

*Building
Sustainable
Housing
on the
U.S.-Mexico
Border*

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CHAPTER FIVE

Selecting Energy Conserving Housing Materials



Selecting the right materials during the design of a house is key to enhancing its energy efficiency. Appropriate decisions regarding choice of materials, if made during the design, layout, and detailing of the home, can lower the energy costs of attaining desired comfort levels.

When outside air temperature is higher than the desired indoor temperature, heat gain through the envelope of the structure occurs. In this situation, mass in the envelope structure absorbs heat during the hottest part of the day and releases it to the internal spaces when temperatures cool thus operating as a moderator of the outdoor climate. A comprehension of heat flow in various materials is essential in making a proper selection. The most common reference to heat flow is "R-value," or resistance to heat flow. The higher the R-value of a material, the more resistance the material offers to heat flow, either heat gain or heat loss.

Heat capacity is another property of materials which can affect a material's energy performance in certain situations. Heat capacity is a measure of how much heat a material can store. The property is most significant with heavy, high-thermal-mass materials. As typically used in computer modeling of energy performance, heat capacity is determined per unit area of wall. For each layer of material in a wall system, the heat capacity is found by multiplying the density of that material, by its thickness, by its specific heat (specific heat is the amount of heat a material can hold per unit of mass). Typically there are various layers in the construction of a wall. Total heat capacity of such a wall is found by adding up the heat capacities for each layer, for example, drywall, masonry block, and stucco. The heat storage or thermal capacity of the materials in the building envelope will define how much energy is required for a wall to change temperature. Heavier mass will be more efficient in the collection and use of solar heat than thermally light structures. The effects of thermal mass on the energy demand of a house are significant. Appropriate materials selection

has allowed for a 40% reduction in energy demand (Vale and Vale, 2000).

The main benefit of thermal capacity of a material is the ability to store, in its own mass, the heat gained during the day and the delayed transmission of that heat when it is needed during cooler parts of the day. Designing to utilize the thermal capacity of a material is more relevant when the approach is combined with other strategies to enhance comfort. Understanding the time frames in which materials gain heat and release heat and the time frames in which particular rooms and spaces in a house are scheduled to be used can result in the design of a house which is much more efficient in passive energy conservation and enhancing thermal comfort. For example, in a cold climate a room such as a bedroom with high-thermal walls facing south would gain heat during the course of the day, while not in use, and release that warmth later in the evening and night when the bedroom is occupied. In a warm climate a room used in the daytime with high-thermal walls facing south would gain temperature during the course of the day, while it is in use, and release that warmth later in the day when it is empty.

Different options which emphasize combined systems and articulate their basic principles are described in the literature. This section will review these and identify which materials are suitable for use in different components of a house such as roofs, walls and pavements. Comparisons will be made between the commonly used materials, new materials and alternative techniques.

RECYCLED MATERIALS

In a global context the impact of construction is dramatic, since almost 10% of the world total economy is dedicated to the building and construction industry. Meanwhile 20% to 40% of the world's wood, minerals, water and energy are used in the manufacture and the transportation of construction materials. Alternative techniques such as the use of recycled materials become important as a fundamental strategic choice to mitigate the negative and polluting aspects of this activity. A sustainable approach to housing development has been defined as one

that takes into consideration present needs of society without compromising the needs of future generations through resource depletion. The current concerns about pollution and resource depletion are based on measurable factors such as the levels of contaminants in the air and water, or consumption of a resource compared with its reserves (Vale and Vale 2000). The use of recycled materials in activities such as home construction, if effectively done to create energy efficient structures, is a contribution to sustainable development.

WALL CONSTRUCTION

The thermal structure of a wall is understood as the distribution of thermal resistance and capacity in its volume. Results in experimental simulations have led to the conclusion that the material configuration of the exterior wall can significantly affect the annual thermal performance of the whole building. However, this effect depends on climate type. Walls that incorporate mass on the internal surface and insulation on the outer surface show the best thermal performance in warmer climatic zones. Differences in total energy demand between the configuration "all insulation inside" and the most effective configuration (from the point of view of energy savings) "all insulation outside" may exceed 11% for a continuously used residential building.

