

## **Alternative Energy and Building Techniques**

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### **Academic Setting**

Rio Grande High School is located in the South Valley: an unincorporated, low-density area adjacent to and south of Albuquerque in Bernilillo County, New Mexico.

The demographic data listed below is from the forty-day count for the 1999-2000 school year. The data is from the APS Research, Data and Accountability Office and the 1990 US Census.

Enrollment at Rio Grande High School (RGHS) for the 1999-2000 school year was at 2,167 students. The average enrollment for the past five years was 2,273.8 students. The smallest school enrollment for an Albuquerque Public School (APS) high school for 1999-2000 was 1,673, and the largest school enrollment was 2,348.

Student ethnicity (displayed in %) at Rio Grande was 83.9 Hispanic, 9.7 Anglo, 4.3 Native American, 1.6 African American, .1 Asian, and .3 "other." The ethnicity (displayed in %) for all APS high schools was 45.8 Hispanic, 43.43 Anglo, 4.8 Native American, 3.7 African American, 2.2 Asian, and .07 "other."

The APS Research, Data and Accountability Office, in 2001 stated:

The percentage of students who receive free or reduced cost meals is considered an indicator of socio-economic status. The higher the percentage, the more likely a school is to have a larger population of students with special needs relating to poverty.

Eligibility for free or reduced price meals is based on family income and household size. For example, a family of four with an income of \$21,710 or less qualifies for free meals for the 1999-2000 school year. Income between \$21, 7111 and \$30, 895 for a family of four makes the student eligible for reduced price meals. Percentage of students receiving free or reduced cost meals: Rio Grande-44.9; all APS High Schools-18.5."

The attendance rate shows the percentage of students who, on the average, attend school each day. In 1997-1998, 87.4% Rio Grande students attended class each day. For all of APS high schools the average was 91.8%. "Mobility" is the percentage of students who, during the course of the school year, transfer into, out of, or within the school system. One student may be counted several times if he/she moves in and out of the same school. From 1989-1992, RGHS's mobility was at 41.8%. For all of APS high schools mobility was at 36.8%.

Sixty-three point four percent (average from 1991-1994) of students participated in ESL and Bilingual Programs at RGHS. Twenty-one point eight percent (average from 1991-1994) of students participated in ESL and Bilingual Programs in all of APS high schools.

The Rio Grande High School cluster has a higher proportion of families that who on a

reduced income, but has a higher proportion of family owned homes and longer duration of residence. With the stability of residence in the South Valley, many families would benefit from building with alternative materials and using solar power as a heating and electrical source.

## **Introduction**

The following unit is designed for juniors and seniors interested in receiving an Environmental Science Endorsement on their diploma. Students enrolled in the Environmental Program will have previously completed two years of science.

The purpose of the unit is to introduce students to "Earth friendly" building techniques and how to provide a home with an alternative source of energy. Students will study how a small impact on the environment affects the global environment. Students will assess the environmental impacts of alternative building styles (straw bale and earth homes) and energy (solar energy) compared to conventional systems.

## **The Facts**

Earth has a finite amount of resources (ore, coal, natural gas, wood, etc). These resources are being used up. To slow down the consumption, implementation of alternative home lifestyles is necessary. Though lumber is a sustainable building medium, caution must be used before deciding to build with wood. In the United States, 1.2 million new homes are built annually. "The framing lumber for 1.2 million new homes alone, if laid end to end, would extend 3 million miles - to the moon and back six and a half times." (Chiras). Now consider the new homes being constructed in the entire world with conventional building techniques. For a 2000 sq. ft. house, the framing would extend 2.5 miles. Framing includes all 2x4's and 2x10's for the walls, roof, doors, windows, and floors.

Making homes energy efficient through alternative methods will decrease greenhouse gases. According to the U.S. Department of Energy, American homes consume 20 percent of the nation's energy and produce approximately 20 percent of the greenhouse gas carbon dioxide.

Another concern is the increase in volume of landfills. "Americans alone produce over 220 million tons of garbage every year - enough to fill the Superdome in New Orleans more than 2.5 times per day." (Chiras). Many communities in the United States have started recycling programs. Though these programs have reduced landfill usage, more Americans need to implement recycling programs. Recycling plastic, glass, and paper is not enough. Programs to compost yard debris and food wastes need to be established. Composting food waste and yard debris not only reduces the amount of trash going into the landfills, but also encourages organic farming and reduces the use of commercial fertilizers.

