The Villa: An Architectural Study in Straw Building

Lindsey L. Buck-Moyer

Signature of Author:
Department of Architecture
May 25, 2006

Certified by:
Ann Pendleton-Jullian
Associate Professor of Architecture
Thesis Supervisor

Accepted by:
Jan Wampler
Professor of Architecture
Director of Undergraduate Architecture Program

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN ART AND DESIGN AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2006

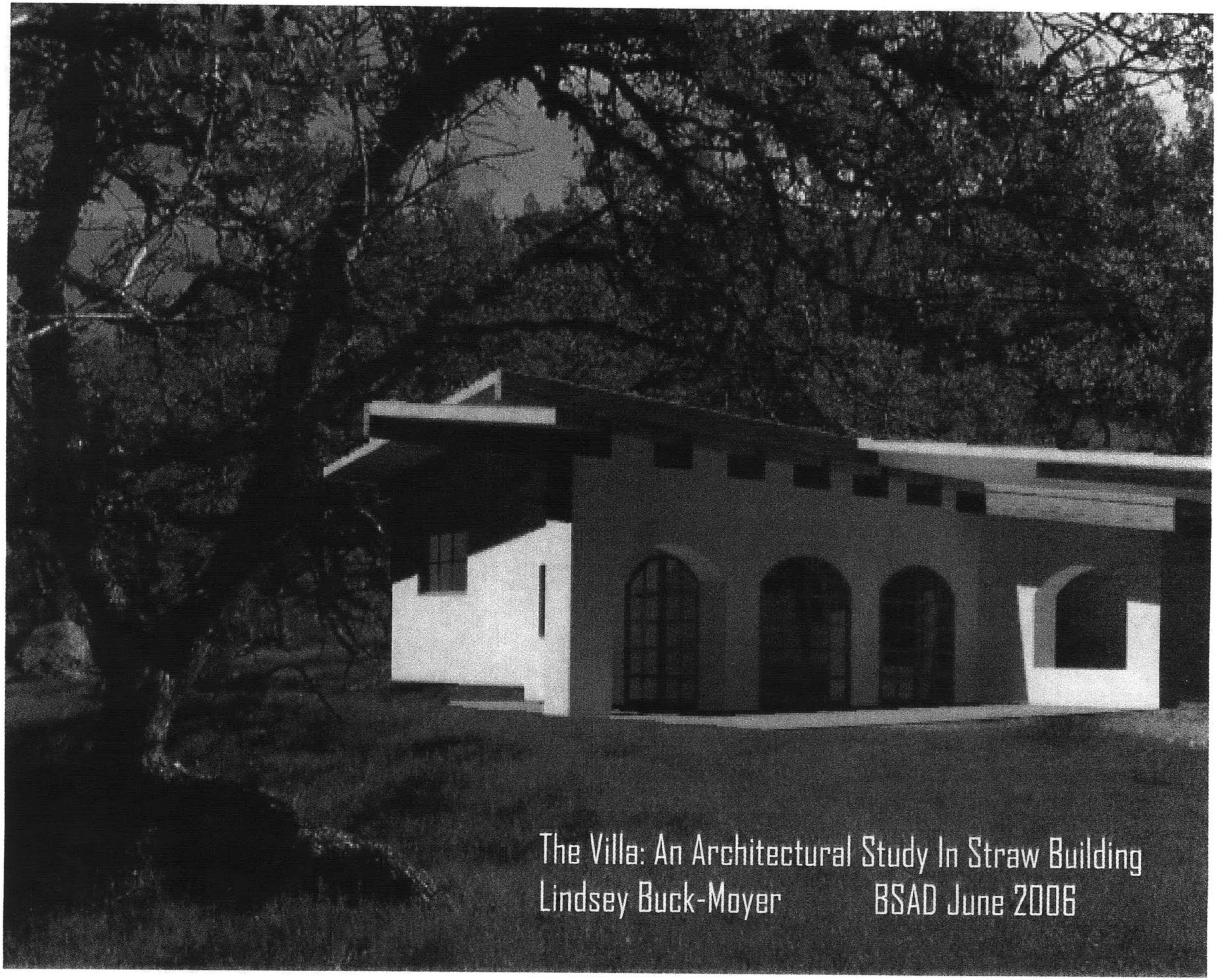
Read By:
Leon Glicksman
Professor of Building Technology

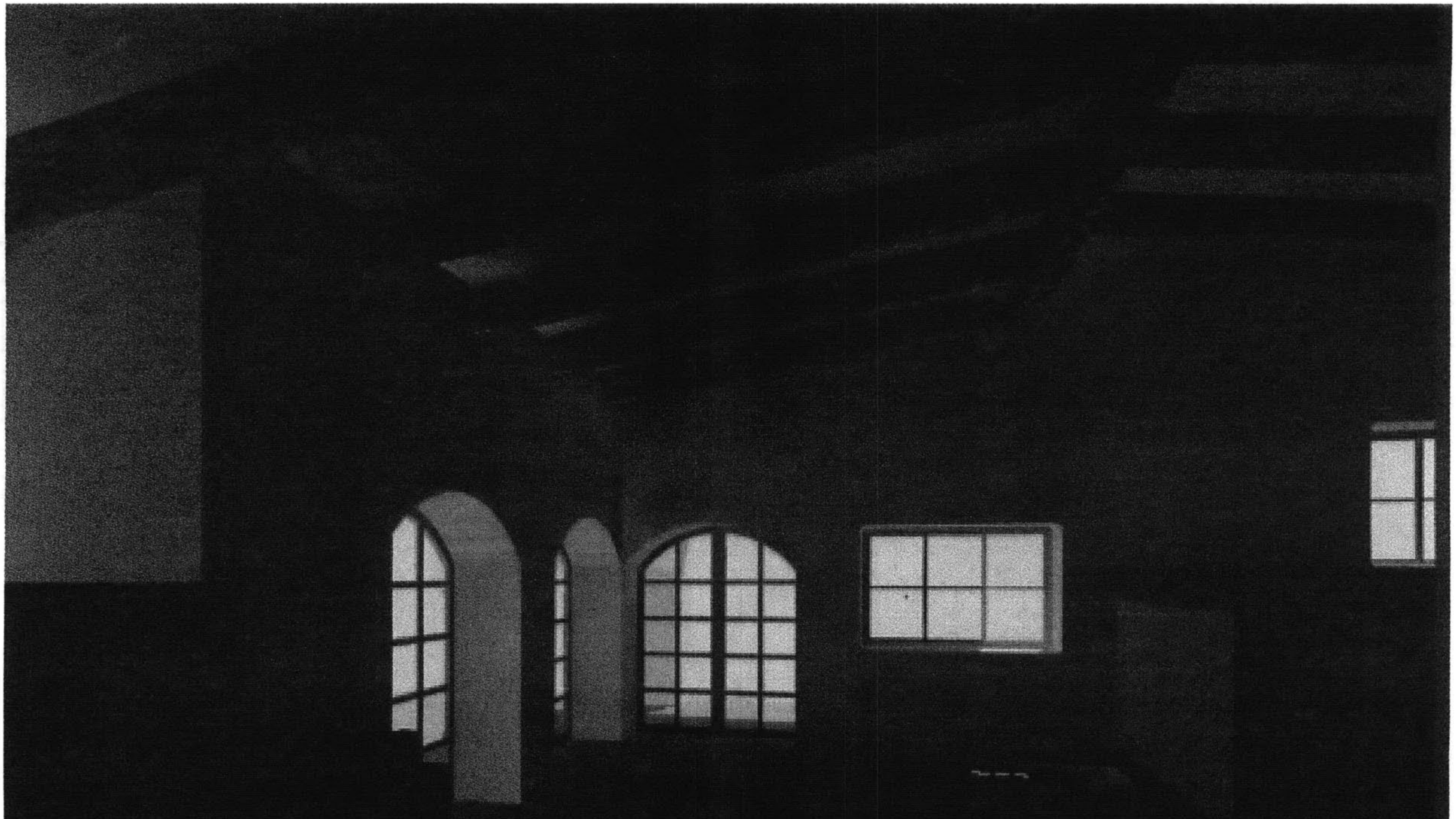
Lindsey Buck-Moyer
June 2006

The Villa: An Architectural Study in Straw Building

Abstract:

Design and develop an environmentally sound home for a single family. Explore the concept that making a that making a home "green" or "sustainable" need not overwhelm the aesthetic, spatial or conceptual components of a house.


The Villa: An Architectural Study In Straw Building
Lindsey Buck-Moyer
BSAD June 2006



Introduction:

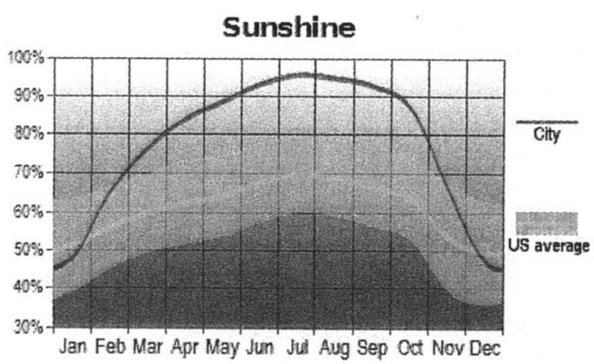
The topic of this thesis is the design of a small, single family home in central California, specifically San Luis Obispo County. This area of the country is both knowledgeable about and concerned with the environmental impact of residential development. The focus of this thesis is the successful integration of appropriate technologies on an individual scale, without dominating the appearance or design concept of the home. This thesis presents the notion that making a home "green" or "sustainable" need not overwhelm the aesthetic, spatial or conceptual components of a house.

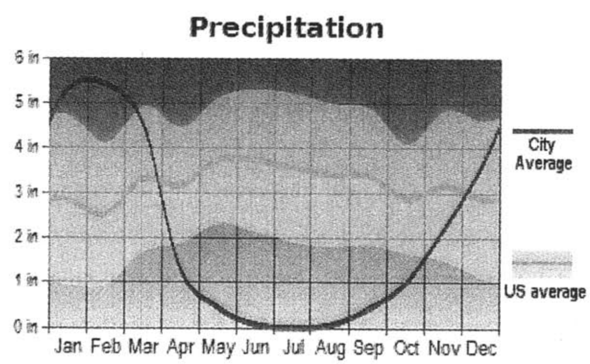
Location

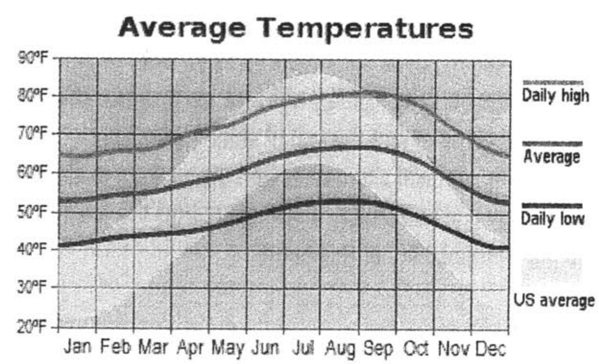
This home is located on a rural site outside San Luis Obispo, California. The area is well known for its beautiful weather: hot and dry in the summer, and only slightly wetter and cooler in the winter. Due to the desert nature of the climate, the diurnal and nocturnal temperatures vary greatly in both the summer and the winter, which makes this site ideal for the use of thermal mass. The seasonal changes in this region are fairly mild, so the temperature can be kept within the comfort range using almost completely natural means.

The main energy concern in this climate is how to keep buildings cool in the summer. Temperatures often reach greater than 100º F for stretches of up to three weeks in the summer. However, the winters are generally mild, and require only minor levels of heating. The winter nights that do drop below freezing are then warmed by the sun, raising daytime temperatures.

San Luis Obispo County is extremely sunny, showing almost no clouds for most of the spring, summer, or fall months. This makes the climate well suited for the use of active and passive solar technology, and using daylight throughout most of the house.



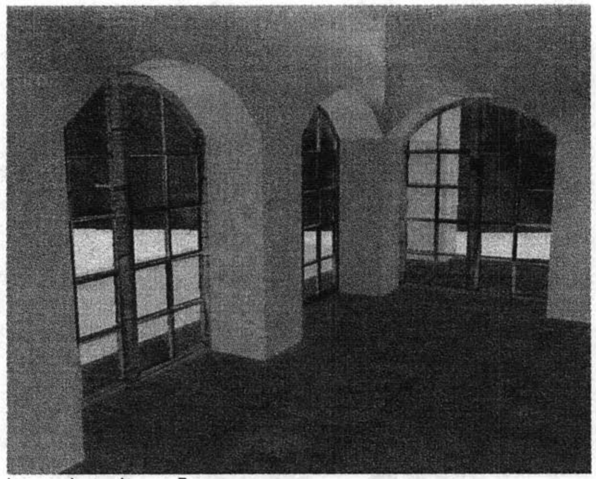




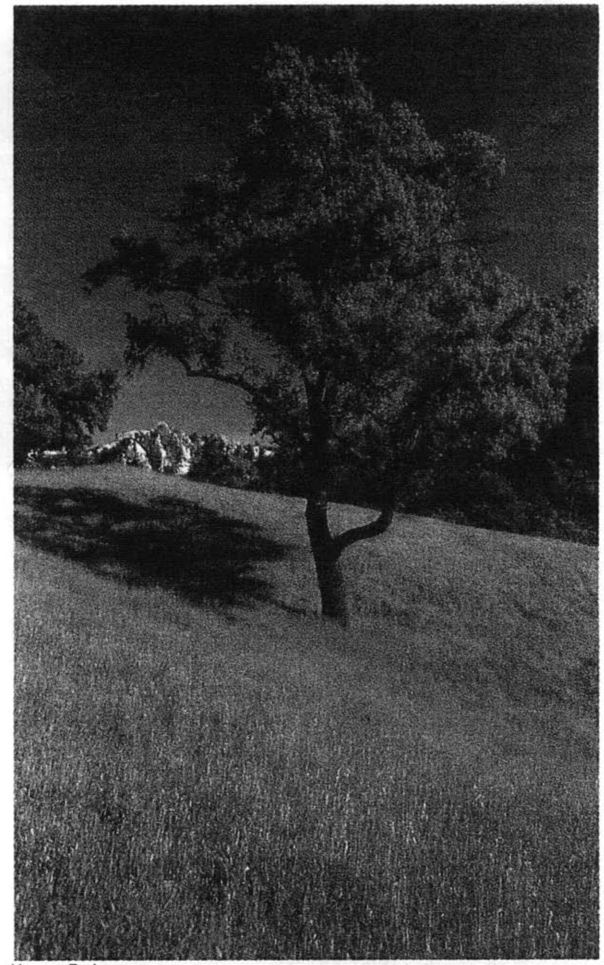
Environmental Sustainability

There are many sustainable components to this design project. These components encompass a range of costs, technologies and design commitments. Some choices are technologically simple, but require much foresight and are highly prominent in the final design. However, some components are simple to integrate into traditional construction. Each technology or material has been carefully selected because it is better than the alternatives. As in all architecture, there is an interplay between components. Some are selected for their environmental impact, with a small detriment to asceticism; some are the other way around. Overall, most components are both most aesthetically pleasing and environmentally sound.