CONCRETE CONSTRUCTION

As a whole, concrete construction provides structural integrity, termite protection, and thermal storage, and it helps reduce air infiltration in buildings. It also readily absorbs heat, making it ideal as thermal mass in passive solar building design. Producing cement uses a great deal of energy, so finding a waste product that can substitute for cement makes good environmental sense. Burning coal to make electric power creates a great deal of waste fly ash, and a smaller amount of slag is created when producing iron in blast furnaces. Coal fly ash, blast furnace slag and other mineral admixtures can substitute for cement in concrete mixes for buildings, saving energy, disposing of a waste product, improving the quality of the concrete, and reducing cost. Cement substitutes should be

distinguished from concrete additives, such as plasticizers and air entrainment agents; and from aggregate substitutes, such as ground glass or ground scrap rubber (NAHB Research Center 2004).

There are many concrete products which offer options for construction materials for homes. They include:

- Masonry
- Precast
 - Autoclaved Aerated Concrete (AAC)
 - Insulated Concrete Forms (ICF)
- Cast in Place

MASONRY

Masonry is concrete blocks assembled with mortar. The design of a building provides opportunities to manipulate the layering of masonry blocks in a way to generate systems which have great energy efficiency levels thus increasing the level of sustainability of the building.

PRECAST CONCRETE

Manufacturers construct precast concrete walls or panels off-site. Most of these are also pre-insulated with rigid foam board. Additional insulation can usually be added inside the wall cavity to achieve a high R-value. The panels typically come in lengths of up to 16 feet and in standard heights of 4, 8, and 10 feet. Once formed and cured in a factory location, they are transported to the building site. A crane is needed to lift them into place. Precast concrete walls have been shown to be very effective in passive solar design.

Precast concrete panels are typically made with fiber-mesh reinforcement and a concrete mix that is much stronger than concrete block or poured concrete walls. The concrete mixture has a low water/cement ratio, resulting in a dense material that prevents water penetration through the walls. However, specific details and quality control vary with the manufacturer. High tensile strength of the panels helps resist lateral forces from outside the wall. Reinforced panel beams uniformly distribute the weight of the superstructure of the house.

Precast concrete systems are competitive with block walls. Walls made with these systems go up more quickly, offering savings in labor costs. Footers are usually not required. Construction in cold weather is simpler because no pouring or curing of concrete is required. Waterproofing is simplified due to the material's resistance to water penetration. Companies and their licensees are regional, located mainly in the Northeast. Shipping costs may be high, depending on location and if erection equipment is needed for on-site lifting.

Autoclaved Aerated Concrete (AAC)

AAC is a precast, manufactured building stone made of all-natural raw materials. It is economic, environmentally friendly, cellular, lightweight but structural material that features thermal and acoustic insulation as well as fire and termite resistance. These units are much lighter than traditional concrete blocks because they use a special mixture of sand, limestone, cement and an expanding agent. Although it has been a popular building material in Europe for over 50 years, AAC has only been introduced to the U.S. in the past few years. Autoclaved aerated concrete comes in plank or block form (U.S. Department of Energy, 2004). Portland cement is mixed with lime, silica sand, or recycled fly ash (a byproduct from coal-burning power plants), water, and aluminum powder or paste. It is poured into a mold. Steel bars or mesh can also be placed into the mold for reinforcing. The reaction between aluminum and concrete causes microscopic hydrogen bubbles to form, expanding the original concrete volume about five times. After evaporation of the hydrogen, the now highly closed-cell, aerated concrete is cut to size and form and steam-cured in a pressurized chamber (an autoclave). The result is a non-organic, non-toxic, airtight material that can be used in non- or load-bearing exterior or interior wall, floor, and roof panels, blocks, and lintels. According to the manufacturers, the production process generates no pollutants or hazardous waste (NAHB Research Center 2004). AAC is available in a variety of forms, ranging from wall and roof panels to blocks and lintels. Panels are available in thicknesses of 3" to 16", 24" wide, spanning up to 20'. Blocks come 24"L × 3"-12"W × 8"H.

FlexCrete, a fiber-reinforced aerated concrete, a product of FlexCrete Building Systems, LC was used in the construction of both the houses built by ASU Stardust Center in Nageezi Navajo Nation and in Guadalupe, Arizona (see Chapter Six, p.53). The web site for FlexCrete <http://www.flex-crete.com> states that the product, “features ease of construction, high fire resistance, excellent insulation, cost effectiveness” and goes on to describe the material as follows:

“Building with FlexCrete provides many advantages over other traditional concrete construction alternatives. All FlexCrete materials are formulated using high volumes of fly ash, a recovered resource that is in abundant supply wherever coal is burned for generating electricity or for other industrial uses. In contrast with other forms of aerated concrete, because of the unique physical properties of fly ash, FlexCrete is cured at low temperatures and ambient pressure, thus eliminating the use of energy intensive autoclaves. Available in block, floor and roof panels, and in FomeStone Thin Unreinforced Panels, FlexCrete is suitable for use in all types of commercial, industrial and residential applications. Used as a stand-alone building system, or in combination with FlexCrete floor & roof panels, FlexCrete block is suitable for load bearing and non-load bearing walls in all types of commercial, industrial and residential applications.”