People living in conventional houses on average pay \$100 to \$300 per month to their local utility company; those living in solar homes made from alternative building materials pay \$10 to \$25 per month. Alternative building materials may include straw bales, earthen materials, used automobile tires, and other natural materials.

Why should we build using alternative building materials? The first major reason is that Earth contains a limited supply of resources: fossil fuels, minerals, and timber. Second, don't use what you do not need. This assures that future generations will have access to the resources that you had and enjoyed. Third, being human does not mean that we have to dominate other species. We must all co-exist and live together in harmony.

## Alternative Building Styles

Though most homes are built with conventional techniques (2x4 framing with fiberglass insulation), it is not the most environmentally friendly way. When designing an alternative house, conventional approaches may be the only option. When this is the case, be environmentally responsible and make sure that the wood comes from a sustainable forest.

Two common "green" building materials are straw bale and earth. Homes made out of straw bale are highly resource-efficient. Straw bales provide high R-values (40 to 50), they are highly fire-resistant, and can last for hundreds of years (Steen). The straw can be grown locally, which reduces energy consumption (transportation) and keeps the revenue in the community.

The use of earth as a building material has been around for thousands of years. It was not until recently, however, that environmentally conscious architects started encouraging the use of adobe bricks as a building material. Adobe can either be made at the building site from readily available materials or purchased from a local manufacturer. The earth bricks provide excellent insulating properties. It keeps the interior of the home warm in the winter and cool in the summer.

The rammed earth home has thermal properties similar to adobe. The difference is that the earth is pounded into place rather than molded into bricks. Like adobe, rammed earth requires little supplemental energy for any rooms not heated by passive solar.

### *Rammed Earth Homes*

The technique of rammed earth has been in use for nearly 10,000 years and is still in use in timber-poor countries. Many of the early structures were more than simple places to live. Churches, temples, and mosques are just a few examples. Rammed earth structures date back to the 7<sup>th</sup> century BC. Rammed earth is used in more temperate climates. The Romans introduced the technology to the Rhone River Valley of France, where it became the dominant form of architecture for nearly 2,000 years (Chiras). The Spaniards introduced rammed earth to North and South America.

Rammed earth construction began to decline as mass-produced building materials allowed workers to build a home easier and faster. Rammed earth houses are slightly more expensive than frame houses (\$65 to \$125 per square foot), but are more resource efficient than frame houses. In many areas, there has been a resurgence in the popularity of rammed earth home building that started in the 1970's. Australia is one such area. In Australia, twenty percent of new construction is rammed earth.

Rammed earth homes are structures in which the walls are built from a mixture of sand and clay. Water is mixed with the sand and clay and poured into forms. A tool called a tamping device is used to compact the first layer. Once it is properly tamped, another layer of the mixture is applied and compacted. Once the wall is built and the mixture is dry, the form is removed and another section is started. When dry, rammed earth hardens like stone. It is durable and weather resistant. It is usually coated with stucco for further protection from the elements.

Rammed earth walls cannot be constructed by throwing just any kind of mud into forms. The best composition is 70 percent sand and aggregate (small stone or gravel) and 30 percent clay. The clay has to be a type that does not expand when it gets wet and does not crack when it dries. In areas where high seismic activity and moisture are a problem, or building codes require it, Portland cement is added (3 to 12 percent by volume) to the earth mixture as a stabilizer. Water should be 8 to 12 percent by volume.

When water is added it should make a slightly wet mixture that forms a ball. When dropped from the waist, the ball should break into several coherent clods. The mixture is then poured into the forms to a depth of 7.5 to 8 inches. The soil is then tamped down to a depth of 4.5 to 5 inches. Tamping can be done either by using a hand tamper or with a special pneumatic tamping device. After the soil is compacted, the next layer of untamped mix is added and the process is repeated until the form is full. Under-tamping and over-tamping can lead to reduced wall strength.