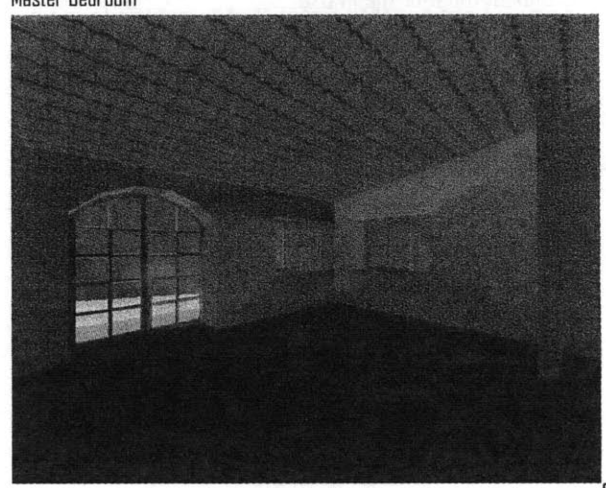
There are many environmentally interconnected elements of this design project. Both active and passive solar technologies contribute to the energy efficiency of the home; flat plate solar collectors provide supplementary domestic hot water while solar shading optimizes winter sun and minimizes summer heat gains. Thermal mass and natural ventilation complement each other to cool the home in the summer and keep it warmer in the winter. Building and finish materials were carefully selected for their embodied energy and the long term environmental benefits they bring to the home. The most prominent material is the use of straw bales as insulating material, but other features are also important. Concrete, timber, rammed earth, adobe and straw bales all work together to make the home as energy efficient as possible. These materials complement the use of solar technology, daylighting, natural ventilation, and thermal mass. Both technology and materiality are essential for the environmental sustainability of this home.



Interior Living Area to Patio



Master Bedroom



Solar Energy

Harnessing solar energy is good for the environment and for the homeowner. Solar energy is the planet's most abundant and most renewable energy source. On a clear day, the sun shines approximately 1,000 watts of energy per square meter of the planet's surface. (SESCI) The sun's energy is a largely untapped resource, and in central California, a ubiquitous presence. This is a huge amount of energy available; but it is difficult to convert it to a usable form, such as electricity or heat.

There are many methods for capturing the sun's available energy. These methods are divided into two categories: active and passive solar technologies. Passive solar is defined by having "no additional mechanical requirements." (SESCI) Passive solar technologies are used in many buildings, and can be as simple as installing interior blinds for increased inhabitant control. Active solar technologies also come in a variety of forms, including flat plate collectors, space heating systems and photovoltaic cells.

This design project uses both active and passive solar technologies. The roof overhang prevents higher summer sun from penetrating into the building, while allowing the lower sun angles of winter to warm the interior space. Windows on west-facing walls are limited, while windows on southern walls are more abundant. Atop the roof, flat plate collectors supplement domestic hot water, while remaining inconspicuous in the roof profile. Together, active and passive solar technologies decrease the environmental impact of this home.

View of Lake Behind House

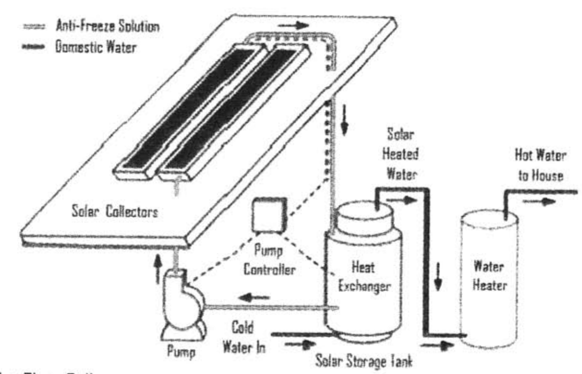
Active Solar

Flat plate collectors are the simplest active solar collectors, composed of a dark back board, a space for air or liquid contained in tubes, and a glass front plate. The solar energy penetrates the glass and heats the air or liquid, which can then be used for domestic heating or hot water.

The flat plate collectors included in this home are filled with water, although other types of collectors contain air. There are advantages to both air and liquid; air heats more quickly and will not freeze or leak. Water is far more conductive than air, which means better efficiency. However, antifreeze must be mixed with the water to keep it from freezing and damaging the collectors. Including antifreeze can present a problem if the liquid ever leaks into the building. (EERE)

When using a flat plate collector to provide domestic hot water, there are two separate circuits of water. One is filled with the water that circulates through the solar panels and antifreeze. This solution is pumped into the plates and is heated by the sun. The heated solution is pumped out, and passes through a heat exchanger, heating incoming domestic water. This is the second circuit of water. The domestic water then passes through a standard water heater, heating it to the final household temperature. (EERE)

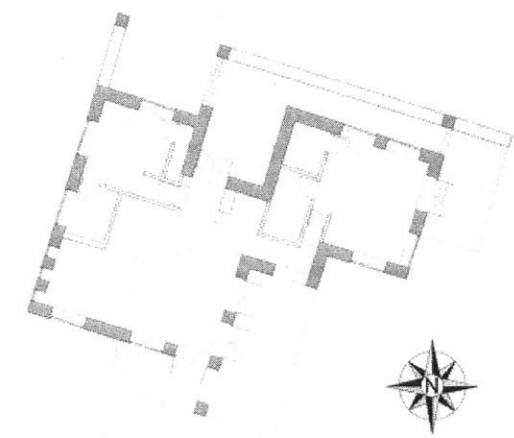
The domestic water needs to be heated much less because of the heat gained from the solar-heated solution. Flat plate collectors convert 60% of the sun's energy to usable energy, (SESCI) which makes them extremely useful and efficient. There are 30 square feet of solar panels on the roof of this project. They are integrated into the tile roof system, and do not project above the horizontal profile of the tile. The panels are on the south facing roof, but the slope of the site does not allow for a clear view of the panels by the homeowner. However, they are in an optimal location for absorbing solar energy in both the summer and the winter. These collectors are both friendly to the environment and the homeowner. Solar is a clean energy, harnessing the untapped rays of the sun to save the homeowner heating costs.



Flat Plate Collector

Passive Solar

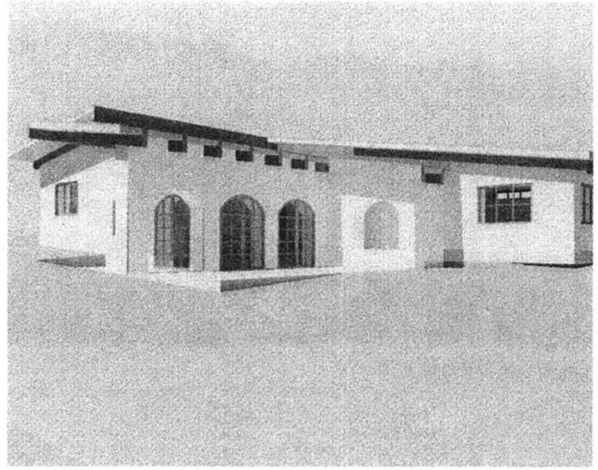
Passive solar technology is defined as having "no additional mechanical requirements." (SESCI) Passive solar relies on window orientation, solar shading and effective use of thermal mass to heat the building. For the best direct solar gain, windows should face true south. However, any orientation within 30° of that will also result in the desired solar gains. (SESCI) The direction defined as south in this project is 17º east of true south, but is well within the 30º limit.

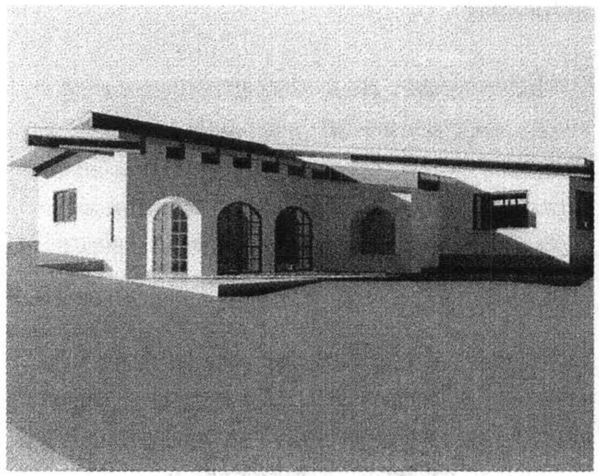


Plan Oriented to True North

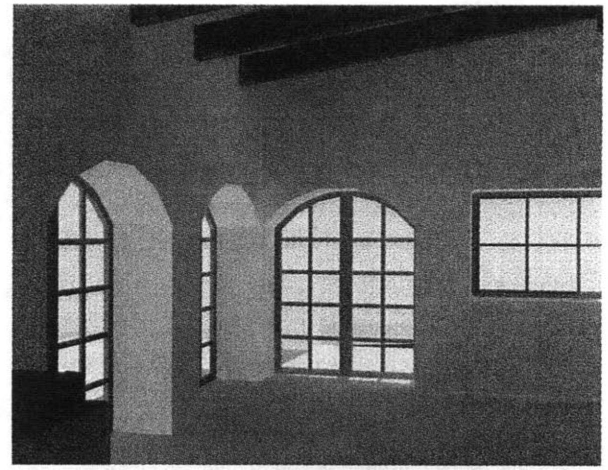
Once the building has absorbed solar energy, low e glass—which will be discussed in later sections—helps reduce conductive heat loss. (Smith 46) If lowered at night, interior blinds or shutters are also very effective at reducing losses. These things will maximize solar gain and minimize energy loss.

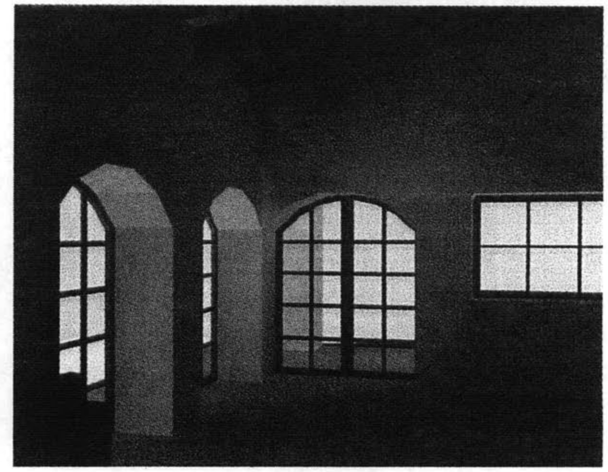
Passive solar heating focuses on maximizing the solar gain in winter, but architects must beware of overheating in summertime. The building will tend to overheat if southern window area exceeds 8% of the total floor area. (Smith 46)





Main Patio
June 21, 9am
June 21, 3pm

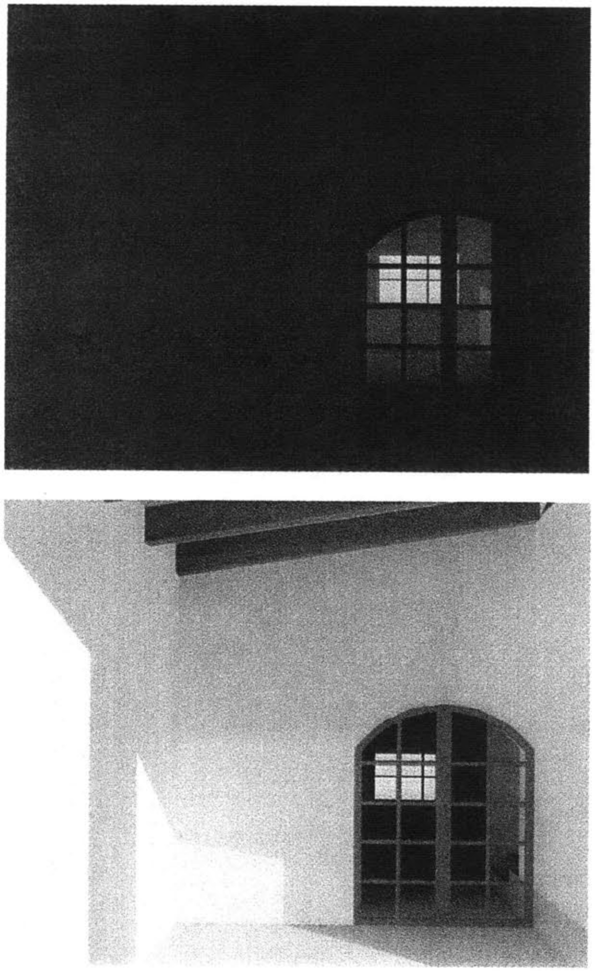




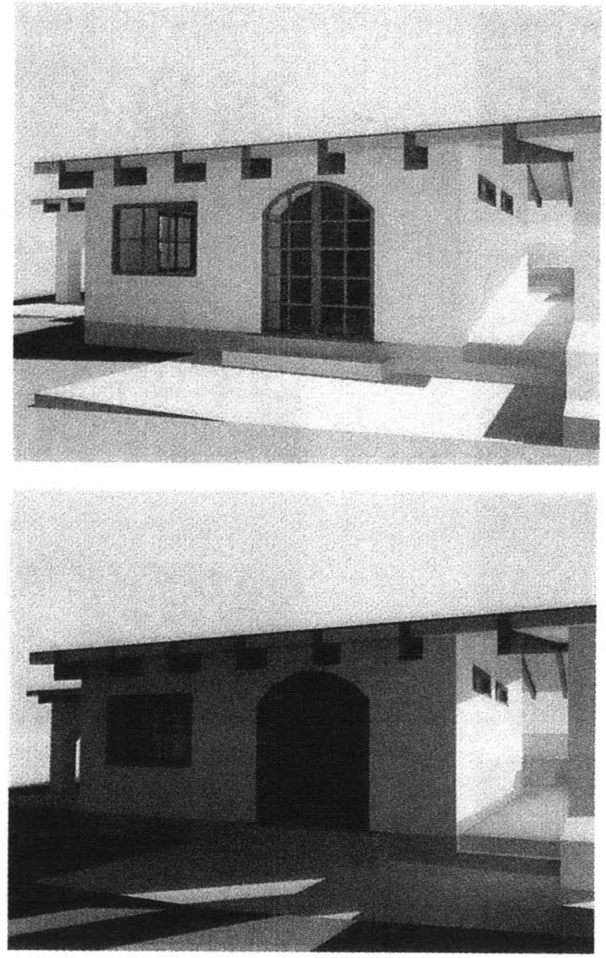
Living Area
June 21, 9am
June 21, 3pm

West Elevation Window Area

During the summer, sunlight can enter the building in the morning through the large southern windows. However, in the afternoon, when the temperature reaches its peak, these spaces are dark and cool for maximum comfort.



Entrance
June 21, 3pm
December 21, 3pm



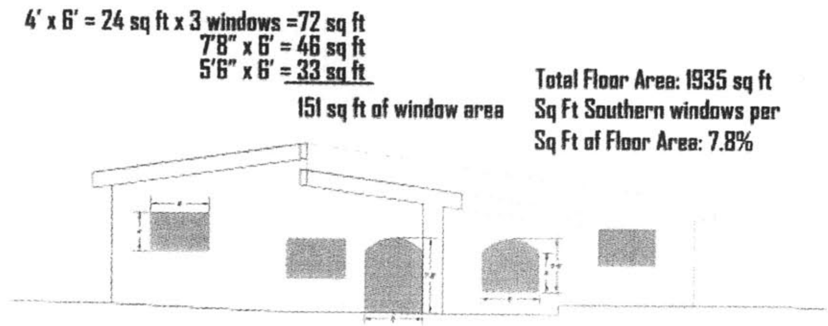
Patio
June 21, 3pm
December 21, 3pm

Another way to control solar gain is the effective use of shading. Deciduous trees near the building provide shading in the summer, but are not an obstruction during the winter. Properly sized exterior shades are also helpful. If the overhang is the right depth, it will keep out the high summer sun, while allowing the lower winter sun to penetrate into the building.

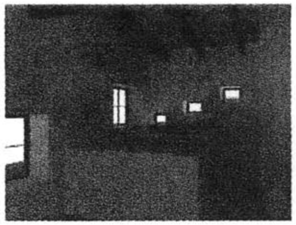
West facing windows are also problematic for overheating. In the afternoon, the sun is low in the western sky. This creates a near-normal angle with western windows, drastically increasing their absorption of solar radiation. (Smith 46) The late afternoon is also the peak of daytime heat, combining increased solar gain with already uncomfortable temperatures.

Passive solar heating does not require advanced technology or mechanical systems. Attention to sun angle, shading and window placement, and the effective placement of thermal mass result in solar gain in the winter, without overheating in the summer. It is a very effective way to decrease mechanical heating by making some very small adjustments.

