

# Mainstreaming Straw Bale Construction

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## 1. INTRODUCTION:

When HOK earned the assignment to design a Transit Maintenance Facility for the City of Santa Clarita, California, the client challenged the design team to deliver the most environmentally innovative project possible on a modest budget. This challenge aligned with the client's strong belief that its public projects should lead by example in its efforts to incorporate sustainable design into the community.

Viewing this scenario as an opportunity rather than an impediment, the design team vowed to exceed the client's expectations while respecting its limited budget. But the task was complicated because of the site's location in the high desert, 25 miles northwest of Los Angeles.

This paper discusses the process undertaken by the team to evaluate and ultimately select straw bale construction as the optimum design solution. The practical discussion will encompass research, design, constructability and cost issues related to straw bale construction in a contemporary one-story office building that is being designed to meet LEED™ Gold Criteria.

## 2. CLIENT INVOLVEMENT & INTEGRATED DESIGN PROCESS

To create an integrated design team and design approach it is imperative to involve the client in the design decision-making process. We are fortunate to have a client that was willing to make the investment in time and manpower to join this effort. Very early in the design process the design team held an eco charette. From the charette came the goals and desires of the owner for a sustainable project. Soon after the charette we embarked on field trips to projects which incorporated the strategies that were seen as most desirable for incorporation into our project. Those were passive cooling with cool towers and straw bale construction.

### 2.1 The Eco Charette

In order to ensure that all members of the design team understand the goals and aspirations of the owner for the level of sustainability to be achieved on the project an eco charette is held prior to the beginning of the design process. It consists of a presentation made by the architect and the key consultants to the owner, users, and possibly the building contractor. The purpose is to educate the group about sustainable design and establish goals for the project through examples of sustainable building systems and construction techniques which are appropriate for the project. If the LEED™ program is used on the project, an effective format for the eco charette is to use the LEED™ criteria as topics in the presentation.

### 2.2 Integrated Design Team

An integrated team is essential to a successful sustainable design. In our case the integrated team consisted of the owner, architect, MEP engineering consultants and the landscape architect.

Since this was a public project, it was not possible to include a contractor because the project would have to be an open bid at the conclusion of design.

### 2.3 Site Visits

The site visits focused on built projects or those under construction which had incorporated straw bale construction and passive cooling. We visited two projects in northern California, the Real Goods Store and Ridge Winery, which used straw bale construction. We also visited the Zion National Park Visitor Center in Utah, which incorporated passive cooling with cool towers.

#### 2.3.1 Real Goods – Hopland, Ca. (Fig. 1)

The design team along with the client first visited the Real Goods store in Hopland, Ca. designed by Van Der Ryn Architects of Sausalito, Ca. and completed in 1996. The building has a load bearing straw bale exterior wall and incorporates many sustainable materials and technologies. The daylighting and passive solar strategies incorporated into the design are so successful that the building operates without a main mechanical system for heating or cooling. Even on 113° days, the indoor temperature is in the 70's.



Figure 1. View of Entry to Real Goods Store

#### 2.3.2 Ridge Winery – Healdsburg, Ca.

South of Hopland and the Real Goods store is the Ridge Winery in Healdsburg, Ca. designed by Freebairn-Smith and Crane Architects of San Francisco. The design team visited the winery during its construction. We were able to see the structural system used to laterally reinforce the two story infill straw bale wall construction (Fig. 2). The building acts as a “thermos bottle” to hold in the nighttime cool air to achieve the low indoor temperatures required for the winemaking process.



Figure 2. View of Entry and Detail of Straw Bale Wall

### **2.3.3 Zion National Park Visitor's Center – Zion National Park, Utah. (Fig. 3)**

Finally, the design team visited the Zion National Park Visitors Center. This project was designed by the architects of the National Park Service with engineering assistance by the U.S. Department of Energy's Office of Building Technology, State and Community Programs. The purpose of this visit was to view the operation of the "cool towers" which are used to passively cool the building. Cool towers use evaporative coolers placed on top of chimneys to create cool down draft air directed into the space. Cool towers can be used in hot climates with low relative humidity. Our project in Santa Clarita site has such a climate. Our original concept for the design of the Transit Maintenance Facility was to have cool towers connected to an under-floor air delivery system. Ultimately, the client was not comfortable with the risk level of such a system and it was not used on the project.



Figure 3. View of "Cool Towers" and Entry Courtyard

### **2.4 Site Visit Conclusions**

The client was very impressed by the projects incorporating straw bale construction, but was skeptical about the passive cooling strategy using cool towers. The quality of the architecture and the finish achieved in the straw bale projects was excellent and was seen a desirable system for use on their project.