The R-Value (see Activity # 2) of rammed earth is only .25 per inch. An 18-inch thick wall only has an R-value of 4.5., but the walls have a high thermal mass. The walls can absorb sunlight that strikes directly on its surface, converting sunlight to heat energy. They can also absorb light bounced off surfaces and objects in a room, converting it to heat. The walls also absorb heat present in a room. The rammed earth wall will release the heat back into the air when the room starts to cool. In hot desert climates, rammed earth homes tend to stay cool during summer months even if sunlight strikes the exterior walls. By the time the sun sets, the heat has penetrated only nine inches into the 18-inch thick wall. When the air cools, heat reverses its path and exits into the cool evening air (Chiras, 2000). This process only occurs in dry climates. In the winter, the procedure is the same except that the heat is coming from within the house, from the occupants, stoves, fireplaces, passive solar, etc... The heat generated never has enough time to exit through the wall, keeping the interior warm during the winter. In hot, humid climates, the walls can't cool off at night. The heat accumulates in the earthen wall, making the interior of the house hot and uncomfortable.

### *Straw Bale Homes*

Building with grass and straw packed in mud for mortar has been around for many centuries. It wasn't till the 1800's, with the invention of the baler, that the straw bale houses emerged. Experimentation began in the Sand Hills region in Northwestern Nebraska. Straw was used to build temporary homes, barns, and churches. Soon the immigrants of Nebraska discovered that the structures were durable and comfortable in hot and cold weather. The homeowners then stuccoed the interior and exteriors and made the homes permanent structures. As the railroad expanded into the region, milled lumber came too. It was not long before the straw bale house was replaced with conventional building techniques.

Building with alternative materials may only save you ten percent or so on building costs. Only a small fraction of the cost of a building goes into the construction of walls. The saving is in the cost to the environment. Price per square foot can range from \$5 (owner built; mainly using recycled products) to over \$80 (contractor built; depending on how customized you make the home). According to Daniel Chiras, straw bale homes are three to four times more energy efficient than conventional brick homes. The average R-value per inch for straw bale is 2.7. The R-value for a three-string bale (24 inches wide) is 54.7. A two-string bale (18 inches wide) has an R-value of 42.8. The compression strength of straw bales is 10,000 pounds per square foot. A typical 2x4 wood wall has a compression strength of 1,500 pounds per square foot.

The use of straw bale as a building material has been increasing since 1979. Every state in the United States has straw bale construction except Hawaii, according to Catherine Wanek, editor of the journal *The Last Straw*. Most of the homes are in New Mexico, Arizona, and California. Straw Bale homes can also be found in other countries. Mexico, Canada, Russia, Germany, France, New Zealand, and England are only a few.

Hay is generally not used for home construction. Hay is made from meadow grasses with seed heads still attached. It is used as feed for animals. Mice are also attracted to

the seed heads. Not a good choice to use for building! Straw is made from the shaft of rice, wheat, rye, and other grain crops. The seed heads are harvested for animal and human consumption, and the shaft is baled for building. Wheat straw is the most commonly used. Before buying bales for a home, make sure they are baled with a compression setting between 250 and 500 pounds. A dry density of 7 to 10 pounds per cubic foot is recommended. Straw bales do not burn easily due to the lack of oxygen. With an added protective coat of plaster the walls become virtually fireproof.

Straw bales can replace wood forms to create stem walls. The straw bales also allow for curved forms. Rebar needs to be placed vertically every two feet to hold the first two rows of bales in place. A two-string bale makes a 17-inch-wide wall; a three-string bale makes a 24-inch-wide wall. Cutting and retying the bales to make minibales can fill small gaps in a wall

Two types of walls can be constructed using straw: load bearing and non-load-bearing (fill-in). In a load-bearing wall the straw bales are stacked like bricks. The bales are pinned together with rebar. The bales support the roof and provide insulation. The fill-in technique (non-load-bearing) uses posts and beams to create a frame. The straw bales are placed in between the posts and provide insulation.

Many communities have straw building workshops. An owner who needs volunteers to help build a home sponsors these workshops. In return, the volunteers gain experience in building a straw bale home that they might need when they build their own.

### *Adobe Homes*

Adobe bricks consist of mud sun-dried in wooden forms. The bricks are cemented together with mud mortar and then either coated with earthen plaster or left unplastered.

