that uses straw bales as its exterior wall construction. This 11,651 kBtu difference is equal to the energy content of about two barrels of oil (one barrel of oil is equal to approximately 6,000 kBtu) (Dorf 118). This is equal to about sixty therms of natural gas or 1,757 kwh of electricity[3]. This is not a significant amount on an individual house basis but considering there were over 1,000,000 new home starts in 1993 (U.S. Bureau of the Census 730), the potential energy savings is reasonably large.

Looking more closely at the energy comparison of the exterior walls, we see that the material with the most impact on the total embodied energy of the standard construction wall is the insulation which accounts for 30% of the total (see Table 2). The most energy intensive components of the straw bale wall are the steel window and door headers (29%) and the steel reinforcing (14%) (These were both included in the framing component of the wall). The straw bales themselves account for only 2% of the embodied energy of the exterior wall.

Straw bale construction does not always save as much embodied energy as one might imagine. This is largely due to the energy intensive materials used in conjunction with the straw bales (such as the steel reinforcing). The limited energy savings is also partly due to the fact that the external walls are only one piece of the entire building, accounting for roughly twelve percent of the embodied energy of the house. The single largest contributor to the house's embodied energy is the slab. Many straw houses are often constructed with a type of earth floor which would provide significant energy savings over using a concrete slab.

It is important to look at the details of construction in terms of embodied energy because the potential savings can be increased significantly if attention is paid to the energy consumption of the details. A comparison was made between the base case straw building and a building with redesigned headers with the objective being to decrease the embodied energy.

The original header detail involved an assembly made up of steel angles and plates. The primary advantage of this detail, other than its strength, was that it works better with standard bale sizes. The next course of bales is able to fit

	Standard	% of Total	Straw	% of Total
Framing	32,703	30	64,176	64
Insulation/Straw	43,251	40	2,137	2
Exterior Finish	15,460	14	16,538	16
Interior Finish	10,158	9	11,588	12
Exterior Tnm	5,281	5	5,284	5
Interior Tnm	1,297	1	611	1
Total	108,152		**100,334**	

Table 2. Embodied Energy of Exterior Wall Components (kBtu)

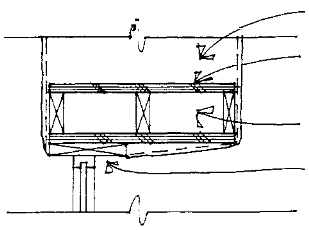

Fig. 4. Alternate Box Header Detail

between the angles without requiring any type of adaptation to the bale itself (see Fig. 3). Unfortunately, steel is an energy- and resource-intensive material and it creates a lot of pollution in its manufacturing process. The alternative header detail is a box beam constructed on-site using wood products rather than steel (see Fig. 4).

The optional header detail saves an additional 3.6 barrels of oil (22,000 kBtu). Other details may be analyzed in a similar manner to find alternatives which consumes the least amount of embodied energy. The type of evaluation can be used to influence the decision to use a particular detail just as issues of structural soundness, resource conservation and aesthetics should impact detail design.

OPERATIONAL ENERGY ANALYSIS

Because of the relatively high R-value and increased thermal mass of the straw bale house wall, most of the energy savings occurs in the conditioning of the house. Compared to the embodied energy figures of 913,237 kBtu for the standard house and 901,586 kBtu for the straw bale house, predicted yearly operational energy of the two houses is 49,920 kBtu and 38,410 kBtu respectively (for Sacramento). This demonstrates that the total construction embodied energy savings is equivalent to only one year's worth of operational energy savings. Table 3 reveals that the straw performs significantly better than conventional construction in the amount of energy it takes to cool. Savings may also be seen in heating energy but the magnitude is not as great as the amount of cooling energy saved.

Unlike the one-time energy expenditure of embodied energy, the amount of energy saved in maintaining thermal comfort in a house will accumulate for as long as the house is occupied. The energy savings for a more extreme climate such as that found in the upper Midwest would be even greater than that seen in this example.

A second evaluation was made by examining the effectiveness of individual building components at controlling heat transmission. The results were as expected. It was shown that the straw bale walls have a significant impact on the amount of conductive heat loss and heat gain while all other aspect of the building operate similarly.

Window set-backs in the walls were also evaluated for their energy use implications. The thickness of the straw bale walls provides an opportunity for decreased summer solar gains by setting the window back from the exterior of the wall and allowing the wall itself to shade the window. This alternative was examined for a six-inch and a one-foot setback on all of the windows, using Sacramento weather data. While this provides a decrease in the summer solar gains and the amount of cooling energy required, the amount of heating energy required increases because of a reduced amount of solar gain in the winter. In the end the overall energy consumption is actually slightly higher for both of the setback cases. (see Table 4)

It is important to realize that for this comparison the house is essentially a replica of the standard tract home in terms of its design. Greater energy savings could certainly be realized if the straw house were designed to take advantage of the thermal properties of the straw through the use of simple passive solar techniques such as large south-facing windows and massive interior materials. These strategies are particularly suited to straw bale construction. However, this side by side comparison provides a basic understanding of the energy savings potential of straw.