These attributes and the price point of the material were persuasive and 6", 8" and 12" FlexCrete blocks are installed and performance is being evaluated in the Nageezi, Navajo Nation house. FlexCrete block has also been used in the Guadalupe house.

Insulating Concrete Forms

To construct an insulating concrete form (ICF), builders pour concrete into a foam form. The form then stays in place to provide insulation. Builders construct walls by stacking ICFs, cutting them where needed to fit windows and corners, etc. They also place steel rebar horizontally and vertically within the form to provide strength. Although all ICFs are identical in

principle, the various brands differ widely in the details of their shapes, cavities, and component parts (NAHB Research Center, 2004).

ICFs come in one of three basic form types, which differ by the size of the units and the way they connect to one another. Panel systems are the largest units, available in sizes from approximately 1'-3" x 8'-9" up to 4' x 12'. Panel systems allow a large section of wall area to be erected in one step, but may require more cutting in the field. The panels have flat sides and are connected to one another with metal or plastic ties. They can be shipped flat. (NAHB Research Center, 2004). However the insulation on the inside negates much of the mass effect, which will diminish much of the thermal benefit of the mass. Also concrete pumping equipment is usually needed for ICF construction.

CAST-IN-PLACE CONCRETE

Cast-in-place framing construction involves setting up removable or temporary forms for the pouring of concrete walls. Rigid foam board insulation is usually placed between the removable forms. Steel rebar is also generally used to add strength to the wall (U.S. Department of Energy 2004).

WOOD CONSTRUCTION

Builders can choose from a variety of wood sheathing products that range in cost, strength, insulation value, and ease of installation. Of the options available, plywood and oriented strand board (OSB) are the strongest and most durable. Wood sheathing panels add shear and racking strength, important characteristics that are engineered to help a structure withstand the forces of high winds and earthquakes. Wood-sheathed walls are also easy to build and easy to insulate for high R values.

Structural insulated panels (SIPs)—which commonly consist of rigid foam board sandwiched between structural wood sheathing (plywood and OSB)—can be used in place of stud-framed construction for both walls and ceilings. While manufactured wood products often perform as well as or better than lumber, the glues used in the manufacturing process can cause

indoor air quality problems. Engineered wood products made with exterior-type glues (phenolic resins) and urethane (polyurea) adhesives give off some of the lowest emissions. Because they are susceptible to damage from termites and dry rot, some wood products also are pressure-preservative treated. These products can also sometimes negatively affect indoor air quality if not used properly (U.S. DOE 2004).

Wood structures usually require additional insulation to acquire comfortable thermal characteristics. Foam insulation typically is more expensive than fiber insulation. But it's very effective in buildings with space limitations and where higher R-values are needed. Foam insulation R-values range from R-4 to R-6.5 per inch of thickness (2.54 cm), which is up to 2 times greater than most fiber insulating materials for the same thickness. Foam insulation is often made with one of three materials: molded expanded polystyrene (MEPS), extruded expanded polystyrene (XEPS) or polyurethane, polyisocyanurate, or a related chemical mixture. Some are installed as a liquid while other types come as factory-made panels called rigid foam boards. (U.S. DOE 2004)

EARTHEN CONSTRUCTION TECHNIQUES

Earthen construction techniques, while housing over 50% of the world's population, are not generally considered mainstream approaches in the United States. More recently higher lumber prices and the potential for lower overall environmental impact have further increased interest in using earthen construction techniques. Adobe, super adobe, "cast" earth, PISE, cob, rammed earth, and wattle and daub are examples of these earth-based construction approaches. (U.S. DOE 2004) Earth as used in walls of buildings has a low compressive strength with large wall thicknesses generally in the range 230mm-400mm. Earthquake loads are critical for most earth buildings and this height limitation recognizes the limits of the material and the current state-of-the-art in understanding modern earth buildings in seismic areas.