The earliest adobe architecture found is from the Iraq region dating to 6000 BC. In Egypt, adobe structures have been found dating back to 5000 BC. The technique was also found in Spain and spread into South America around 1600 AD. Adobe architecture then spread north into the southwest region of the United States. However, archaeologists have uncovered adobe structures made by the Native Americans prior to the arrival of the technique introduced by the Spaniards.

Adobe is a sustainable form of building material. The mud used for the bricks is usually available locally. The dimensions of the blocks are typically 10 x 14 x 4 inches. Like rammed earth walls, adobe uses its thermal mass (ideal for solar heating and passive cooling) to keep the building comfortable.

Adobe bricks are made from mud containing approximately twenty percent clay and eighty percent sand. Too much clay will cause cracking, and too little clay creates brittle bricks that are not resistant to erosion from wind and rain. Some adobe is made with straw to strengthen the brick and to prevent cracking. However, many modern brick makers believe that the straw is not needed; it is the clay content which determines the strength of the brick. Mortar is used to set the bricks in place. The mud mortar is made from the same mud that the bricks were made from, without the stones and pebbles. The stones and pebbles make the mortar difficult to work with. Mortar is applied ¾-inch thick between the adobe brick layers. No more than six or seven courses should be laid in a day. If more layers are built the mortar will compress and change the wall height.

### Section Summary

More information about other natural building techniques can be found in Daniel D. Chiras's book, *The Natural House: A Complete Guide to Healthy, Energy-Efficient, Environmental Homes*. In addition to rammed earth, straw bale, and adobe homes, also discussed are cob houses, cordwood homes, log homes, stone homes, and other emerging natural building techniques.

Alternative building techniques reduce environmental impact. Fewer resources are consumed using locally available materials. Transportation of materials is less needed (lowers dependency of fossil fuels), manufacturing of materials is reduced, and using local materials brings jobs to the community.

### Alternative Sources of Energy

Renewable sources of energy (soft energy) include solar, hydroelectric, wind, biogas, and biomass (plants and trees). Soft energy differs from "hard energy." Hard energy is the non-renewables: coal, oil, and natural gas. In this unit, students will investigate one type of soft energy - solar.

#### *Solar Energy*

Using the sun for energy in your home can be done anywhere in the world. A home does not have to be located in the Southwest, Florida, or any other area that receives a lot of sun. Homes in the northern latitudes can also take advantage of the sun's energy.

Many homes and businesses rely on fossil fuels and oil to provide electricity and heat. Now look at the environmental impact: global warming, oil spills, health risks, deforestation, habitat destruction, etc... If it were not for the subsidies the government gives to the fossil fuel and oil industries, these hard energy sources would be very expensive.

The cost of passive solar is competitive with conventional systems. Active solar systems cost a lot more initially. The cost is in the components; the energy is free. Spread over 20 to 25 years (average life of a photovoltaic panel) the cost of an active solar system becomes competitive with the conventional system. When the environmental costs are added into the equation, both passive and active solar systems cost dramatically less.

Changing the placement of windows and adding thermal mass and Trombe walls (discussed later) can turn your conventional home into a passive solar home. Making this simple, inexpensive modification can reduce your use of hard energies and save you thousands of dollars in energy bills.

#### *Passive Solar*

A passive solar system uses no mechanical devices to transport energy. The thermal mass of the building is used to store the heat energy. Heavy masonry such as bricks, blocks, concrete, and earth have good heat-retaining properties. Adobe, rammed-earth, and concrete walls are ideal for thermal mass heating.

To make solar energy most beneficial, placement of the home is very important. A site with unobstructed access to the sun from 10 A.M. to 3 P.M. for many days out of the year is best. Properly positioned trees around the property will prevent the building from overheating in the summer. Well-designed eaves and cantilevers on the home will prevent unwanted sunlight entering the home during the warmer months and allow winter sunlight into the home (see Figure 1). Remember that the sun is higher in the sky during the summer months. A well insulated home is also important. Insulation not only keeps warm air in during the winter, it keeps hot air out and cool air in during the

summer. With proper planning the passive solar house will not overheat in the summer or become too cold in the winter.