## **3. BENEFITS OF STRAW BALE CONSTRUCTION**

Straw bale construction has many unique advantages of conventional wood frame or light steel construction. Contrary to popular belief, straw bale construction is extremely durable and long-lived. It provides a very high insulation value (aprox. R-3/in.). It contributes to excellent indoor air quality since it contains no V.O.C.'s or other toxic compounds,. Straw is a waste product of the grain farming industry and up until recently the burning of rice straw in California was the single largest contributor to air pollution in the state. It is a rapidly renewable resource. The cost of straw bale construction can be lower than wood framing.

### **3.1 Basic Construction Techniques**

Structures built over 100 years ago exist and are still used in Nebraska where the technique of using straw bales for building construction evolved. Its resistance to burning, pest infestation, and high insulation value make it one of the most efficient and cost effective building materials for one and two story applications. It can be used in non-load bearing (infill) and load bearing

configurations. In California, rice straw is used for the bales where it is readily available and inexpensive. The bales generally come in two sizes, but the three-string 23 by 48 by 16 inch version is preferred for construction.

Quite a bit of testing has been performed on straw bales. ASTM E84-09 documents the surface burning characteristics. Baled straw is resistant to burning because to maintain combustion three elements must be present: fuel, heat, and oxygen. Straw bales are so tightly compacted that there is not enough air inside to maintain combustion. The surface of the bale will burn but once it has charred the fire is then deprived of fuel and cannot continue. The greatest danger of fire is during construction. Measures must be taken to avoid loose straw on the jobsite, which can be ignited.

Straw bale construction is pest resistant. Once straw is dry it is made up of mostly cellulose and lignin. Rice straw also contains silica, which makes it somewhat harder to cut with tools. There is virtually no nutritional value in the dried straw, so pests are not drawn to it. Once the wall is covered with plaster there is no opportunity for pests to use the wall interior as a nest or for bedding.

To build with bales the moisture content must be less than 20% of their total weight. It is advisable to purchase the bales well in advance of when they are required and stored in a dry place to allow them to reach and maintain the specified moisture content. The interior of the wall once constructed needs to breathe. Lime plaster must be used as the exterior enclosure of the straw bale wall because it is porous and allows moisture to move through it maintaining the desired level inside the wall. No lath to adhere the plaster to the straw is required. The ends of the straw shafts left exposed in the straw bale act as lath providing the surface area required to the plaster to grip the straw bales. Once the plaster has been “blown-on” to the straw bale wall and the finish coats have been applied, the wall is a straw/plaster unit with a surprising amount of lateral force resistance. 1 ½” of lime plaster on both sides of the wall is used on the Santa Clarita project. A lime-plaster slurry can be used as the final finish of the wall maintaining the breathability of the wall and eliminating the need for paint. Some projects, such as at the Real Goods Store have used up to 4” of an earth plaster (pisé) mixture on the interior surface to create thermal mass.

One of the obvious challenges of straw bale construction is the additional width of the wall compared to standard construction and the size of the foundation required to support it. The size of the foundation is not so much related to the load of the wall as it is to the width of the bales themselves. The design of the foundation must be considered carefully because the added cost of a perimeter foundation that is 24” wide could lessen the economic viability of the wall system. The foundation of the wall must rise above the surrounding grade by at least 6” to protect the bottom of the wall from moisture. It is advisable to have through wall flashing at the base of the wall to direct any moisture from the interior of the wall to the outside. Some method of restraining the wall during construction must be considered. On Santa Clarita we used internal pinning to hold the bales together while they are going up. Other types of restraint are also used, such as wrapping the wall with expanded metal from the foundation up and over the top of the wall. A perimeter bond beam can be constructed on the top of the wall and tied to the foundation

by means of straps or threaded rods. This beam will “pre-compress” the wall taking out unwanted future settlement.

### 3.2 Super-Insulated Envelope

Straw bale wall construction can be combined with high performance glazing and a well insulated “cool” roof come together to create a super-insulated envelope. (Fig. 4) This is the strategy we adopted in the design of the Santa Clarita Facility. The strategy is well suited to the climatic conditions in Santa Clarita where large diurnal temperature swings allow the storage of cool nighttime air inside the building. The straw bale envelope insulates against the extreme daytime temperatures. Glazing is shaded by deep roof overhangs which also provide protection of the straw bale walls from direct moisture contact. The system maximizes energy-saving potential and creates compelling and innovative contemporary architecture, well suited to a desert environment.