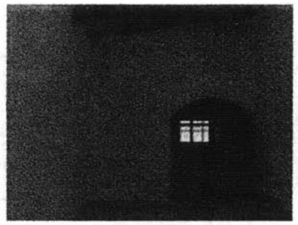
In the hot summer months, the deep overhang prevents the sun from penetrating into the building. However, in the cooler winter months, the lower solar angle lets sunlight into the home and warms the thermal mass in the floor.



South Elevation Window Area



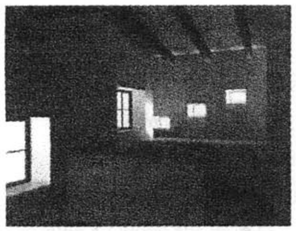
Kitchen
December 21
9am



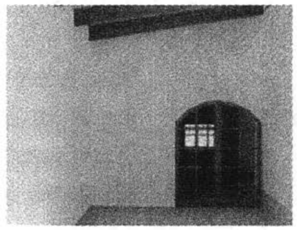
Entrance
December 21
9am

Patio
December 21
9am

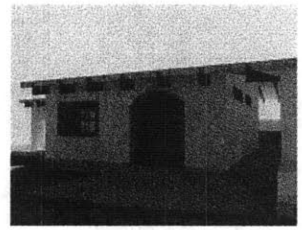
Bedroom
December 21
9am



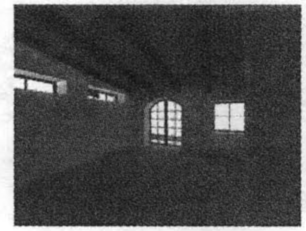
Noon



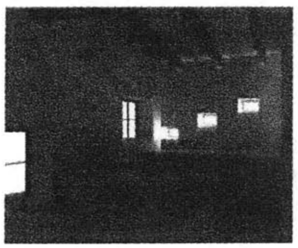
Noon



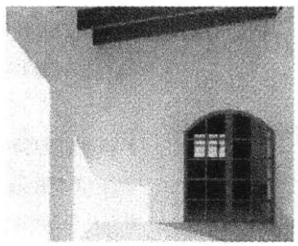
Noon



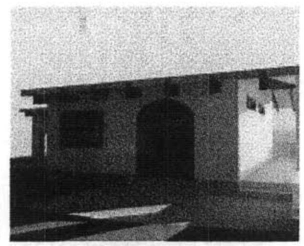
Noon



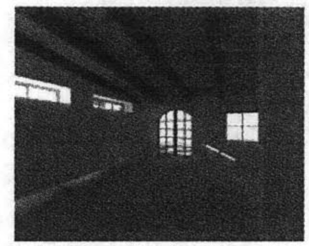
3pm



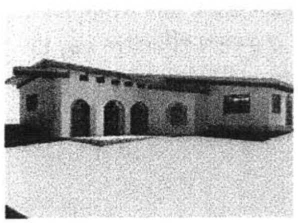
3pm



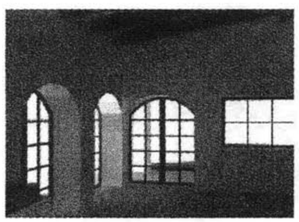
3pm



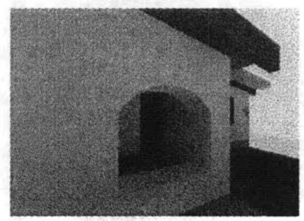
3pm



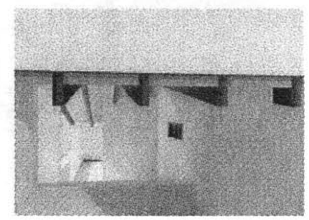
Main Patio
December 21
9am



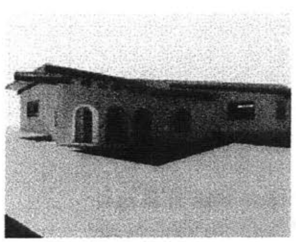
Living Area
December 21
9am



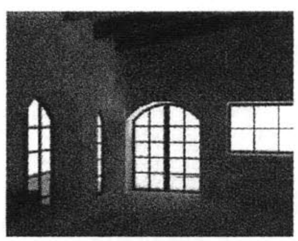
Birdcage
December 21
9am



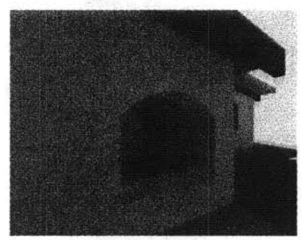
Entrance
December 21
9am



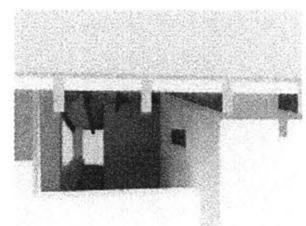
Noon



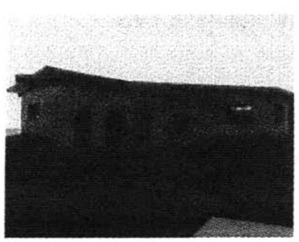
Noon



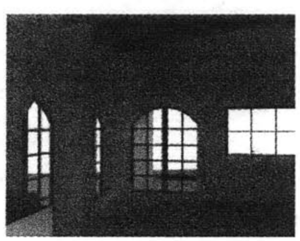
Noon



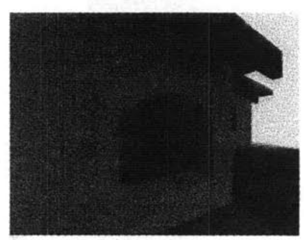
Noon



3pm

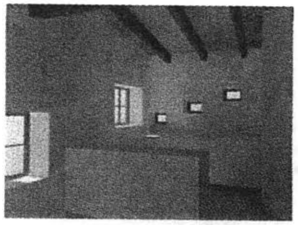


3pm

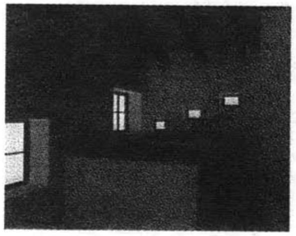


3pm

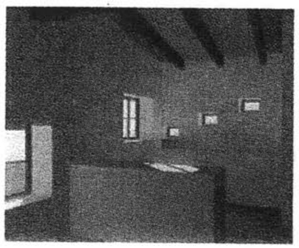
3pm



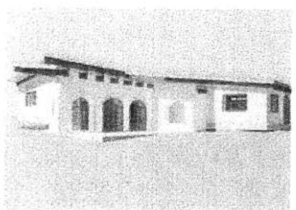
Kitchen
June 21
9am



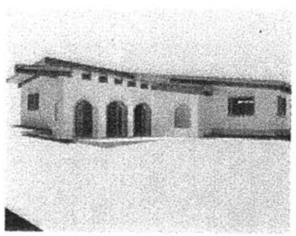
Noon



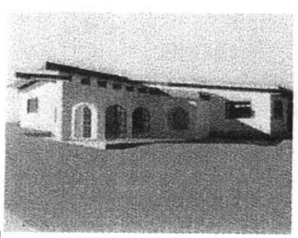
3pm



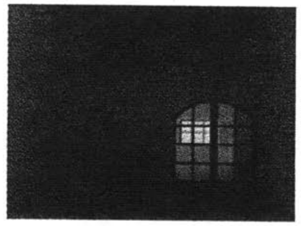
Main Patio
June 21
9am



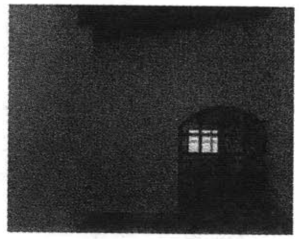
Noon



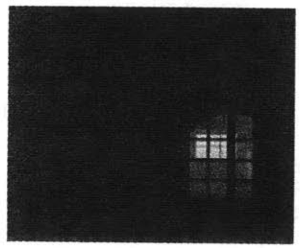
3pm



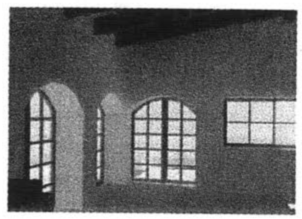
Entrance
June 21
9am



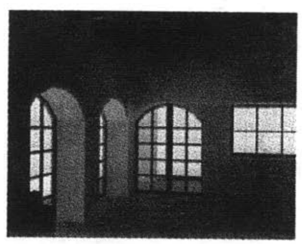
Noon



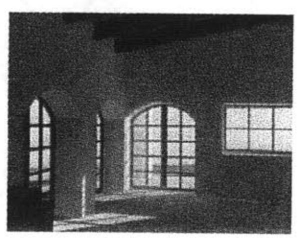
3pm



Living Area
June 21
9am

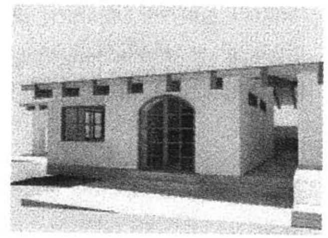


Noon

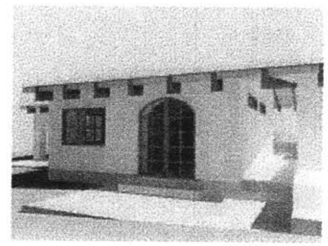


3pm

Patio
June 21
9am

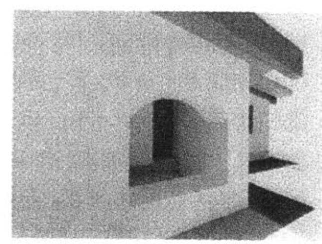


Noon

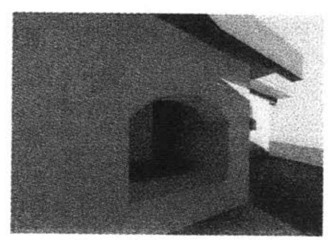


3pm

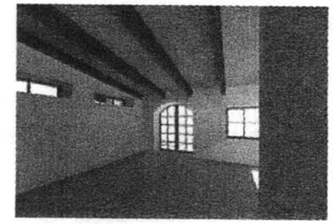
Birdcage
June 21
9am



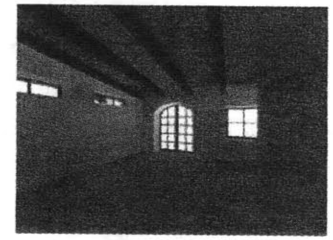
Noon



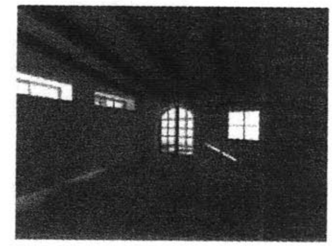
3pm



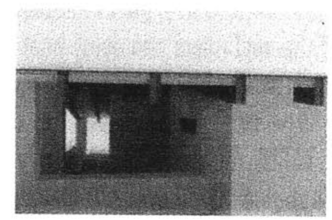
Master Bedroom
June 21
9am



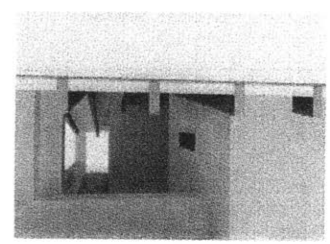
Noon



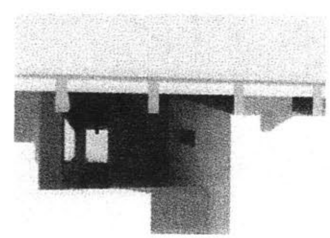
3pm



Entrance
June 21
9am



Noon

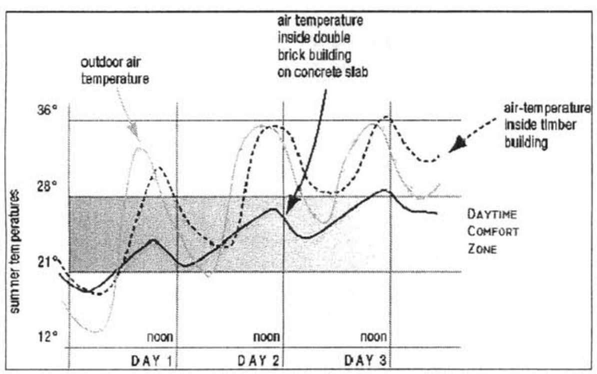


3pm

Thermal Mass

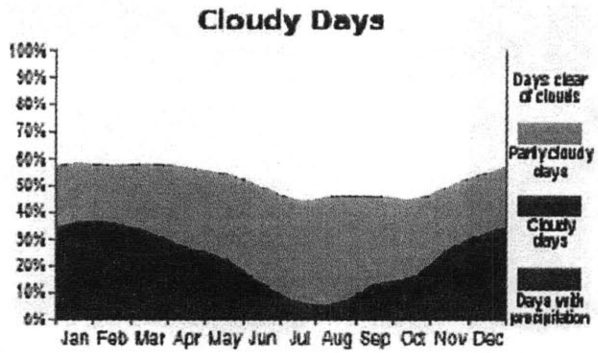
Thermal mass is an intrinsic property of a material. The denser the material, the more thermal mass, but less insulative value, the material has. The proper placement of thermal mass can warm buildings with solar gain in the winter, and absorb excess heat in the summer. During the day, the mass absorbs solar energy, which is then re-radiated to the surrounding air at night. Thermal mass is somewhat analogous to a heat battery: it absorbs heat in the day, then re-releases it at night. It is a technologically simple way to increase the energy efficiency of the home.

During the winter, the daytime absorption and nighttime release of solar energy increase indoor nighttime temperatures. In the summer, thermal mass acts as a daytime heat sink. (SEAV) The mass absorbs solar energy that would otherwise increase the indoor air temperature. At night the heat is still released, but the temperature stays within the comfort range, due in part to natural ventilation. Effective use of thermal mass can delay heat flow into the building for ten to twelve hours. This produces a warmer house at night in winter, and a cooler house during the day in summer. (AGO) Thermal mass not only reduces the amplitude of the temperature swing, it also delays the delivery of the heat from the solar energy.

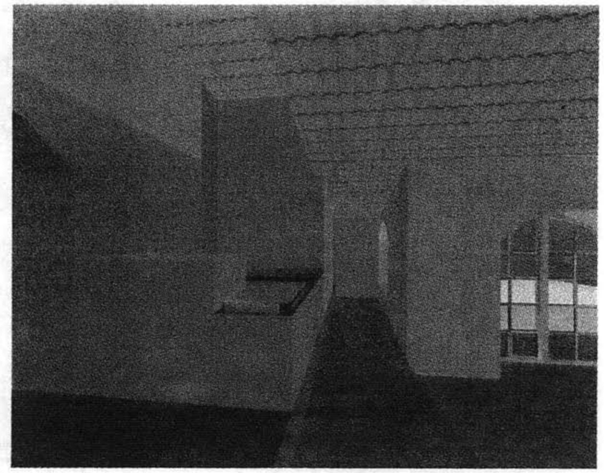


Thermal Mass Delay

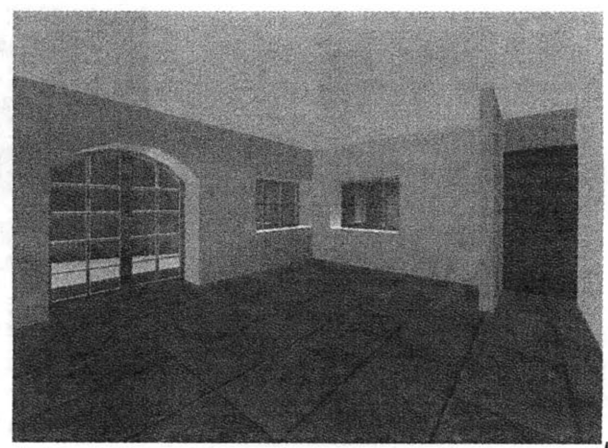
Thermal mass is used most effectively when there is a large difference between nocturnal and diurnal temperatures. (AGO) If summer nighttime temperatures are not sufficiently low, the thermal mass has no chance to cool. The next day, the mass cannot absorb as much solar energy and more is energy is absorbed by the space. The climate of San Luis Obispo is ideal for thermal mass. Because the area is traditionally very dry, nights cool quickly when the sun goes down, even on the hottest of summer days.