Orientating the house true south, plus or minus 10 to 20 degrees, will optimize the solar gain. This goes for any type of house. Doing so will reduce energy bills by about 30 percent. Placing windows on the south side of a home can reduce heating costs by 50 percent. Using thermal mass, water storage, proper insulation and ventilation, and a few other energy measures can reduce heating needs by 100 percent. Placing the long axis of the home east-west orientates the home towards the south. When placing the home on the property, be sure to use true south (solar south) not magnetic south. Magnetic declination for the New Mexico region is approximately 11.5 degrees east. That makes magnetic north 11.5 degrees east of true north (See Activity # 4).

Windows and solar collectors should be placed on the south side of a house. In the winter, when the sun is low in the sky, sunlight can reach more than twenty feet into a room. Tilting the glass toward the sun increases the amount of solar radiation received. When sunlight is perpendicular to the window, less radiation is reflected which maximizes the transmission of light into the glass; hence, more solar gain. While this may be beneficial for maximizing solar gain, tilted windows are more susceptible to leaks and may overheat the house in the summer.

Placing thermal mass walls in direct sunlight in the interior of the house is most efficient. The mass walls absorb sunlight, convert it to heat, and then release the heat when the room temperature drops. Thermal mass floors can also be built into the home. Any thermal mass should be a dark color for maximum absorption. Without proper airflow throughout the house, heating and cooling by passive solar will not be as efficient. The air in the house should be able to circulate using convective currents. If there is not enough thermal mass, the interior home can drop more than 20 degrees during a winter night. If there is too much thermal mass, the walls will not heat up and the home will be uncomfortable during the cooler months.

A Trombe wall is an efficient way of heating a home. The wall (constructed of earthen material or concrete) sits behind a wall of glass. An airspace is left between the wall and windows. There are air vents located at the top and bottom of the wall to allow convection currents to carry the warm air into the house. The wall radiates heat into the house as well. At night the air vents are closed off to prevent heat loss.

Keeping a passive solar house cool can be achieved by a few simple methods. One way is to replace all of the incandescent light bulbs with compact fluorescent light bulbs. Ninety-five percent of the energy consumed by standard incandescents is converted into heat energy. That leaves only 5% for light energy. Fluorescents use about one-fourth the energy of incandescents to produce the same light energy. Though fluorescents cost more to purchase, they use less energy to operate and last ten times longer. For example, a 22-watt fluorescent will last 10,000 hours and provide the same illumination as a 125-watt incandescent that will last for only 1,000 hours (Chiras).

Limiting the number of east and west facing windows will reduce the amount of unwanted sunlight entering the home. Properly placed shades, curtains, shutters, trees, and roof overhangs will aid in keeping the house cool. During the nighttime hours, the windows are opened allowing the air to cool the thermal mass walls that were designed to keep the home warm in the winter. During the day, the windows are covered and shut, and the walls absorb the interior heat keeping the air temperature comfortable.

*Active Solar*

An active solar system requires mechanical devices to transport energy. Solar collector panels are commonly used in an active system. Photovoltaic (PV) cells (modules) are used to convert sunlight directly into direct current (DC) electricity (see Activity # 6). Both systems can work independently or dependently of each other.

Solar collectors are, essentially, a black box with a glass top. Fluid is piped through the box. With temperatures inside the box reaching over 200 degrees Fahrenheit, the fluid in the tubes is heated and then transported into a water storage tank where it radiates heat to the surrounding water in the tank. In an active solar water heating system a pump is used to circulate the water through the solar collector. In a passive solar system natural convection currents circulate the water. The heated water in the storage tank can be used directly or as a preheater for a hot water tank powered by electricity or gas. Technology has made this simple design very efficient. For more information on the latest technological advancements look at *Solar Today* magazine or visit the Real Goods website ([www.realgoods.com](http://www.realgoods.com)).

### *Anatomy of a Solar Cell*

Photovoltaic systems are used to provide direct current (DC) electricity to the home. Photovoltaic (photo = light, voltaic = electricity) cells are made out of semiconductors made from silicon. Each cell is a single silicon crystal and is about ½ inch to four inches in size. Each cell can produce one to two watts of power.