REINFORCED ADOBE

Adobe is air dried "mud-bricks" made from a puddled earth mix cast into a mould. The earth mix contains sand, silt and clay and sometimes straw or a stabilizer which is also used to mortar the walls. Richard Walker from the Department of Civil and Resource Engineering, at The University of Auckland (New Zealand) has developed ways to improve the structural response of adobe walls. Three New Zealand Standards for earth building have been developed. The standards cover adobe (sun dried brick), rammed earth and pressed brick construction including reinforced and unreinforced walls. Few performance based standards have been developed internationally. Simple and low cost materials tests were adopted to establish that earth wall materials meet the building code requirements.

HIGH-TECH ADOBE

Although the basic sand to clay ratio is the same as adobe an asphalt emulsion is added to the mix. Asphalt emulsion is an oil by-product commonly used in road construction. It is mixed with water and then sand and clay. The end result, depending on the amount of emulsion used, is an adobe which is either water resistant (semi stabilized), or totally water proof (fully stabilized). For an exterior patio or courtyard wall the addition of the emulsion makes sense. The adobe purists cringe at the idea of adding an oil by-product to what they see as a beautiful, natural building material. There is also a concern about the possibility that the material might give out harmful gasses. All building materials release some fumes from the components used in the making of the material.

RAMMED EARTH CONSTRUCTION

The principle behind rammed earth construction is to turn soil into sedimentary rock walls in just minutes. Using high pressures and heavy equipment drastically shortens these geologic processes. The resultant rammed earth buildings have strong, thick walls that require little maintenance. Several rammed earth buildings in France, Germany, and England built in the 1500s are still occupied. Rammed earth walls are created using soil, water, formwork, and tamping equipment. The result of rammed earth construc-

tion is a massive structure that will temper the interior space against outdoor temperatures. Solar radiation is absorbed by the walls, travels slowly through the structure, and is released indoors or re-radiated to the nighttime sky. The buildings are slower to heat up in the summer sun, and retain heat because the thermal mass is very slow to give up its heat. Typical insulation values for rammed earth walls are R-0.25 per inch or R-4.5 for a typical 18-inch wall. The real energy efficiency lies not in the insulation value, but in the massive structure's ability to reduce interior temperature swings.

Rammed earth construction usually starts with a foundation of stone or concrete. In dry climates on stable ground, however, a foundation can be nothing more than beginning the base of the rammed earth wall a certain depth below grade. The irregular surface of a stone foundation serves as an area where a strong mechanical bond can be made with the wall.

The ideal soil for rammed earth construction is a mixture of roughly 70 percent sand and 30 percent clay, although non-ideal soil can be enhanced with stabilizers such as Portland cement or other additives. With the right soil material, unstabilized rammed earth is allowed as long as exterior walls are well protected from moisture damage, through the use of hard plaster or stucco finishes. Other plasters that are stabilized with softer materials such as asphalt emulsion can protect exterior walls semi-covered by overhangs.

Custom forms are used to create window and door openings. Windows and doors are installed by drilling holes into the jambs and header. Concrete bond beams typically are used to tie the system together and to anchor the roof. A sill plate is bolted to the top of the bond beam for roof attachment. The roof may also provide structural stiffness to the building. Deep window wells resulting from the thick walls provide an opportunity for passive solar benefits.

Building materials for rammed earth construction are widely available and inexpensive. Unlike adobe that is made of small blocks and may require 30 days to cure, a rammed earth wall is

monolithic and cures in situ. Rammed earth wall construction is about \$60 per linear foot for a 9-foot wall. Cost will depend greatly on the ratio of wall area to floor area and exterior and interior finishes. Stabilized rammed earth does not need interior or exterior finish, which can reduce costs of construction.

Public perception of earthen buildings is not always good in regions familiar with common timber-framed housing. Accordingly, infrastructure-regulators, financing, mortgage groups, insurers, developers, builders, realtors are poorly equipped to accommodate earthen construction. Earth-building methods are almost always very dirty, labor intensive, and take extended time for construction. Care must be taken to avoid breakage of plumbing lines embedded in earthen walls.

STRAW BALE CONSTRUCTION

Straw bale construction uses baled straw from grain such as wheat, oats, barley, rye. The walls are covered by stucco. Straw bales are traditionally a waste product, which farmers sell for animal bedding or landscaping as it is durable. Straw is the dry plant material or stalk left in the field after a plant has matured, been harvested for seed, and is no longer alive. Hay bales are made from livestock feed grass that is green and alive. Hay bales are not suitable for this type of construction.