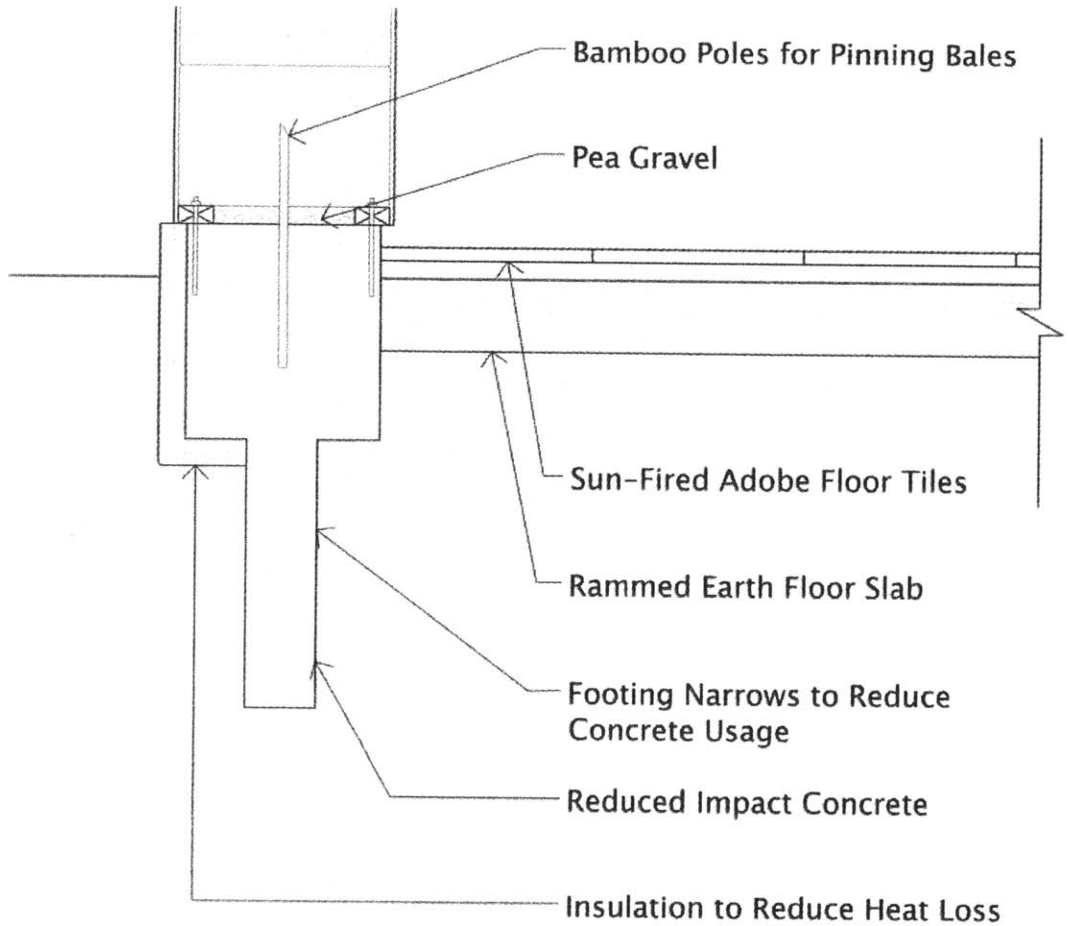


Thermal mass cannot be effective in the winter if it does not receive winter sun. (SEAV) Thermal mass can become extremely problematic if it goes for many days without sun. When the auxiliary heat is turned on, the thermal mass still acts as a heat sink, and the entirety of the mass needs heating before the space gets any warmer. (SEAV) Observing the average sunshine for the city of San Luis Obispo, this should not present a problem for this design project. Even during the months of January and February, an average of 45% of the days are sunny. (city-data.com) This weather pattern allows ample time for the thermal mass to absorb solar energy.



A designer must take careful care with the location of insulative materials. The thermal mass should be exposed to the interior space to facilitate heat transfer to and from the air. Any wall insulation must go outside the thermal mass (SEAV), or heat will never successfully transfer through the insulative barrier. For the same reason, carpet was not installed over the floor slab; this greatly decreases the effectiveness of the thermal mass. (SEAV) Instead, thermally conductive adobe tiles cover the floor slab. However, the concrete that is exposed to the outside air is insulated to ensure heat will not escape, but rather seep into the ground, increasing the effective thermal mass of the building.





In this project, the walls are devoted to straw bale construction, so do little to contribute to the thermal mass of the building. To add to the thermal mass, the building uses a technique called earth coupling. Earth coupling places the building floor slab in direct contact with the earth. Then the building uses both the slab and the earth for thermal mass. In a very cold climate, this is undesirable. (AGO) If there is no insulation between the slab and the earth, all the heat from the sun and from mechanical heating systems simply seeps into the earth and is lost. However, in the climate of San Luis Obispo, winters are mild, while the summers can be quite harsh. Therefore, the main concern is keeping the building cool, and losing heat to the earth is favorable.

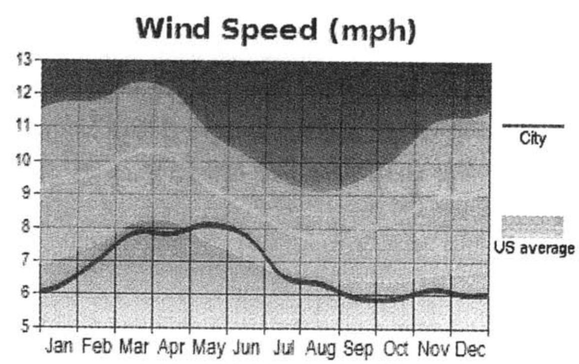
Thermal mass is an effective and technologically simple way of increasing a building's energy efficiency. Thermal mass delays the flow of heat into a building, heating during cold nights and cooling during hot days. The dry climate of this project makes it ideal for nighttime cooling, taking advantage of earth coupling to increase the effective mass of the building. Thermal mass increases the occupant comfort of this project, as well as decreasing energy costs; an ideal situation for the environment and the occupant.

Natural Ventilation

Natural ventilation occurs when the air in a space is changed with outdoor air without the use mechanical systems. In residential buildings, such as this project, the most effective way to naturally ventilate a building is through cross ventilation using operable windows. All reachable windows in this project are operable, and the open plan facilitates ventilation through the whole space.

In order for natural ventilation to be effective, comfortable wind speed, temperature and humidity must be maintained. During the day, the indoor wind speed should be between 0.1 m/s and 2.0 m/s. At night, the comfort zone is between 0.1m/s and 1.0 m/s. (Koch-Nielsen 34) The comfort range for temperature depends on a few other factors, but is generally between 65°F and 80°F. Humidity levels are comfortable between 25% and 70% relative humidity. (SEAV)

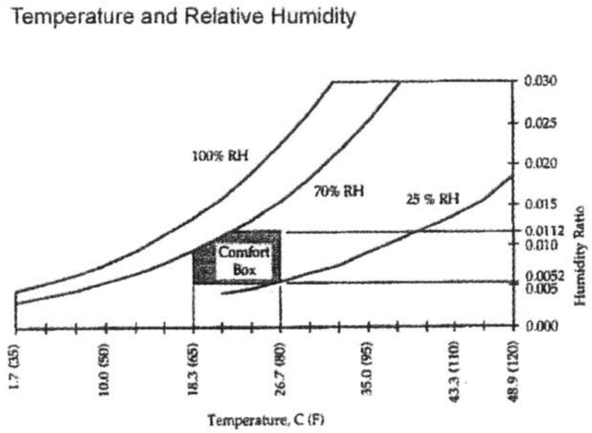
However, these are not the only factors that affect comfort. Body temperature is affected by convection, conduction, evaporation and radiation. If the air is too cold, convection takes heat away from the body, making people uncomfortable. As the temperature difference between the body and the air increases, so does the rate of convection. (Koch-Nielsen 34) Conduction between the air and a



building is affected by the materiality of a space. (Koch-Nielsen 34) Window placement is important; glass is highly conductive. It can make people feeler cooler or warmer than the dry bulb temperature. If people become too warm, the body produces sweat, which evaporates into the air. However, the rate of evaporation is dependant on air speed and humidity. (Koch-Nielsen 34) If either is unfavorable to evaporation people become uncomfortable as soon as it gets warm. Finally, some interior objects emit long wave radiation which can make a space feel warmer than it is. (Koch-Nielsen 34) Each of these four things influences comfort, and designers must be conscious of them all.

Occupants are comfortable over a larger range of temperatures and humidities if they have some control over their environment. This is one of the advantages to natural ventilation. Operable windows not only facilitate ventilation, but also give control to the occupant. Thus, energy costs are reduced in two ways. Cooling costs are reduced because of the increased airflow, and both heating and cooling systems are used less, since the comfort zone is increased by personal control.

The system used in this home is cross ventilation, which allows pressure differences or prevailing winds to push fresh air through the entire plan. The system has some requirements which affect the architecture of the building. However, it can be implemented easily and unobtrusively, and the building will benefit from decreased energy costs and increased comfort. The building depth must be less than five times the floor to ceiling height for this to work effectively. Horizontal openings must be at least 5% of the total floor area and be placed on at least two sides of the building. (Smith 112)



Materials

Windows

Windows are an essential feature to any architectural project. However, they are also the least insulative piece of a building envelope, conducting heat and allowing solar energy to penetrate the building. There are a variety of both technologically advanced and simple solutions to this problem. Low emissivity coatings, multiple paned windows and exterior shading devices have become commonplace, but interior shading, deep ledges and deciduous trees are not to be neglected. These solar technologies can complement the design of the house, as well as make it more comfortable.

Exterior shading has been used for hundreds of years to reduce solar gain and keep interior spaces cool. However, there are several new twists on this idea. Computer models—as seen in the solar technology section of this document—can accurately predict the sun angle for an entire year, allowing architects to precisely calculate the angle and depth of an exterior shade. The roof overhangs in this project are calculated to shade the windows from the excessive summer sun, but are shallow enough to allow the lower winter sun to warm the building.

Another technique used to reduce the absorption of solar energy is installing double-paned windows. Double or triple paned windows are significantly more insulative than single-paned windows. (THERMIE 71) However, the extra pane of glass is not actually very important. Rather, it is the air that is trapped between the panes that gives the added insulation. Additionally, the gap between the panes is filled with argon, which is less conductive than air. With no reduction of vision, the U value of the window can be reduced by as much as 20%. (THERMIE 100)

Low emissivity, or low e, coatings target radiation in the non-visible spectrum. A thin layer of silver or tin oxide is applied to the exterior of the pane. (In double paned windows, the coating is applied to the interior pane, on the side facing the air gap.) These coatings reflect infrared radiation back into the building, reducing wintertime heat losses. Although intended for non-visible radiation, the light transmission through the windows is affected slightly. (THERMIE 100) Low e coating is extremely effective at reducing heat loss, and is applied to all windows in this project.

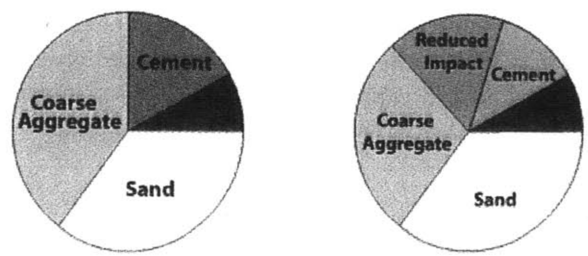
Although the initial cost of these technologically advanced windows is higher than traditional windows, the long term savings outweigh the early spending. Less heat is lost to the exterior during winter, and less can be absorbed during the summer. This reduces the need for supplemental heating and cooling systems, saving the occupant money and reducing environmental impact.

Source of Recycled Concrete

Concrete

Concrete is one of the most prevalently used building materials, but it is also one the most damaging to the environment. Standard concrete is composed of 12-14% cement, 6-7% water, 25-35% sand, and 15-35% gravel, crushed stone, or another aggregate. (THERMIE 119) The production of one cubic yard of concrete consumes 1.7 million BTUs of energy, and every ton of cement produced also produces one ton of CO2. (Paschich 34) In order to reduce the huge environmental cost of concrete, the composition of the concrete can be changed, even reusing old concrete as aggregate. During building demolition, some of the old concrete can be kept separate. Then, during building construction, the coarse aggregate (which makes up 15-35% of the concrete) can be replaced by the old, crushed concrete. Up to 30% of the coarse aggregate can be replaced before there is a noticeable difference. Above 30%, there is a greater water demand, the concrete is less workable and has lower strength, so this should only be attempted under controlled conditions. (AGO)

The most energy intensive component of concrete is the cement. Therefore, attempts at reducing the environmental impact of concrete often focus there. Replacing a proportion of the cement with waste products



such as fly ash, ground blast furnace slag and silica fume can significantly reduce embodied energy and greenhouse gas emissions. (AGO) Using these substitutes does not significantly affect the quality of the concrete, but it does significantly affect the amount of energy needed to produce the concrete. Between 15-35% of the cement can be replaced by fly ash, with no detriment to the strength or durability of the concrete. (THERMIE 119)

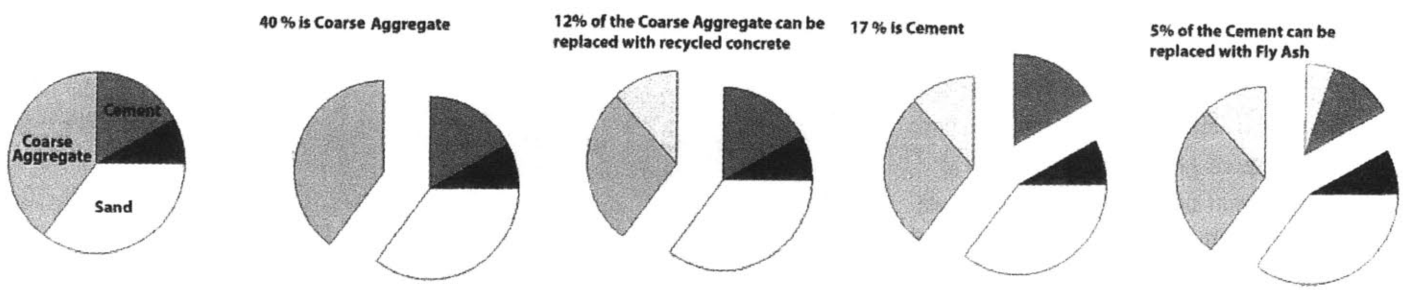
Earth Construction

Earth has been used as a building material for centuries. It is cheap, abundant and relatively strong. More recently, there has been an increased interest in returning to some of the traditional earth construction techniques, as well as developing new technologies and methods for earth building.

One way to integrate earth into a design is to build with adobe bricks. Adobe or mud bricks are created by filling molds with mud, then allowing the sun to bake them into hardness. (THERMIE 118) They can then be assembled almost identically to traditional brickwork. However, their compressive strength is somewhat lower than that of traditional brick, so some taller structures may require reinforcement. (SEAV) Additionally, the adobe bricks are susceptible to degradation if exposed to extreme weather, so they may require a finish or some other protection from the elements. Walls of adobe are extremely dense; they provide excellent thermal mass. However, they are not very insulative since they contain so little trapped air. Compared to a traditional brick veneer construction, about six times as much heat passes through an adobe wall. (SEAV) this is advantageous to our floor system because it reduces the resistance to earth coupling. Heat can easily pass from the air to the adobe tiles to the concrete floor slab and then to the earth.