The Crystalline Cell has an efficiency of 10-30%, very long lifetimes, and is most commonly used. Other types of cells are the polycrystalline and thin film or amorphous silicon. The polycrystalline is a collection of many small silicon crystals. They also have high efficiency (10-30%) and very long lifetimes because the crystal structure is very stable. Thin film cells are most commonly found in calculators and other low voltage devices. Each cell is made from non-crystalline thin films of silicon atoms. These tend to have lower efficiencies (5-10%) and more limited lifetimes, because the silicon atoms have some freedom to move around over time. Typical commercially available PV panels have an efficiency of about 15%, which means that they can deliver about 150 watts of power per square meter (New Mexico Solar Energy Association).

Scott Alduous, in *How Solar Cells Work*, states:

An atom of silicon has 14 electrons, arranged in 3 different shells. The first 2 shells, those closest to the center, are completely full. The outer shell, however, is only half full, having only 4 electrons. A silicon atom will always look for ways to fill up its last shell (which would like to have 8 electrons). To do this, it will share electrons with 4 of its neighbor silicon atoms.

Silicon is a poor conductor of electricity because of its covalent bond (none of the electrons are free to move). These covalent bonds cause the silicon atoms to form a very stable silicon crystal (Aldous). When a small number of phosphorous atoms are added to the silicon crystal, an electron is left free to move about. Each phosphorous atom has five electrons in its outer shell (valence shell), instead of four. But only four of these electrons are needed to bond with four nearby silicon atoms, so the fifth one is left over. Because it is not involved in a bond, it can move freely through the silicon (the process of adding impurities is called "doping"). The silicon now has a net negative charge, so it is called n-type (n for negative).

Only part of the solar cell is n-type. The other part is doped with boron, which only has three electrons in its valence shell. The silicon now has a net positive charge, and it is called p-type (p for positive). The boron doped silicon crystal will then have electron vacancies in its structure, called "holes."

When the two types of silicon crystals come into contact with each other an electrical field is created. The electrons from the p-type fill the holes of the n-type. When the electric field reaches equilibrium, the field acts as a diode allowing the electrons to flow only in one direction (from p-type to n-type). When photons of light contacts the semiconductors (silicon crystal), electrons begin to move. The electrons from the p-type cell flow to the n-type cell to fill the holes. When electrical contacts (wires) are attached to the positive p-type and negative n-type cells, the electrons start to move (produce a current). This flow of electrons creates electricity of power (see Figure 2). Remember that current flows from negative to positive, not positive to negative.

The most radiation (light energy) a simple solar cell can absorb is around 25%. The average is 15%. This is because photons that hit the cell have wide ranges of energy. Some photons won't have enough energy to form an electron-hole pair. They'll simply pass through the cell. Other photons have too much energy. Only a certain amount of energy, measured in electron volts and defined by the semiconductor material (about 1.1 eV for crystalline silicon), is required to knock an electron loose. The optimal energy of a photon is 1.4 eV based on power (watt); where Watts = Volts x Amps (Aldous).

Since silicon is not the best conductor of electricity, a metallic contact grid is added to a portion of the cell. The contact grid reduces resistance and shortens the distance the electrons have to travel to reach the external circuit. The contact grid cannot be too large or it will block the photons. Silicon is also highly reflective so an antireflective coating is applied to the top of the solar cell. This reduces reflection loss too less than 5%. A glass cover plate is installed over the entire cell that provides protection from the weather (See Figure 3).

### *Components and Cost of a Photovoltaic System*

The sun produces 1,000 watts per square meter at the earth's surface. When a solar cell converts sunlight to electricity, the electricity is either wired to direct current appliances or a storage bank of batteries. Having the PV's wired to batteries allow the user to access the electricity at any time. The basic components of a PV system consist of PV panels, batteries (about 12 deep-cycle lead acid batteries), a charge controller (regulates the charging of the batteries, prevents over-charging and over-draining of the batteries), and an inverter which converts the low voltage DC current to alternating current (AC) for use by appliances (see Figure 4). Thirty-six cells are usually connected in a series to make a solar module. Modules are connected to produce enough wattage to power the home.

The cost of a Photovoltaic System depends on the amount of power a home uses. A home that uses 100 kWh (kilowatt-hour) a month will need a system that can generate around three kWh a day. You can check your local utility bill to see how many kilowatt hours per month you used. Or you can list the power consumption (watts) of all appliances, lights, and electronic devices, then estimate the daily usage (in hours) of each item on the list. Multiply the wattage by the hours of usage (gives the watt-hour) and add the results to calculate the household usage for the day (see Activity # 7).