Straw bale technique for constructing walls has recently been revived as a low-cost alternative for building highly insulating walls. The technique was practiced in the Plains states in the latter 1800s and early 1900s. Many of the early structures are still standing and in use. The technique has been applied to homes, farm buildings, schools, commercial buildings, churches, community centers, government buildings, airplane hangars, well houses, and more.

Straw is also currently used as a building material in sheet materials such as sheathing and wall panels. From a regulatory standpoint straw bale construction is a new technique and cities such as Austin, Texas have recently passed straw bale construction building codes. Walls of straw bales can be built by unskilled labor, and

the low costs of the bales make this technique economically attractive. However the cost of straw bales differs depending on what time of year they are harvested and how far they must be transported. They are cheaper at harvest time and if they are transported a shorter distances. Bales must also be protected from moisture and from getting wet. Costs also depend on the type of stucco finish selected and its method of application. A mud plaster made from site soil, applied by the owner/builder, and maintained by the owner is quite inexpensive, but may take a long time to apply. Cement stucco applied by a contractor is quick and lasts a very long time without maintenance, but it also costs more. As with any construction the more labor input an owner/builder can make and the less that is done by a contractor, the lower the cost of construction.

OTHER ALTERNATIVES

Earth and recycled materials have also been used as low cost construction alternatives. For example, used tires can be filled with earth and stacked like bricks. Once the tires are packed, they are very difficult to move and form quite a dense wall. The walls are load bearing and provide thermal mass, which is an important attribute to any energy efficient house. Once the walls are in place, the walls are quite often plastered over and appear very similar to an adobe style house. This type of construction provides a large amount of thermal mass which helps keep the house cool in the summer and warm in the winter. Most homes of this type have been built in the southwestern part of the United States (Daycreek.com). One of the advantages of this construction is that can be owner-built. Although there is extensive labor involved, a house of this type could be built with just a couple of workers. Basic carpentry, plumbing and electrical skills are required.

ROOFS

Roofs play a key role in protecting building interiors and their occupants from weather, primarily moisture. The roof, insulation, and ventilation must all work together to keep the building free of moisture. Roofs also provide protection from the sun. In fact, if designed correctly, roof overhangs can protect the buildings

exterior walls from moisture and sun. Different roof designs and materials are used for residential and commercial buildings. Roof design can impact the building's thermal performance. For example, in a metal-framed building, the metal eaves can act as thermal fins, moving heat out of the building.

A number of roofing choices are available for high-performance buildings. New roof shingles on the market today even produce electricity using solar technology. Reflective roofing materials or coatings help send the heat back into the sky rather than into the building. And recycled content shingles are available that look like slate or wood (U.S. Department of Energy 2004). The roofing industry is developing products that reuse waste from other industries. For instance, waste from manufacturers of car hoses, shoes, tires, and other rubber products is now being directed to the manufacturing plant of EcoStar Inc., which makes a 100% recycled lightweight rubber "slate" tile. Another recycled product, the eco-shake, looks like wood and contains reinforced vinyl and cellulose fiber. A number of roofing materials are available including: asphalt: metal; wood; concrete and tile; single-Ply; solar Shingles; and coatings.

ASPHALT ROOFS

Asphalt is the most commonly used roofing material. Asphalt products include shingles, roll-roofing, built-up roofing, and modified bitumen membranes. Asphalt shingles are typically the most common and economical choice for residential roofing. They come in a variety of colors, shapes, and textures. There are four different types: strip, laminated, interlocking, and large individual shingles. Laminated shingles consist of more than one layer of tabs to provide extra thickness. Interlocking shingles are used to provide greater wind resistance. And large individual shingles generally come in rectangular and hexagonal shapes. Built-up roofing (or BUR) is the most popular choice of roofing used on commercial, industrial and institutional buildings. BUR is used on flat or low-sloped roofs and consists of multiple layers of bitumen and ply sheets. Components of a BUR system include the roof deck, a vapor retarder, insulation, membrane

and surfacing material. A modified bitumen membrane assembly consists of continuous plies of saturated felts, coated felts, fabrics or mats between which alternate layers of bitumen are applied, either surfaced or unsurfaced. Factory surfacing, if applied, includes mineral granules, slag, aluminum or copper. The bitumen determines the membrane's physical characteristics and provides primary waterproofing protection, while the reinforcement adds strength, puncture resistance and overall system integrity.