Traditional Concrete Composition

40% Coarse Aggregate
17% Cement
8% Water
35% Sand



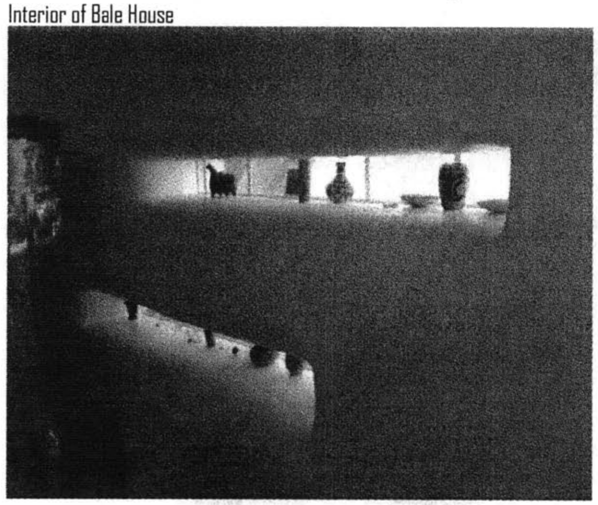
Adobe bricks are extremely low impact. All construction labor is either from human hands or from the sun. Most locations can provide the correct materials, and there is no disposal problem at the end of the building's life. A great deal of water is required to make the bricks, which can prove problematic in some dry locations. (SEAV) However, this is only a one time requirement, and a comparable amount of water would be needed for the more standard concrete construction. Traditionally, adobe construction was done by the owner, which allows for custom design and building. Adobe bricks are easily integrated into standard construction systems, and the advantages of the thermal mass and the low environmental impact materials are extraordinary.

Another method of using earth for construction technique is rammed earth, or pisé de terre. Rammed earth walls or floors are created with form work made from wood or metal. These forms are filled with layers of earth, packing each layer by hand or machine before adding another. (THERMIE 118) Walls can be built with a variety of earth, ranging from small cobbles to silt, depending on the target strength and appearance of the wall. (THERMIE 118) As with other forms of earth construction, rammed earth walls are poor insulators, but good sources of thermal mass. This is very advantageous to the project's earth-coupling floor slab. This construction is low impact; most locations can build using on-site earth.

For structural reasons, the composition of the earth is very important, especially in walls. With some adjustments, rammed earth walls can be of comparable strength to concrete. (THERMIE 118) Openings up to one meter do not even require a lintel. (AGO) However, in order to insure stability in seismic zones, the wall must use 4-12% Portland cement by volume and contain steel reinforcing. (King 64) This drastically increases the environmental impact, making these rammed walls very similar to standard concrete walls. In a seismicly active zone such as San Luis Obispo, the rammed earth walls are not very environmentally practical.

The presence of earthquakes does not entirely eliminate rammed earth as a building material, however. Rammed earth can be used to supplement a concrete floor slab. With just a 2" layer of concrete, the remainder of what would usually be concrete can be filled by rammed earth construction. Where a traditional floor slab would need to be 12-16" thick, the concrete consumption can be reduced greatly by rammed earth. This not only decreases the environmental impact and embodied energy of the floor system, but also decreases the resistance of the heat flow to the earth, increasing the effective thermal mass. Rammed earth is an excellent alternative to traditional concrete.

Interior of Bale House



Straw Bale Construction

The defining environmental consideration of this project is the use of straw bale construction. Straw bales make great insulators, and can even be used as structure. Not to be confused with hay, straw is an agricultural waste product. After grains like wheat, oats, barley, rye, and rice are harvested, the excess straw is baled. While grains feed animals and people, straw is usually burned to dispose of it. Straw has a one year growing cycle, and enough excess straw bales are produced each year to "provide for all of North America's housing needs." (OSBBC) Straw bales have great potential to influence home design, and positively affect the environmental impact of the housing industry.

There are a few problems with straw bales as a construction material. As with all biological materials, there is some risk of fungus or rot. If the moisture content of a bale exceeds 20%, fungi will begin to break down the straw. (OSBBC) However, if the bales are pre-purchased and allowed to dry out before construction, they will not grow fungi inside the sealed wall cavity, even if there is some moisture penetration. (King 98) Since most baled walls are coated with cement, earth or stucco, bales are only subject to moisture during the building process.

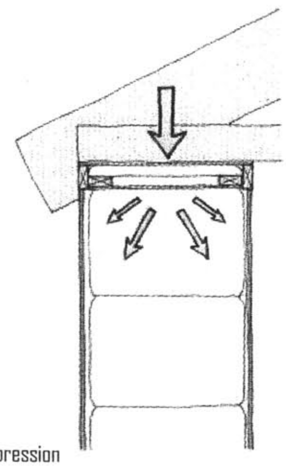
The threat of fire concerns many potential bale-builders. Actually, bales are naturally resistant to fire. The straw is packed very densely, leaving little room for oxygen. The bales cannot sustain fires; they are actually less flammable then a traditional fire-rated home. (OSBBC)

Many builders assume that straw bale homes are magnets for vermin, like mice or termites. However, straw bales have no nutritious value; they are composed of chaff and stalks. Straw is, in fact, less likely to attract rodents or insects than timber. (OSBBC) If concerns persist, bales can always be treated with boron, reducing the likelihood of pests and fire even further. (THERMIE 118)

Straw bales are durable, flexible and highly insulative. A straw bale building can reasonably be expected to last 100 years without decay. (OSBBC) Bales can be easily integrated into traditional construction methods using a post and beam framing, or a more adventurous builder can build "Nebraska style," using the bales as the primary structure, as is done in this project. Perhaps the biggest advantage to bale construction is the insulative value they offer.

Free-standing bales are tested to insulate at an average of 0.012 W/m2K. (THERMIE 118) A standard stucco and wood frame building may have walls with R 19. (Paschich 26) In contrast, straw bale buildings will have walls with R 40-42. (Paschich 26) This is an increase of over 200%. Not only does this benefit the environment, but it also saves money on heating and cooling bills, benefiting the homeowner. "Straw bale homes typically use 25-40% less heating/cooling energy than their frame-walled equivalents." (OSBBC) Insulation is one of the most important advantages of a straw bale building.

A standard straw bale is 23" wide, 15-16" high, and 42-48" long. (King 98) The bales can be cut using a steel baling needle (Paschich 62) or a chain saw (OSBBC) to accommodate wall cavities of different lengths. There are two standard methods of construction: the "Nebraska style" which uses the bales as both structure and insulation, and the infill, or post and beam, method which uses a timber frame as structure and bales as insulative infill.



Bale Wall Compression

This project uses the more adventurous Nebraska style of building. Named for the early prairie homes constructed from straw bales, Nebraska style consists of stacking bales with no supplementary structure. The bales have to be pinned with rebar, wood dowels or bamboo as they are stacked, or held together in a process known as grippling. For grippling, the builder runs wires around the bale walls every 18", making sure to run the wire outside the top and bottom plates, then tightening the wires. (OSBBC) Grippling gives the bale walls better compressive strength and reduces the amount of settling in a bale wall's lifetime. Although less common than infill bale houses, Nebraska style bale houses are quite sturdy. Unreinforced, they can be stacked up to 8' high and 20' long, as long less than 50% of the area is left open. (OSBBC) With some pinning or grippling, but no frame, they can safely make structures up to three stories high.

Another concern with straw bale building is the integrity of finish materials. The builder must be careful that the bales are pre-compressed before applying any wall finish. After the roof is installed, the wall will settle, and may lose up to 4". (King 119) State codes that include straw bale buildings usually require some level

Code Requirement:

Use: wire rated 500lbs
24" OC throughout house
Cinch to 400lbs
800lbs tension/24" = 400lplf

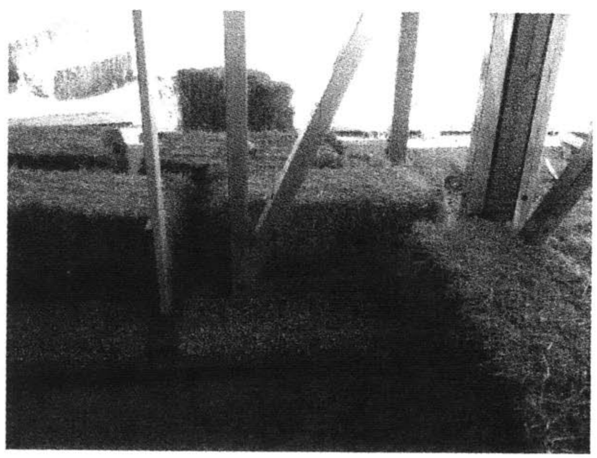
Roof Dead Load: 20psf
Roof Live Load: 16psf
Overhang: 24" per side

(2' + 16'/2) x (20 + 16) = 10' x 36psf
= 360plf along top of wall

California Code: <400psf

360plf + 400plf = 760plf
760plf/24" bale = 380psf. Meets Code Requirement

Bale Construction Detail



of pre-compression. In California the requirement is 400psi. (King 125) The bales are very spongy, while the plaster skin is rigid. If the bales compress too much after the finish is applied, the load may rest solely on the plaster. Alternatively, the bale may grow wider as it is compressed, pushing the plaster outward. Both of these result in the plaster cracking or flaking off. (King 121) To help reduce these effects, a builder can pin the bales tightly before installing the next row, or use grippling or chicken wire to maintain the bales' pre-compressed state. (King 120)

Straw bales are economic, environmentally low impact and easy to integrate into existing building practices. Building with straw bales makes use of a waste product and provides superior insulation. The buildings are resistant to fire, pests and thermal loss. Straw bales are an excellent building material.

Earthquake Computations:
(King 129)

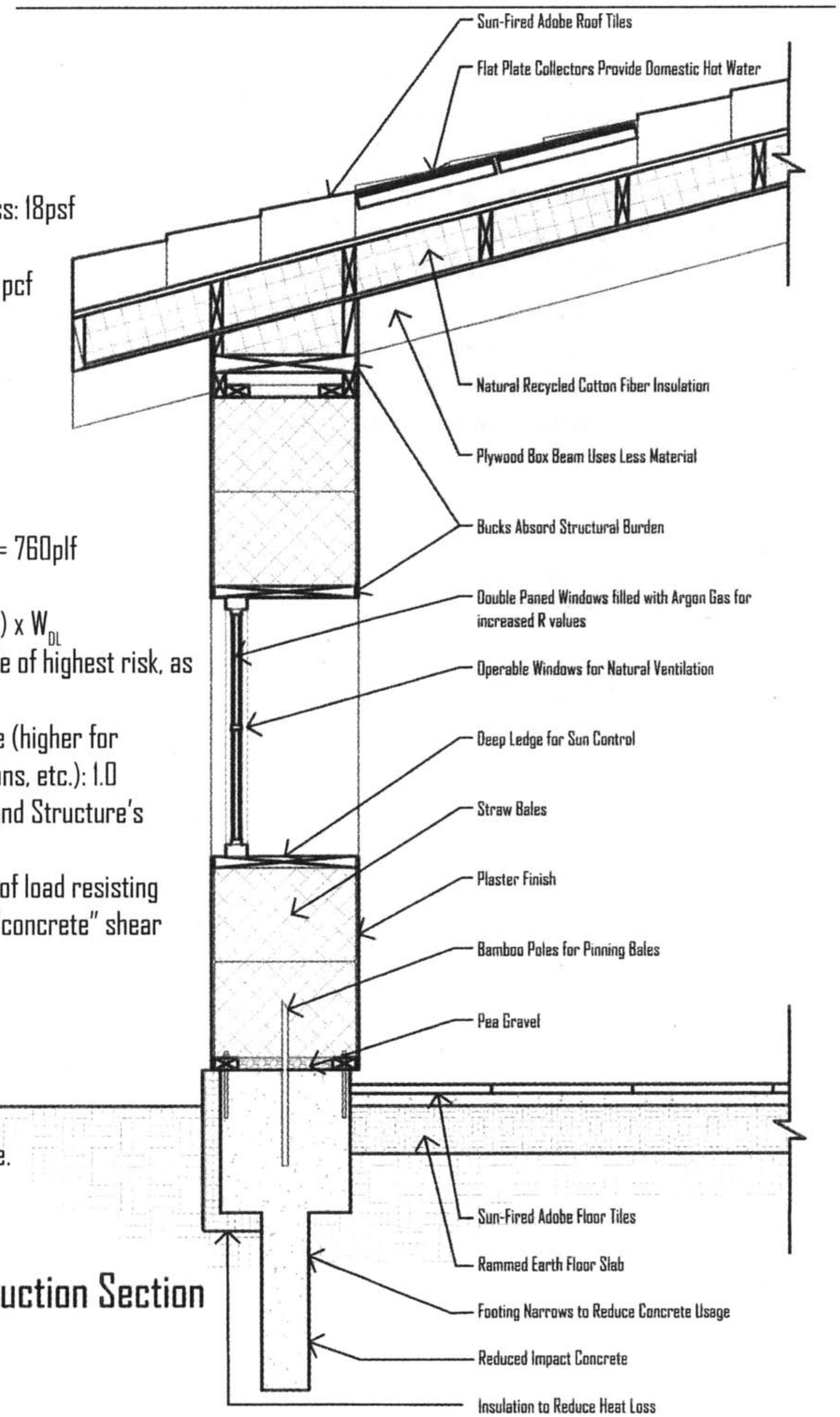
Wall's Dead Weight:
Bale Weight: 8.9 pcf
8.9pcf x 24" bale thickness: 18psf
Stucco Skins:
(2 skins x 1.5" thick) cb ft/ sq ft x 150 pcf
= 38 psf

Total Wall Weight: 18 + 38 psf = 56psf
For a 10' Wall: 56psf x 10' = 560plf

Total Dead Load at Bottom of Wall:
560plf wall weight + 200plf roof load = 760plf

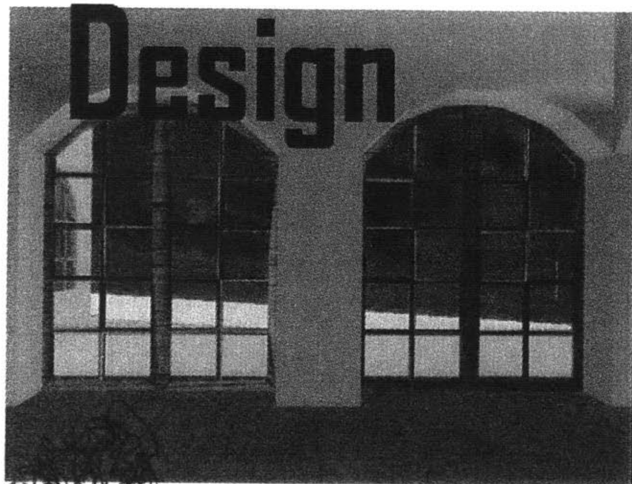
Horizontal Earthquake Load: $(ZIC_p / R_w) \times W_{DL}$
Z: Seismic coeefficient for Zone 4 (zone of highest risk, as in San Luis Obispo): 0.4
I: Coefficient of Occupancy Importance (higher for hospitals, schools, fire stations, etc.): 1.0
C_p: Structure Coefficient for site soil and Structure's response to shaking: 2.75
R_w: Structructure Coefficient for type of load resisting system (in this case a rigid "concrete" shear wall system: 6
W_{DL}: Structure Dead Load: 760plf
F_p: $(ZIC_p / R_w) \times W_{DL}$ = 140 lb/ft

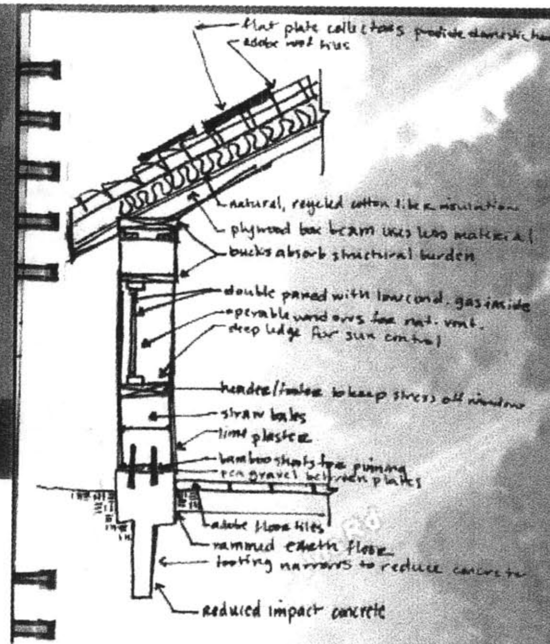
UBC allowable shear load for stucco:
F_V: 2 x 180 plf = 360 plf > 140. Allowable.