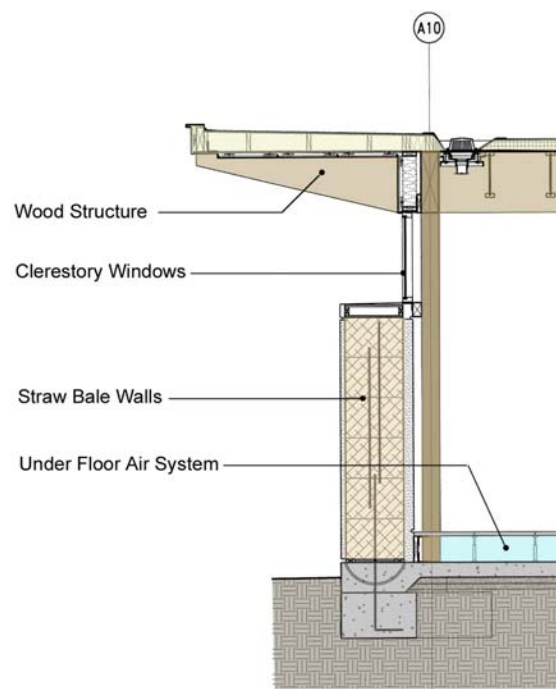


Figure 4. Wall Section – Straw Bale Wall System

## 4. STATE AND LOCAL CODE ISSUES

Introduced in February and amended in March of 2001, the state of California has passed bill number: SB 332 that allows straw bale construction for 1 and 2 story, load bearing and non-load bearing structures. The intent of the bill is to:

- Promote low cost, energy efficient housing (construction)
- Offer alternatives to lumber framed housing and its associated rising costs
- Promote the use of an annually renewable material – Straw
- Help reduce the burning of straw in the fields and its polluting effects.
- Assist in the creation of an economically viable straw bale market
- Allow the use of straw for load bearing and non-load bearing construction according to certain provisions.

Local jurisdictions in California can adopt the language of this legislation allowing the use of straw bales into their local code. Santa Clarita, an unincorporated city in Los Angeles County, has its own building department that has accepted straw bale construction. This allowed us to pursue straw bale construction on the project.

## **5. INNOVATIVE DESIGN TECHNIQUES FOR MANAGING COSTS**

The budget for the Santa Clarita project was modest, which was a primary reason we originally considered the straw bale wall system. We had to go further to reduce costs of the systems to achieve our budget. Rather than using the typical steel-braced frame for the main structure, we used heavy timber construction with long spans. An off-the-shelf, highly efficient water source heat pump HVAC system delivers air to the project through an under-floor air delivery system. All of these systems combined to allow us to have an aggressive material efficient design. The wood structure was left exposed; no overhead ducts meant a clean unobstructed ceiling. The raised floor system uses concrete filled metal pans. These are left exposed as well eliminating the need to carpet or other floor covering for the majority of spaces. We were driven by a “less is more” mind set.

### **5.1 Integrated Systems**

Buildings must respond to their immediate environment to be truly sustainable. Generally, the architecture of the recent past has tended to rely upon a “one design fits all” approach to the environment. This tendency is mainly due to the reliance upon building technology to equalize the effect of the exterior environment regardless location. A building in New York often looks quite similar to one in Los Angeles. Obviously the building’s systems are dealing with a different set of parameters based on the particular climatic conditions but because of our clever manipulation of materials and technology, we are free to shape the building without regard to the effects of the sun, the movement of the wind, or any other component of the environment. The cost of our neglect is high as evidenced by the energy use of these buildings. Buildings account for more than 40% of total energy use in the US and are trending higher each year.

An integrated design strategy begins with the basics. Proper building orientation is essential. The building is oriented with its long facades facing north and south. Glazing is minimized on the east and west and shaded as much as possible. Glazing on the south is maximized but shaded from summer sun. The form of the building is analyzed to maximize indirect solar penetration to support a daylighting strategy. The floorplates are narrow to support this idea as well. Opportunities for natural ventilation are explored. All of these things are done at the outset of design as simple lines on paper, yet the result is a basis of the design which will require less energy to operate and less material to construct. This is before more complex strategies are explored, such as, high performance glazing, high efficiency mechanical systems, under-floor air distribution, renewable energy generation, and so on.

## 6. SANTA CLARITA TRANSIT MAINTENANCE FACILITY – A STRAW BALE CASE STUDY

### 6.1 Project Description

The project is located on a 12 acre site north of downtown Santa Clarita, California in the high-desert region. (Fig. 5&6) The total building area on the site is 66,700 gross square feet. The project consists of two principal buildings; the administration building, and the maintenance garage. There are unconditioned buildings on site used for bus fueling and washing. Parking for buses and staff vehicles take up most of the rest of the site area. A facility for storage and dispensing of compressed natural gas (CNG) to the buses is located on the south east corner of the site. A public CNG station will be built under a separate contract on the northern edge of the site.



Figure 5. Site Plan – Santa Clarita Transit Maintenance Facility

This project is the headquarters for the Santa Clarita Transit District. It is located in an existing industrial park a few miles north of downtown Santa Clarita. The primary design response is to the desert environment. The administration building creates a courtyard which provides a pleasant landscaped atmosphere away from the harsh environment of the bus yard.