METAL ROOFS

Most metal roofing products consist of steel or aluminum, although some consist of copper and other metals. Steel is invariably galvanized by the application of a zinc or zinc/aluminum coating, which greatly reduces the rate of corrosion. Metal roofing is available as traditional seam and batten, tiles, shingles, and shakes. Products also come in a variety of styles and colors. Metal roofs with solid sheathing control noise from rain, hail, and bad weather just as well as any other roofing material. Metal roofing can also help eliminate ice damming at the eaves. And in wildfire-prone areas, metal roofing helps protect buildings from fire should burning embers land on the roof. Metal roofing costs more than asphalt, but it typically lasts two to three times longer than asphalt or wood shingles (U.S. DOE).

WOOD ROOFS

Wood shakes offer a natural look with a lot of character. Because of variations like color, width, thickness, or cut of the wood, no two shake roofs will ever be the same. Wood offers some energy benefits, too: it helps to insulate the attic, and it allows the house to breathe, circulating air through the small openings under the felt rows on which wooden shingles are laid. A wood shake roof, however, demands proper maintenance and repair, or it will not last as long as other products. Mold, rot, and insects can be a problem. The life cycle cost of a shake roof may be high, and old shakes can't be recycled. Most wood shakes are unrated by fire safety codes. Many use wipe-on or spray-on fire retardants, which offer less protection and are only effective for a few years. Some pressure-treated shakes are impregnated with fire retardant and meet national fire safety

standards. Installing wood shakes is more complicated than roofing with composite shingles, and the quality of the finished roof depends on the experience of the contractor as well as the caliber of the shakes used. The best shakes come from the heartwood of large old cedar trees, which are difficult to find. Some contractors maintain that shakes made from the outer wood of smaller cedars—the usual source today—are less uniform, more subject to twisting and warping, and don't last as long. A recycled content roofing material, the eco-shake, looks like wood and contains reinforced vinyl and cellulose fibers.

ENVIRONMENTAL RATING SYSTEMS FOR RESIDENTIAL BUILDINGS

During the design, construction, and operation of a home, site design, energy and water efficiency, resource efficient building materials and indoor environmental quality are all taken into account in assessing the energy utilization, efficiency and hence sustainability of the house. In the U.S. there are primarily two national environmental rating systems for residential buildings: the National Association of Home Builders (NAHB) Green Home Building Guidelines and the U.S. Green Building Council's (USGBC) LEED for Homes. NAHB's Green Home Building Guidelines are voluntary guidelines designed to move environmental-friendly home building practices into the mainstream. The guidelines are organized into six primary sections:

- Site Preparation and Design
- Resource Efficiency
- Energy Efficiency
- Water Efficiency and Conservation
- Occupancy Comfort and Indoor Environmental Quality
- Home Owner Guidance on How to Optimally Operate and Maintain a Home

Described in each section are ways home builders can incorporate green building practices into a project. Points are given for meeting the criteria and projects are given a bronze, silver or gold rating. Since the NAHB guidelines were designed to be customized and administered by local home building associations they may lend

itself to being customized by a community like Tecate. The NAHB guidelines can be downloaded from: www.nahb.org/gbg.

USGBC's LEED for Homes is also a voluntary program designed to recognize the top 25% of homes with best-practice environmental features. It is a national consensus-based, market-driven building rating system designed to accelerate the development and implementation of green building practices. It is nationally administered by the USGBC which will also providing training workshops, professional accreditation, resource support, and third-party certification of home performance.

LEED-H reward points are given to homes that:

- Use energy resources efficiently;
- Use water resources efficiently;
- Use building construction resources efficiently (through improved design, material selection and utilization, and construction practices),
- Use land resources efficiently, and
- Use materials and practices designed to safeguard occupants' and workers' health.

Buildings can receive certified, silver, gold or platinum rating. LEED for Homes is a national environmental rating system across the US, and is not customized. This may render it not an ideal environment rating system for a community like Tecate. However it could still be useful in guiding the design.