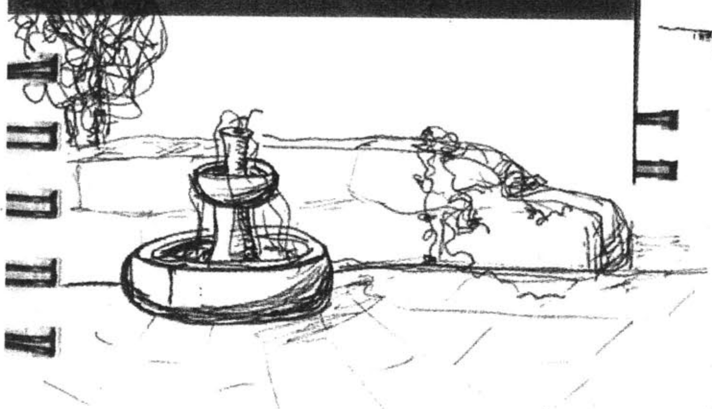


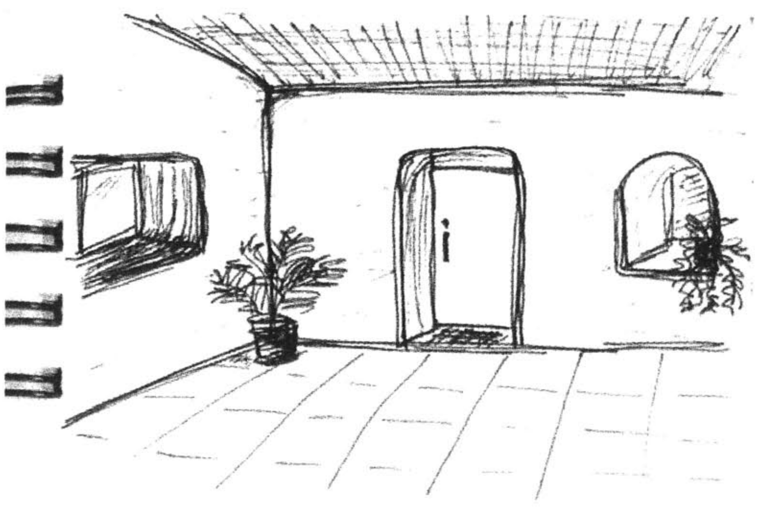
Construction Section
3/8"=1'

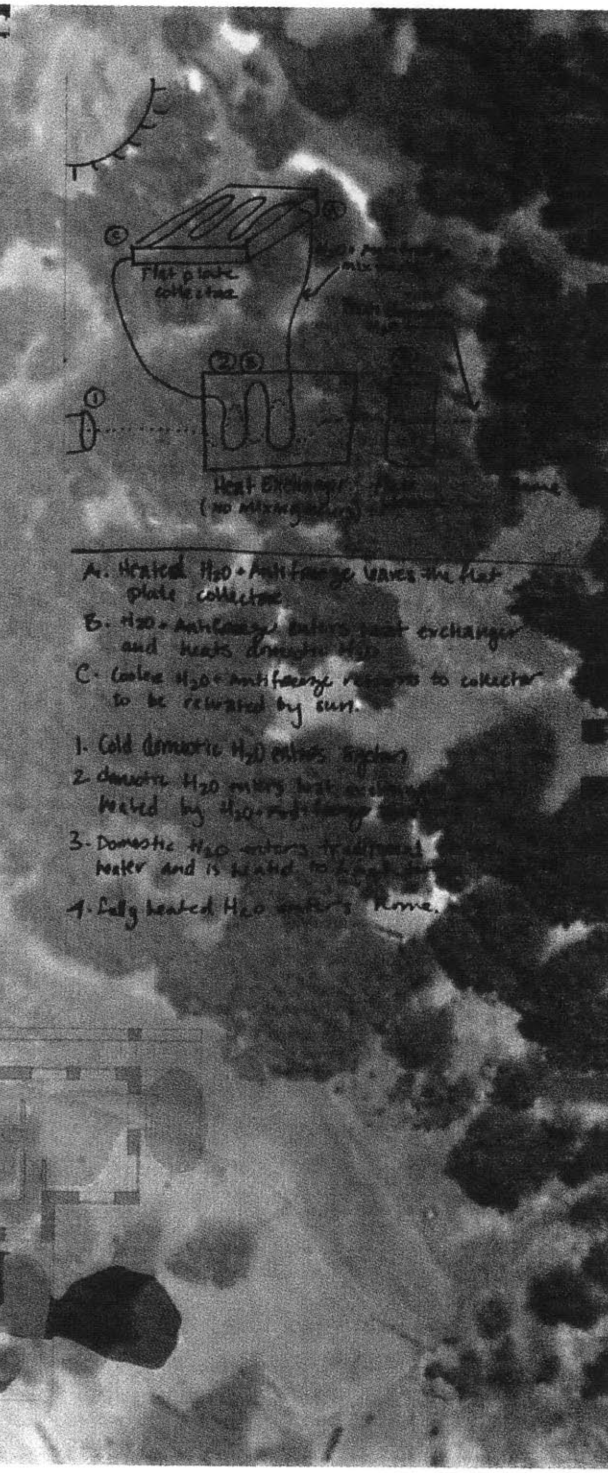
Design

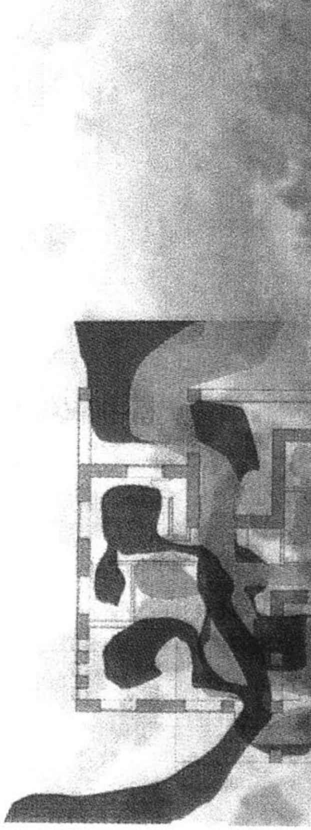


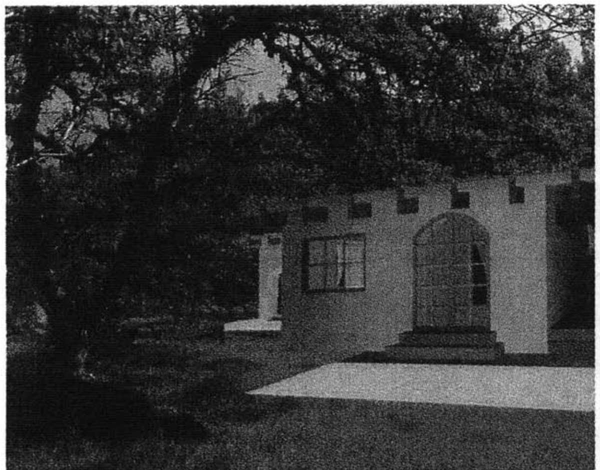

flat plate collectors provide domestic h
adobe roof tiles
natural, recycled cotton fiber insulation
plywood box beam uses less material
bucks absorb structural burden
double paned with low cond. gas inside
operable windows for nat. vent.
deep ledge for sun control
header/lintel to keep stress off window
straw bales
lime plaster
bamboo shoots for pinning
pea gravel between plates
adobe floor tiles
rammed earth floor
footing narrows to reduce concrete
reduced impact concrete

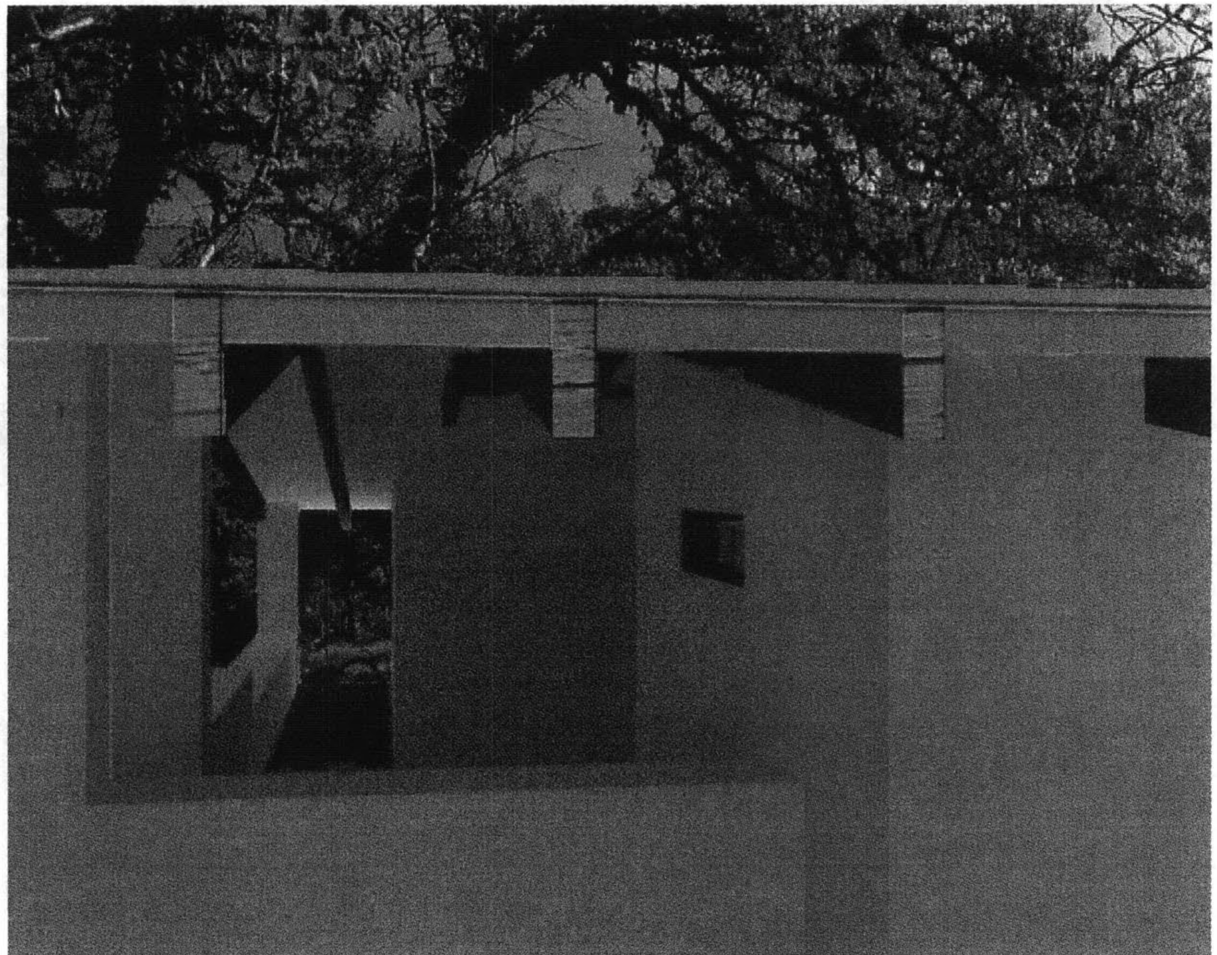





A. Heated H_2O + Antifreeze leaves the flat plate collector
C. Cooler H_2O + Antifreeze returns to collector to be reheated by sun.
1. Cold domestic H_2O enters system
home.




Master Bedroom from Exterior


Main Entry Path from Exterior

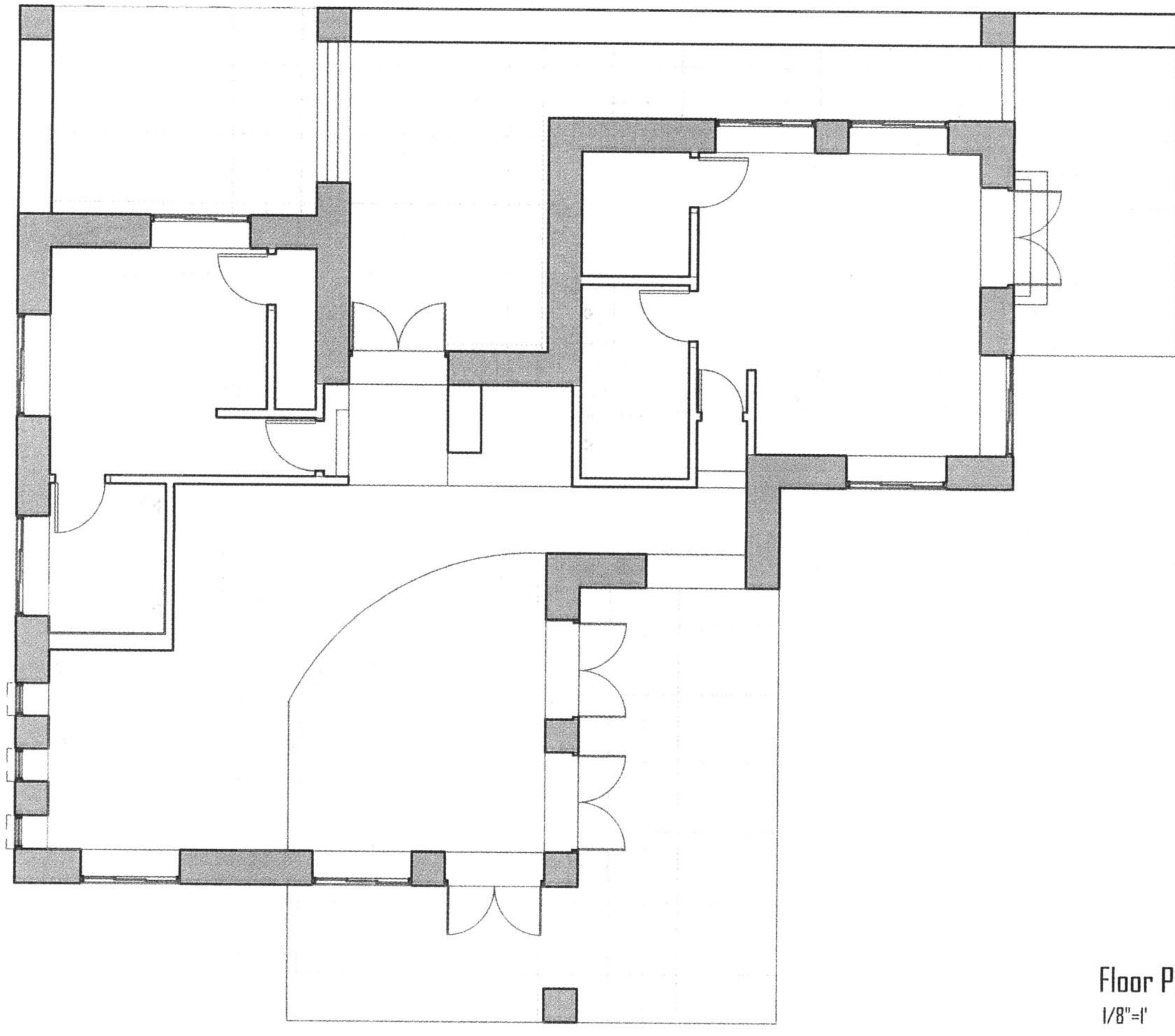
Design Elements

The design of this home is intended to examine the character of the familial relationship. The nature of family is contradiction. Although family members have shared most—or all—of their lifetimes, they have not shared all of their thoughts, feelings or ambitions. Always there is tension in the inherent nature of the family: parent and child, older sibling and younger, spouse and partner. To live in a space together is to be in tension; the resolution is the rarity.