### 6.2 Sustainable Design Strategies

This is a list of sustainable design strategies incorporated into the project:

- Exceeds T-24 energy requirements by 37.5%
- Under-floor air distribution
- Straw bale wall construction
- Narrow floorplates
- Integrated daylighting strategy
- Skylights
- Nighttime ventilation
- Water source heat pump mechanical system
- High efficiency lighting fixtures
- High performance glazing
- Shading devices
- Fly ash substituted for portland cement

- Building materials are supplied locally and selected for durability
- Indigenous landscaping – reduced irrigation
- “High cut-off” site lighting fixtures
- Light colored materials
- Dual flush toilets
- Waterless urinals
- Low VOC finish materials
- Rapidly renewable materials
- Material reduction – “less is more”
- Designed to achieve LEED Gold level rating.



Figure 6. Aerial Perspective View of Project

This is HOK’s most highly integrated sustainably designed building thus far. The administration building is planned around a central courtyard to maximize the connection between indoors and outdoors. The floorplates are narrow, no more than sixty feet. Very few spaces are without views of the exterior. (Fig. 7) The building is heavily shaded by roof overhangs. This accomplishes two things, shading of windows and protection of the perimeter straw bale walls.



Figure 7. Floor Plan – Administration Building

The non-load bearing straw bale walls create a super insulated skin. These walls are highly fire resistive and are not subject to pest infestation. High performance glazing completes the envelope. Conditioned air is supplied via an under-floor air system. Building occupants are able to control their immediate environment by manipulating floor diffusers.

The climatic conditions in Santa Clarita promote the use of nighttime ventilation. The desert environment has large diurnal temperature swings; cool night air is brought into the building at night to pre-condition the space for the following day. The under-floor air system reduces loads by allowing conditioned air to be delivered at a higher temperature and is designed to only condition space 7' above the floor. The mechanical system is a series of water source heat pumps. Chilled water is generated by a cooling tower on site.

Water efficient plumbing fixtures are used throughout the project. Dual flush toilets offer the option of 1.6 or .8 gallon flushes. Waterless urinals are used to further reduce water use.

The structure of the buildings utilizes engineered wood to maximize material use. Engineered wood is made from relatively young trees that are from managed forests.

Interior finishes of the administration building were selected for their recycled content, low toxicity, and use of rapidly renewable materials. All casework and millwork is constructed of wheat straw board instead of the conventional medium density fiberboard or plywood. Wheat straw board is rapidly renewable and contains no VOC's.

The maintenance garage is a more conventional structure. It has the same clerestory and skylight design to enhance daylighting as the administration building, but the exterior walls are of tilt-up construction. Fly ash, a recycled product from coal burning utilities is substituted for Portland cement in the concrete walls and slabs throughout the facility.

The exterior finish of both buildings is simple. The Administration building uses lime plaster on the straw bale walls and is finished with slurry made from the lime plaster itself. Metal shingles made from highly recycled copper cover exterior wall surfaces that are not straw. The maintenance garage tilt-up panels are use integral colored pigments to match the light color of the administration building. This durable finish can be cleaned with water and will not need painting.

Conservation of materials was a fundamental principal of the project. Materials were only used as necessary and many areas inside the administration building are left without carpeting or ceilings. The concrete panels of the raised floor and the wood of the roof structure provide an adequate and aesthetically pleasing finish for the interior of the building. This focus on "less is more" has helped to produce a project with a high level of sustainable design on a budget consistent with conventional buildings of the same type and size.



Figure 8. Exterior Perspective of Entry to Administration Building

## 7. CONCLUSION

The process of integrated design is fundamental to a sustainable design approach. An integrated team strategy leads to early incorporation of methods and technologies that lead to a truly sustainable design. An integrated design allows the building to do more with less, leading to a more economical and sustainable design. Tools such as the eco charette and field trips to completed projects which exhibit the desired systems allow a design team to make informed decisions early and to more quickly develop their own design. Straw bale construction may be a rediscovered technology, but it is a technology that is appropriate and sustainable by today's standards. When combined with more current technologies like under-floor air distribution, high performance glazing and daylighting, it can become a powerful strategy for creating an extremely energy efficient building.

Careful consideration of protection for the straw bale wall is essential. The worst enemy of the straw bale wall system is moisture. Every effort during design must be made to create a straw bale wall system that will not trap moisture in its interior.

Straw bale construction offers many design opportunities. The thickness of the bales gives the design a massive appearance. Setting the glazing in the deep openings takes advantage of shading and gives shadow and contrast to the exterior façade. To achieve the thickness of a straw bale wall with conventional construction much more material would have to be used. Straw bale construction opens up the possibility of a whole new aesthetic, one where only the essential materials are needed to render form to the building while helping achieve a cost and energy efficient building and promote a healthier indoor environment; the basis of a sustainable design.

## 8. REFERENCES

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