APPLICATIONS TO TECATE

With temperatures in Tecate reaching highs of 104° F and lows of 30° F it is extremely important to design urban layouts and homes so that they are energy and resource efficient and also responsive to the economic conditions of the community they serve. In Mexico, especially along the border, income limitations in communities such as El Rincon can be challenging when designing homes for affordability and sustainability. Housing projects which are affordable are often limited in their access to technical and material resources. Historically, low-income urban developments in Mexico's borderlands are not a priority in city development plans. In addition, as in El Rincon, a fair number of these

communities are self-built with poor or little knowledge of what works best for the climate in which they are located and are illegally occupying land they do not own or to which they do not have tenancy rights.

In contexts such as El Rincon the need to reach ideal thermal comfort levels is great, however, attaining it with mechanical heating and cooling equipment can be very expensive. In addition access is often limited to basic services such as electricity, sewer service and potable water, so relying on attaining desirable thermal comfort levels with mechanical systems is not realistic. Appropriate and sustainable design solutions must focus on inexpensive strategies, such as the passive strategies described in Chapter Four, in order to make them appealing to lower income self builders as well as government officials. In lower income communities the design of a house and the layout of the community must take optimal advantage of passive and low-energy strategies. Creating a pleasant environment by maximizing energy efficiency through building orientation, material selection, and, architectural form can create a climatically and culturally responsive architecture.

The design principles described in Chapter Four can be applied to home design in the Tecate region. Lower-income owners of self-built homes can construct more energy efficient, climatically responsive homes. Passive and low-energy use strategies can make houses more affordable when costs are calculated over the life cycle of the house.

CHALLENGES AND SOLUTIONS FOR HOUSING DESIGN IN TECATE:

The climatic factors affecting the design of houses in Tecate are:

- Mild to hot summers reaching 104° F
- Cold winters with lows of 30° F
- Low humidity all year round
- Low rainfall (13 inches annually)
- Elevation 1650 feet

SUMMER TEMPERATURES

In climatic conditions like these of Tecate, using thermal mass for cooling is essential. Typically nights are cooler than days. Mass provides a building the opportunity to store night time cold for longer periods of time thus reducing cooling loads during the day or eliminating them entirely. In the summer time storing night-time cooling can bring enough cooling into a house to keep the residence within thermal comfort limits during the day without the assistance of mechanical systems. If night-time cooling does not cool the house mass enough to keep indoor temperatures within comfort limits, stack ventilation can assist the cooling. Stack ventilation allows buildings to constantly flush warm air through clear story windows while pulling more cool air through lower fenestrations. Trees and native low-maintenance plants can bring enough shade and evaporative cooling to lower temperature by three to ten degrees.

WINTER TEMPERATURES

Purposive orientation has always been a key design element of most indigenous architecture. It works efficiently although not always achieving the comfort levels which are deemed ideal today. Carefully orienting buildings can maximize solar heat gain, exposure to cooling breezes and increase wind protection. It can help reduce dust and noise pollution. Passive heating is very effective in warming small to medium buildings from solar heat gain on exterior walls. In smaller structures there is a high external wall surface to internal volume. South-facing walls can be designed so as to be excellent gateways to bring in sunlight through the use of large windows with regular double pane systems which reduce heat loss. The summer solar heat gain can be reduced with a well designed trellis which casts shadows and provides shade. Mass is as essential in winter time as it is during the hot season. Mass provides day-heat-gain storage that will then be released during the cold night. Insulation is also important. Designing compact communities with housing units which share a common party-wall reduces the surface area and the need for insulation. Exterior walls need to have mass and two to three inches of exterior insulation.

WALL CONSTRUCTION AND THERMAL TRANSMITTANCE

The three wall types illustrated in Figures 47–49 demonstrate how appropriate selection of materials, construction and use of insulation in a concrete block wall can decrease the thermal transmittance (a reflection of the rate of heat transfer) of a wall assembly and make it more useful in passive cooling or heating. Note that with increasing insulation, transmittance of a concrete block wall was lowered nearly by half as observed experimentally (from 1.9 to 1.04 W/m²K). Standard recommendations for such walls issued by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) are also shown.

ALTERNATIVE TO ADOBE WALL CONSTRUCTION

Professor De La Fuente at La Universidad Autonoma de Colima has designed an alternative to adobe wall which uses bagged earth blocks to construct walls (Figure 50). His research suggests that this is a feasible option for wall construction in low-income housing. The wall provides great thermal properties especially for extreme weather. There has been a resurgence of interest in this type of construction, generically termed earth bag construction, since architect Nader Khalili, Cal-Earth Institute, began experimenting with bags of adobe soil as building blocks for creating domes, vaults and arches (Figure 51). The Cal-Earth Institute trains people in the technique of building with earthbags that are laid in courses with barbed wire between them (Green Home Buildings: 2006).