This home attempts to encompass and express the contradictions inherent in familial living. The tension between public and private spaces, the interplay between the changing floor levels and the consistent ceiling slopes, the opposition of spacious interior of the living space with the small floor plan: these things all reflect the incongruity of the family.

The public and private spaces in this home manifest in surprising ways. The most public area of the home—the front entryway (top right)—is the space in the house that has the lowest ceiling. Walking into this tight space conveys a feeling of intimacy, of privacy. Yet, this area is the most public space in the home, open to visitors and residents.

By contrast, the most private space in the home is physically the most exposed. The private patio (top left) is accessible primarily through the master bedroom, a space few would have access to. Yet, upon arrival onto the patio, the resident is greeted by an expansive vista.

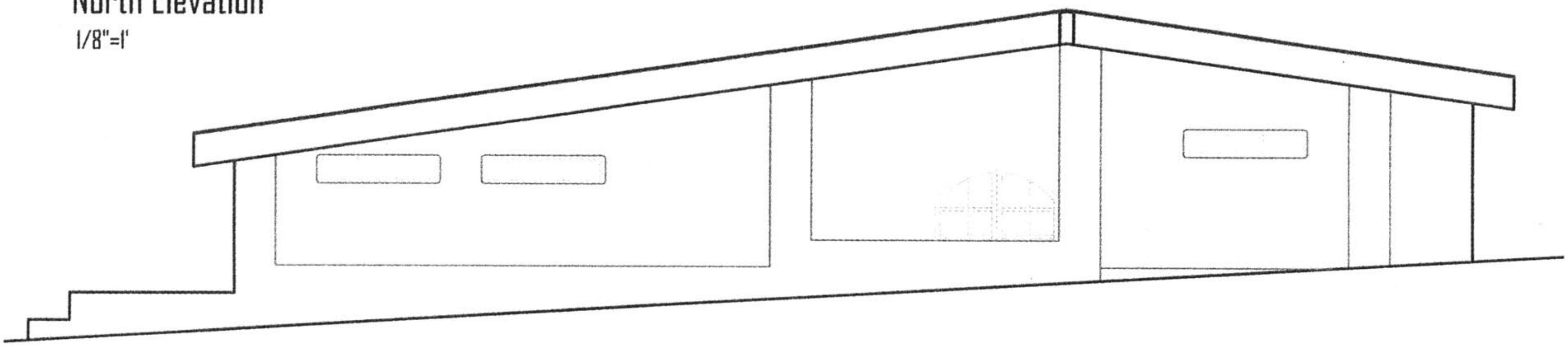


Floor Plan

1/8"=1'

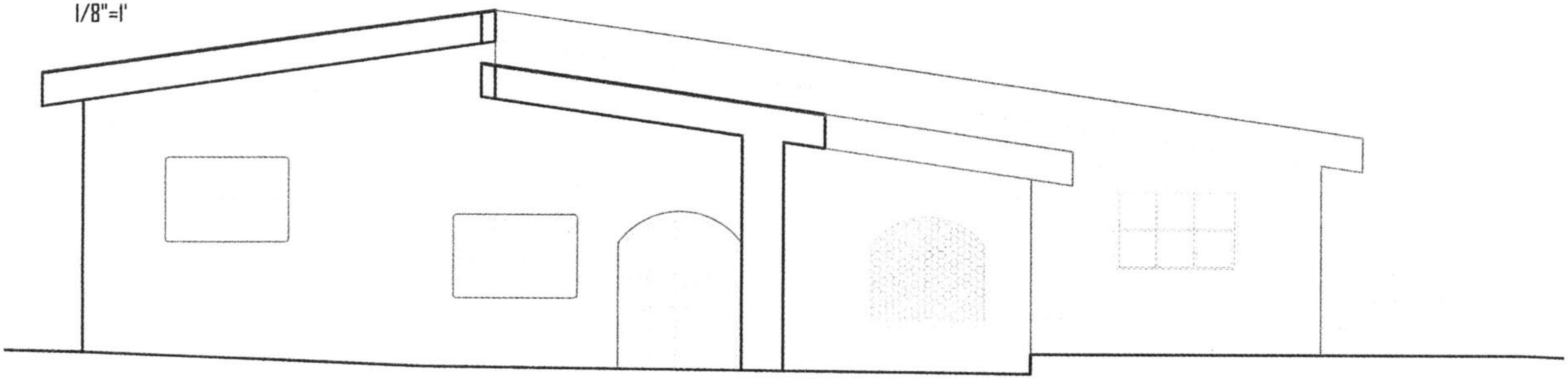
North Elevation

1/8"=1'



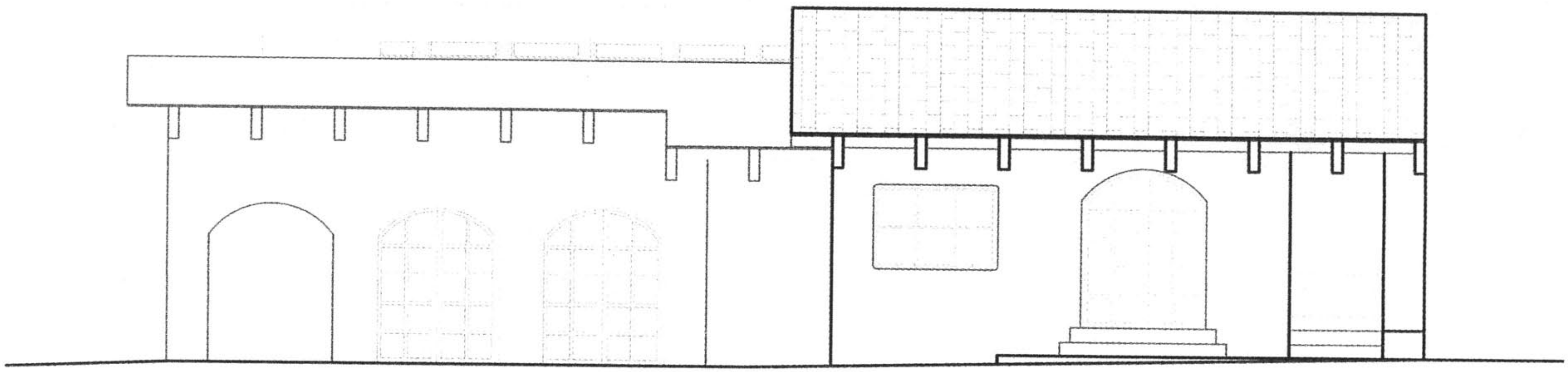
South Elevation

1/8"=1'



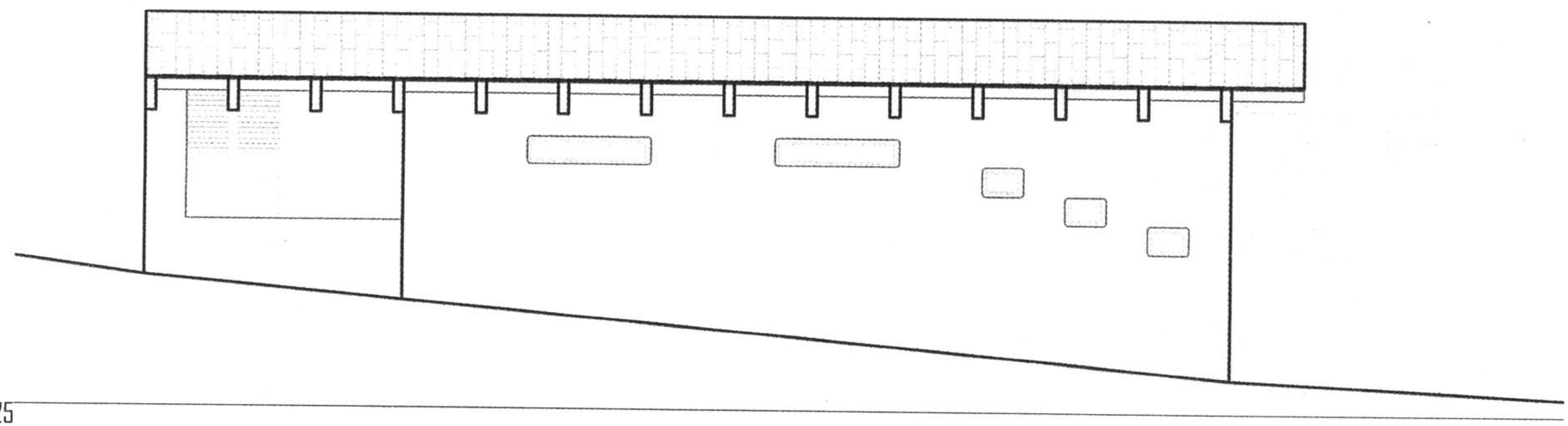
East Elevation

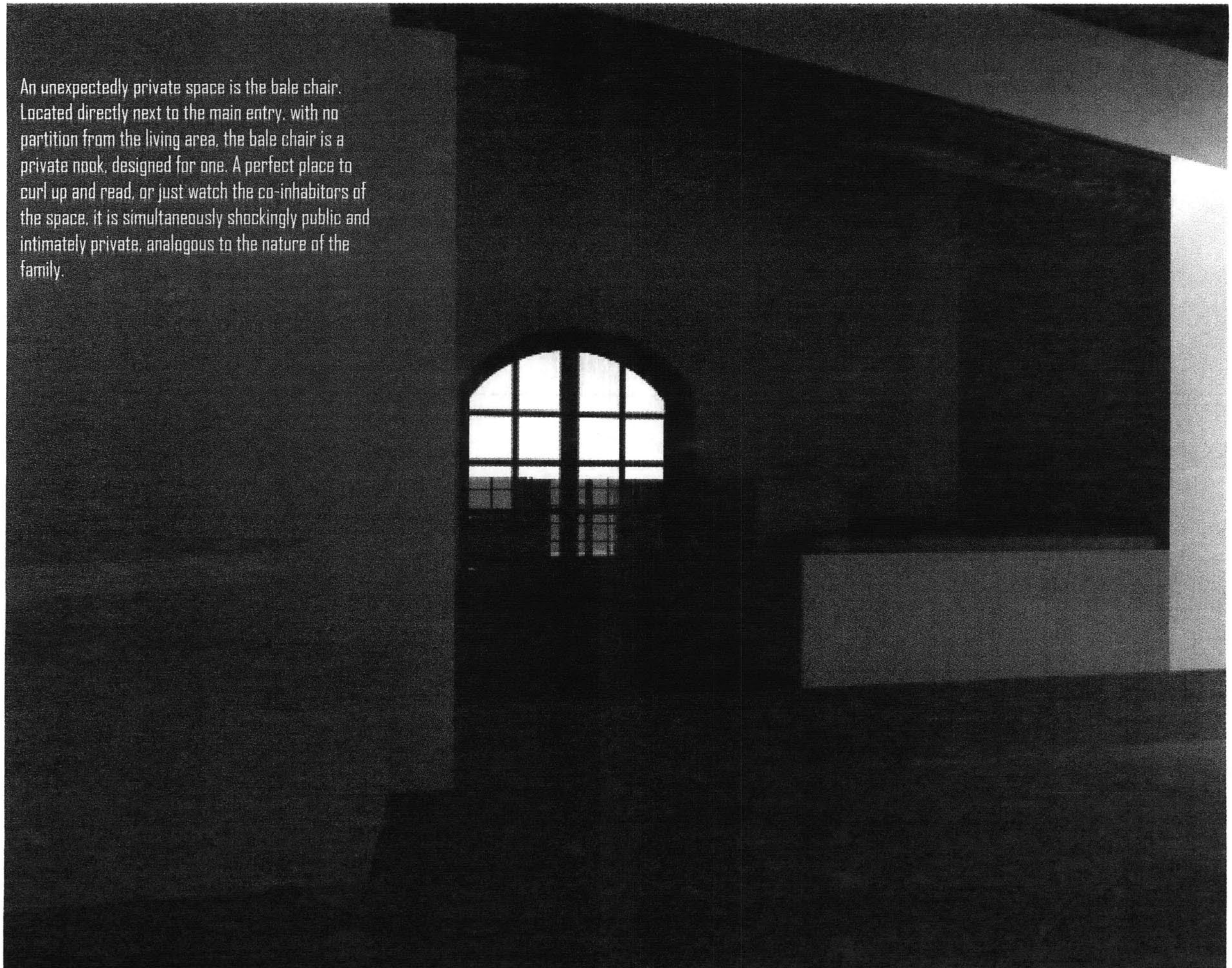
1/8"=1'



West Elevation

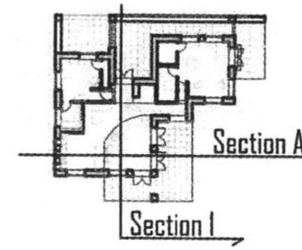
1/8"=1'





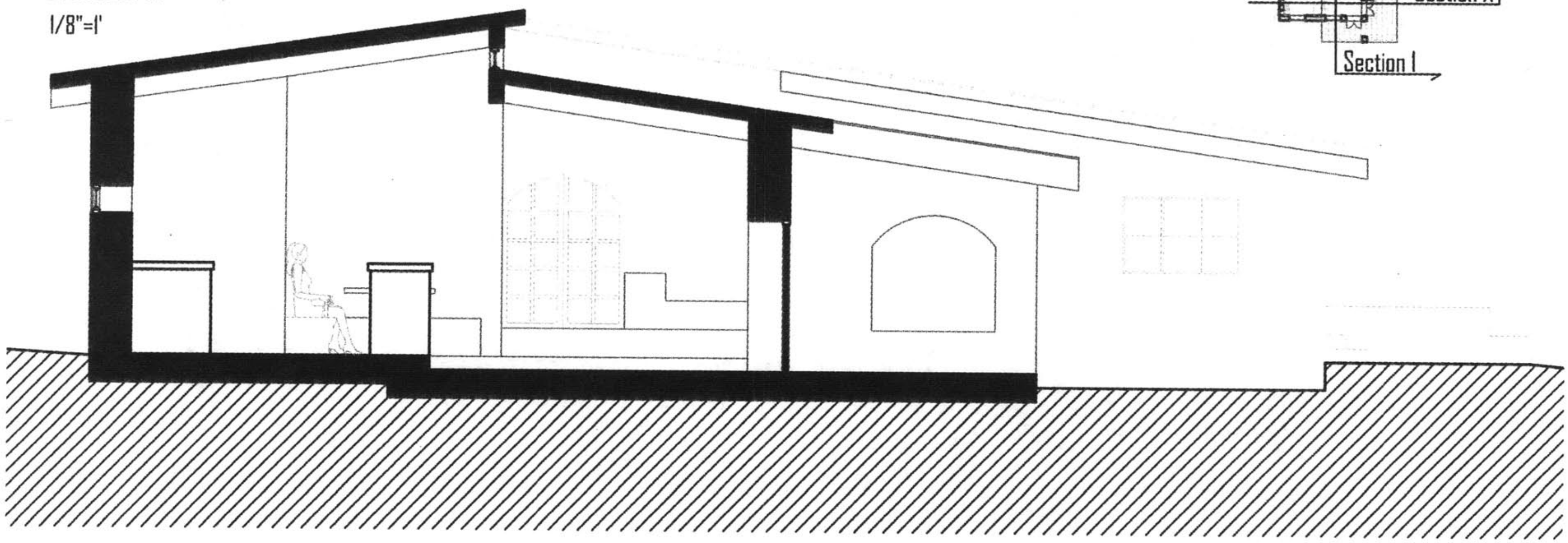
An unexpectedly private space is the bale chair. Located directly next to the main entry, with no partition from the living area, the bale chair is a private nook, designed for one. A perfect place to curl up and read, or just watch the co-inhabitors of the space, it is simultaneously shockingly public and intimately private, analogous to the nature of the family.