ECONOMIC IMPLICATIONS

According to straw bale architect Bob Theis, the cost of straw bale construction is presently running about the same as conventional construction methods, with a similar range from high to low depending on finishes and level of detail. It is slightly less expensive per square foot than wood frame construction, but this savings is mostly offset by the larger footprint required to accommodate the thicker walls. Theis points out that the extra cost is for additional roof area and greater foundation width, which is more closely equivalent to the square foot cost of garage construction rather than the cost of finished house construction (Theis).

The operational cost savings are shown in Table 5, which compares the costs for heating and cooling each house for a year using gas heat and electric cooling.

	Standard	Straw	% of Standard
Lighting	17,120	17,120	100
Heating	21,300	18,800	88
Cooling	3,830	1,900	50
Misc Pumps	430	4.30	100
Ventilation Fan	240	160	66
Totals	49,920	38,410	

Table 3. Operational Energy Comparison (kBtuh)

	6" Setback	1' Setback	Original
Heating	19,600	20,800	18,600
Cooling	2,180	1,780	2,490

Table 4. Window Setback Savings Comparison (kBtu)

	Standard	Straw	Savings
Heat (therms)	$117.80	$105.34	$12.46
Cool (kwh)	$143 01	$87 35	$55 69
Totals	**$260.81**	**$192.69**	**$68.13**

Table 5[4]. Annual Heating and Cooling Savings (for Sacramento)

CONCLUSION

This process has demonstrated that straw bale construction clearly provides savings in energy consumption when compared with standard wood-framed construction methods. The energy required in the production and assembly of the materials into a finished house has been shown to be *33,650* kBtu less than a comparably designed wood framed house (using the more efficient header detail). This is about 96% of the amount of energy required to produce the standard home and a savings equivalent to *5.6* barrels of oil. The savings could be significantly increased with further exploration of details that contain less embodied energy. For example, a structural system without steel reinforcing would save considerable energy. Some possibilities include using bamboo or wooden rods to reinforce the bales. Narrower but taller windows would require smaller headers, a high source of embodied energy particularly if detailed in steel.

The straw house's performance with regards to thermal comfort was also addressed. In this area the straw house also showed notable savings when compared to the standard, especially with regards to its cooling energy consumption (a *50%* reduction over the standard home).

There is another issue pertaining to energy consumption that was not addressed in this paper but should be examined to learn the full energy impact of straw bales as an alternative construction process. The choice of particular details or material can impact the lifetime energy consumption for maintenance of the building. If a material with less embodied energy requires painting every ten years, its lifetime energy costs may eventually be higher than an alternative material which only needs repainting every twenty-five years. Frequent cleaning or replacement due to normal wear and tear (as in the case with different roofing systems) will also significantly impact a material's lifetime energy costs.

In the past, students have only been taught to evaluate energy usage in the operational phase of a building. Teaching the evaluative technique described in this paper will enable students to begin to understand the more far-reaching implications their decisions have on energy use and the environment. This examination of straw bale construction demonstrates that it can be an environmentally beneficial alternative to standard construction practices, particularly in terms of energy consumption. It is hoped that by using evaluative processes such as this one we will begin to make wiser choices in the materials and details we choose to build with.

Although this study has demonstrated some of the environmental benefits that can be obtained from the use of straw bale construction, it is unlikely that straw bales will ever become a widespread replacement for mainstream construction methods. Like brick and cement block, straw bales are too heavy to be economically transported great distances, so the revival of their use will probably be limited to locales where straw is readily available. However, as the price of more commonly used building materials continues to rise (e.g., wood and steel), locally available straw bales may become economically feasible alternatives for certain segments of society.

ACKNOWLEDGMENTS

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NOTES

1 For further information on the history of straw bale construction and on the current trends in its revival, see *The Straw Bale House* by Steen, Steen, Bainbridge and Eisenberg.

2 This value also agrees with the values arrived at by Bainbridge as noted in footnote 24 of Richard Hofmeister's "Plastered Straw Bale Construction: A Renewable Resource for Energy-Efficient Self-Help Housing." ACSA Technology Conference, 1994.

3 1 therm = 100 kBtu, 1 kwh = 3.413 kBtu

4 Costs were figured using Pacific Gas and Electric baseline rates of $0.56633/therm; $0.1195/kwh.

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