How finished a wall constructed with alternative adobe looks after the application of stucco plaster is illustrated in Figure 52. Walls like these can attain simple compression strengths of 20 kilograms/square centimeter in fourteen days and this strength increases over the next fourteen days. Professor De La Fuente has completed full testing on this alternative material including market pricing and manufacturing costs. Given the prevailing building standards in Mexico, this alternative adobe represents a viable material and construction method to create affordable housing.

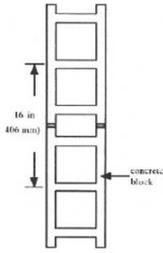


Figure 47: Wall Construction 1

20.3 cm medium-weight concrete block wall with a 28.9° C mean temperature.

Description:

20.3×20.3×40.6 cm medium weight hollow core concrete block, 1842 kg/m³ and 0.753 W/mK

10 mm wide mortar joints and 0.86 W/mK

Experimental Results

Thermal transmittance; 1.99 W/m²K
 Mean Temperature; 28.9° C
 Temperature Difference:
 Air-to-air 12.2° C and
 Surface-to-Surface 8.9° C.
 ASHRAE recommended value:
 Thermal Transmittance: 2.48 W/m²K

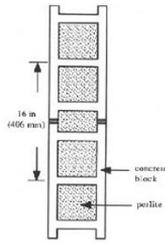


Figure 48: Wall Construction 2

20.3 cm Medium weight concrete block wall with perlite insulation cores with a 37.6° C mean temperature.

Description:

20.3×20.3×40.6 cm medium weight hollow core concrete block, 1842 kg/m³ and 0.753 W/mK

10 mm wide mortar joints and 0.86 W/mK

Perlite insulation, 97.7 kg/m³ in cores and 0.049 W/mK

Experimental Results

Thermal transmittance; 1.44 W/m²K
 Mean Temperature; 36.7° C
 Temperature Difference:
 Air-to-air 28.3° C and
 Surface-to-Surface 24.4° C.
 ASHRAE recommended value:
 Thermal Transmittance: 1.34 W/m²K

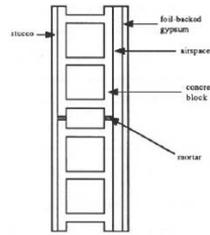


Figure 49: Wall Construction 3

20.3 cm normal weight concrete block wall with reflective air space with a 37.9° C mean temperature.

Description:

20.3×20.3×40.6 cm normal weight hollow core concrete blocks (2 per block), 1842 kg/m³ and 0.72 W/mK
 10 mm wide mortar joints and 0.864 W/mK

19mm reflective air space,
 12.7 mm foil-backed gypsum wall-board (emittance of 0.05) and 0.16 W/mK

Experimental Results

Thermal transmittance; 1.04 W/m²K
 Mean Temperature; 37.9° C
 Temperature Difference:
 Air to air 28.3° C and
 Surface-to-Surface 24.4° C.
 ASHRAE recommended value
 Thermal Transmittance: 1.02 W/m²K



Figure 50: Alternative to Adobe Construction



Figure 51: Forming Alternative Adobe Block

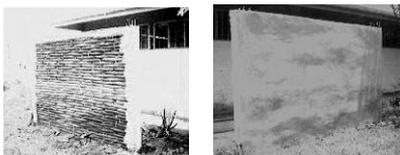


Figure 52: Alternative Adobe Wall Before and After Application of Stucco

ASU's Stardust Center for Affordable Housing and the Family has utilized FlexCrete block walls in two prototype houses built in the United States. One is in a rural location on the Navajo Reservation in Nageezi, New Mexico (see Figure 35 in Chapter Six) and the other is in an urban location in Guadalupe, Arizona (see Figure 36, Chapter Six), a small Yaqui and Hispanic community in metropolitan Phoenix. These houses are in climatic and socio-cultural contexts which are similar to those found in the U.S.-Mexico border region. They illustrate how quite different houses result from the application of design principles described here. Consideration has been given to site and location, community, socio-cultural attitudes and expectations, materials, and the price of factors of production (the price of land, labor and materials) as well as the regulatory environment and real estate values. Such a tailoring of housing and settlement design to client, context and energy conserving construction can create environmentally friendly and sustainable housing.