Interior of Living Area Through Main Entrance



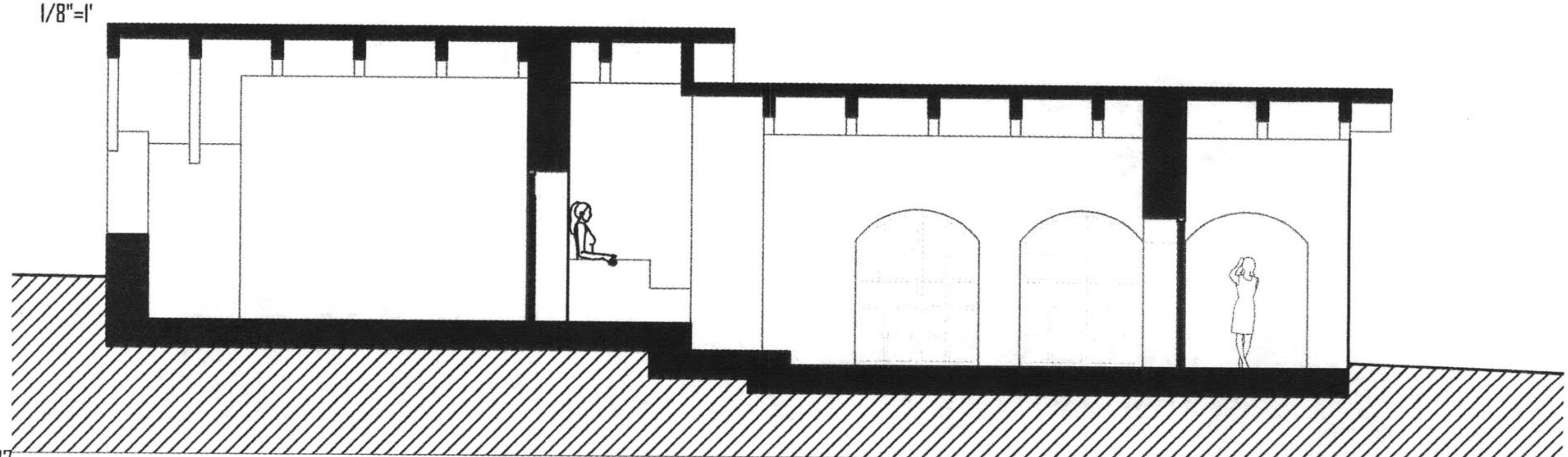
Section A

1/8"=1'

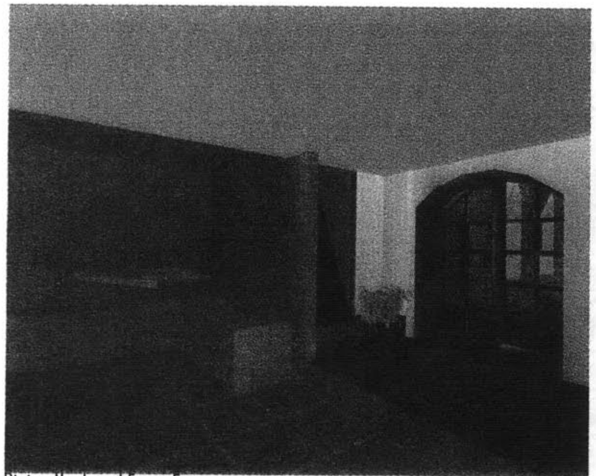


Section 1

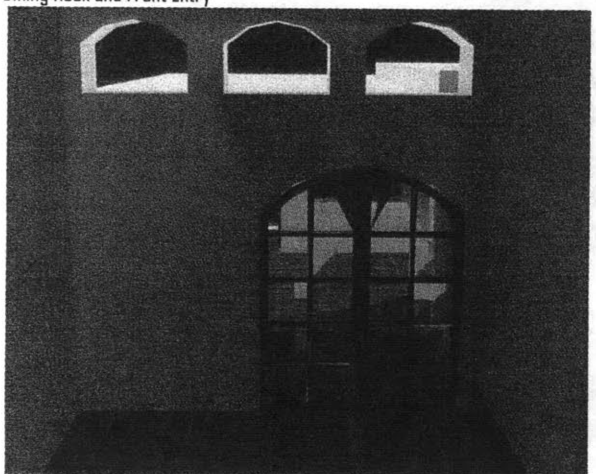
1/8"=1'



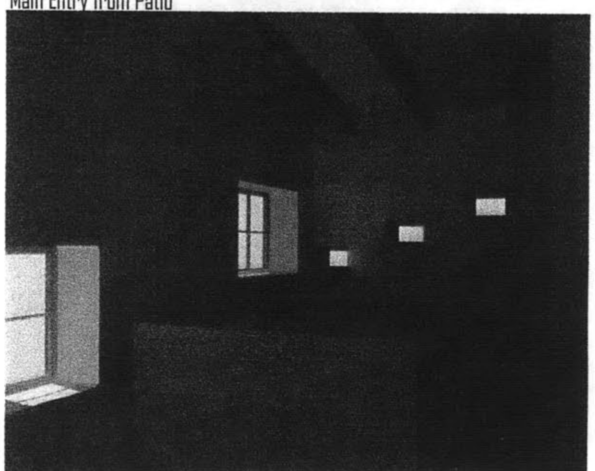
Master Bedroom to Patio



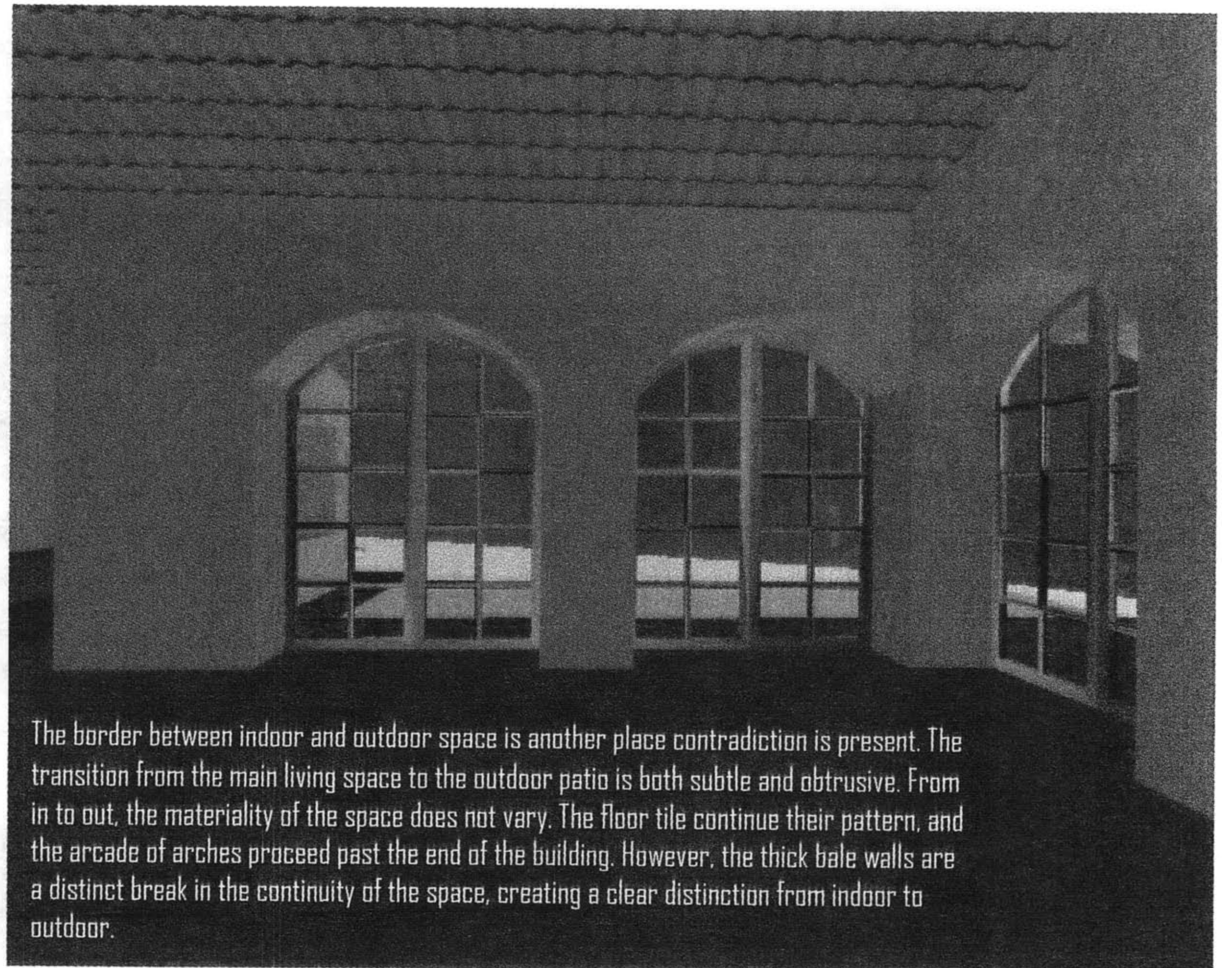
Dining Nook and Front Entry



Main Entry from Patio

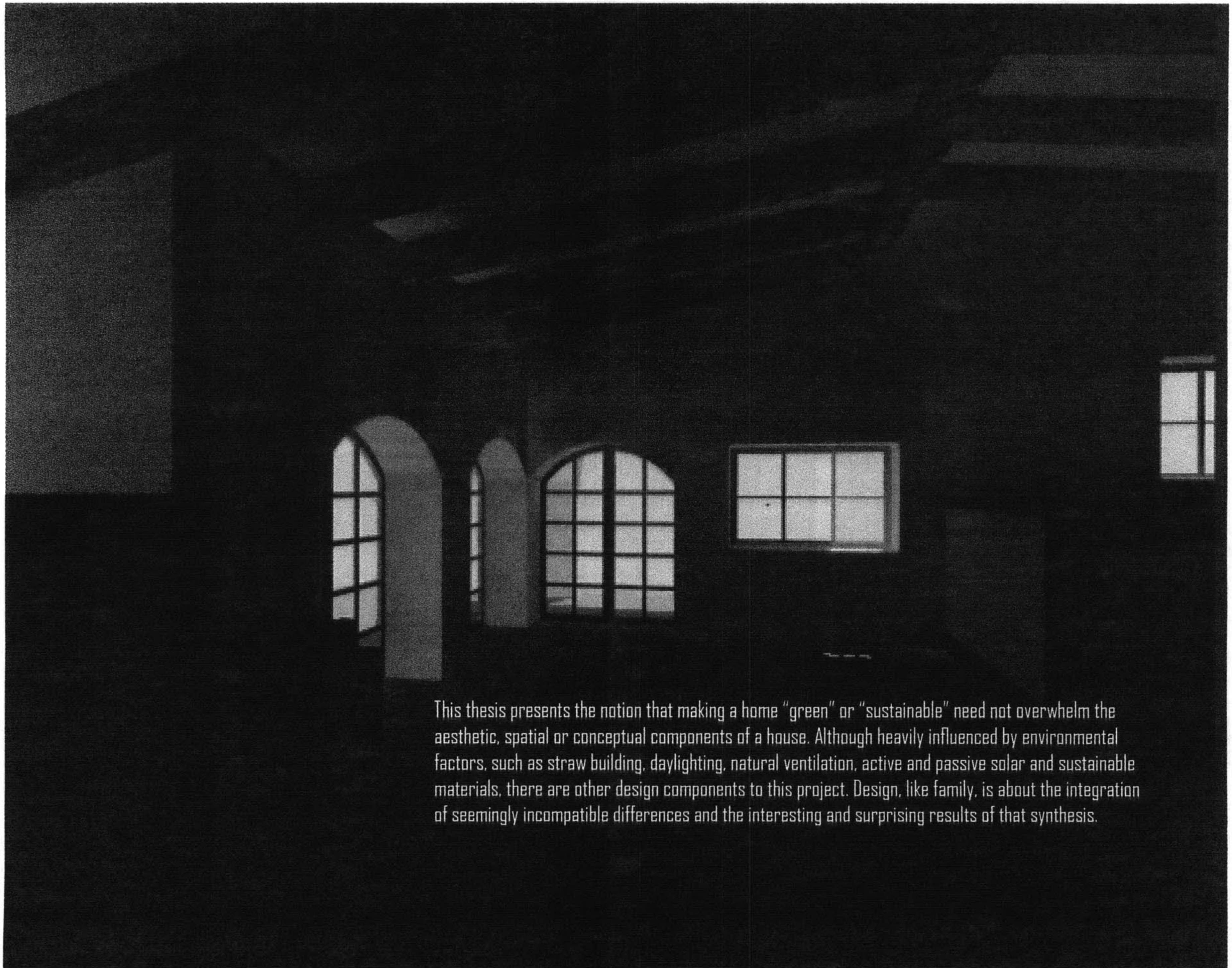


View of Kitchen from Living Area



The border between indoor and outdoor space is another place contradiction is present. The transition from the main living space to the outdoor patio is both subtle and obtrusive. From in to out, the materiality of the space does not vary. The floor tile continue their pattern, and the arcade of arches proceed past the end of the building. However, the thick bale walls are a distinct break in the continuity of the space, creating a clear distinction from indoor to outdoor.

Living Area to Patio



This thesis presents the notion that making a home "green" or "sustainable" need not overwhelm the aesthetic, spatial or conceptual components of a house. Although heavily influenced by environmental factors, such as straw building, daylighting, natural ventilation, active and passive solar and sustainable materials, there are other design components to this project. Design, like family, is about the integration of seemingly incompatible differences and the interesting and surprising results of that synthesis.

Works Cited

(AGO) Australian Greenhouse Office. Australian Greenhouse Office, Department of the Environment and Heritage. December 11, 2005. Australian Government. November 11, 2005. http://www.greenhouse.gov.au/

(CEC) California Energy Commission. Consumer Energy Center. September 2005. November 13, 2005. http://www.consumerenergycenter.org/homeandwork/homes/construction/steel.html

Clements-Croome, Derek. Naturally Ventilated Buildings: Buildings for the Senses, the Economy and Society. London: E&FN Spon, an imprint of Chapman and Hall. 1997.

(EERE) Energy Efficiency and Renewable Energy. Ventilation Preheating. September 19, 2005. U.S. Department of Energy. November 12, 2005. http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12510

Gauzin-Müller, Dominique. Sustainable Architecture and Urbanism: Concepts, Technologies, Examples. Basel: Birkhauser: Publishers for Architecture. 2002.

Glaser, Anthony. The Cob Construction Renaissance. March 5, 2000. Peace and Environmental News. December 11, 2005. http://perc.ca/PEN/1999-10/s-glaser.html

HowStuffWorks, Inc. How Stuff Works. December 10, 2005. November 11, 2005. http://www.howstuffworks.com/

King, Bruce, P.E. Buildings of Earth and Straw: Structural Designs for Rammed Earth and Straw-bale Architecture. Sausalito: Ecological Design Press. 1996.

Koch-Nielsen, Holger. Stay Cool: A Design Guide for the Built Environment in Hot Climates. London: James & James (Science Publishers) Ltd. 2002.

(OSBBC) Ontario Straw Bale Building Coalition. What is a Straw Bale Building? November 11, 2005. December 6, 2005. http://www.strawbalebuilding.ca/strawbales.shtml

Paschich, Ed. Jan Zimmerman. Mainstreaming Sustainable Architecture. Casa de Paja: A Demonstration. Corrales: High Desert Press. 2001.

(SEAV) Sustainable Energy Authority: Victoria. Sustainable Energy Info. December 8, 2005. Government of Victoria, Australia. November 28, 2005. http://www.sustainable-energy.vic.gov.au.

(SESCI) Solar Energy Society of Canada Inc. Solar Energy. November 25, 1997.Canadian Government. December 10, 2005. http://www.newenergy.org/sesci/publications/pamphlets/active.html

Smith, Peter F. Architecture in a Climate of Change: A Guide to Sustainable Design. Oxford: Architectural Press. 2001.

THERMIE Commission. A Green Vitruvius: Principles and Practice of Sustainable Architectural Design. James & James (Science Publishers). 1999.

(TXSES) Texas Solar Energy Society. Renewable Energy and You. December 10, 2005. November 25, 2005. http://txses.org/basics.php?sessionid=