Solar panels generally cost about \$5-7 per watt. For a typical three kW system, the panels would cost about \$15,000 - \$21,000. A charge controller costs several hundred

dollars. Estimate about \$1 per watt for the inverter; a three kW system would need a \$3000 inverter and require around 30 kWh of energy storage (batteries). Plan on paying about \$100 per kilowatt-hour for energy storage. A three kW system might require 30 kWh of storage (use only 10 kWh in active use to extend battery life). The batteries will cost around \$3,000. The total cost for the PV system, not including installation, for a home that uses around 90 to 100 kWh's per month is about \$24,000.

Deciding to go solar can be a difficult decision. A lot of money has to be paid up front for the equipment. Other than routine maintenance of the system, the energy it produces is free. Spread over 25 years, the \$24,000 system, would cost approximately \$80 per month. Depending on your location, \$80 per month for all the home's electrical needs may be worth the investment. When the environmental costs are added into the calculation, the investment becomes worthwhile.

Photovoltaic systems can be connected to the local power grid. These systems are called Utility-Intertie Solar Systems. When the homeowner needs more electricity, it is purchased from the local utility company. If a surplus of energy is generated from the PV system, the surplus can be sold to the utility company.

### Section Summary

Using solar energy (passive or active systems) combined with a straw-bale, rammed earth, or adobe home, is a very environmentally friendly way of building (or remodeling) a home. If most of the work is done by the homeowner, the cost of building a solar home is greatly reduced. If using photovoltaics is not economically possible, using passive solar concepts in a home can lower energy bills and reduce the dependency on hard energies.

### Lessons and Activities

Below are some suggestions on activities that supplement the curriculum. The time for the unit can range from one to two months, depending on how detailed the instructor wishes to be. The activities listed below are for the high school level. Each activity can be modified for the appropriate grade level. Where noted, some of the activities can be viewed in their entirety online. Other activities can be explored using the Internet. Each website listed has been carefully selected to cover the material adequately without needing a Ph.D. in physics to figure it out!

#### Activity # 1: Exploring Environmental Issues and Solar Designed Houses

This is a discussion and student research activity to introduce students to these three topics: 1) benefits of renewable energy, 2) the dangers of nonrenewable energy sources, and 3) solar designed houses. The class is to be divided into thirds. Each third will take one of the topics introduced above. Remind the students not to go into too much detail. They are to get a general idea. Detailed research will be done at a later time or on their own.

After brainstorming some ideas, allow at least four to five days for them to research the information. At the end of the research, engage the students in a discussion on the subject matter. Each group will provide visual aides (drawings or models) to go along with the information.

Below are some internet sites for the students to explore. Encourage the students to explore the entire site, not just the page listed. Suggest to the students that following the links on the web page is a great avenue to

related information:

[http://www.nmpirg.org/reports/renew\\_energy/index.html](http://www.nmpirg.org/reports/renew_energy/index.html)

[http://www.nmsea.org/Curriculum/Primer/from\\_oil\\_wells\\_to\\_solar\\_cells.htm](http://www.nmsea.org/Curriculum/Primer/from_oil_wells_to_solar_cells.htm)

[http://www.nmsea.org/Passive\\_Solar/Passive\\_Solar\\_Design.htm](http://www.nmsea.org/Passive_Solar/Passive_Solar_Design.htm)

<http://www.taosnet.com/architectVRe/html/SolarDesignb.html>

[http://renewable.greenhouse.gov.au/home/passive\\_solar.html](http://renewable.greenhouse.gov.au/home/passive_solar.html)

<http://www.solarstraw.com/who.html>

New Mexico Content Standard 6: Students will understand the process of scientific inquiry. Students will apply scientific knowledge, technological, computer, problem-solving, and other skills to design investigations and to collect data; explain and interpret the results of investigations to teachers, peers, parents, and others.

### Activity # 2: Exploring R-Values

Students can calculate the Resistant Value (R-Value) of different types of walls. R-value refers to the resistance to conductive heat flow through a material. The higher the R-value, the lower the conductive heat gain or loss will be (Vila). Each type of material has its own R-value. The websites listed below provide tables for common materials. R-values are typically calculated per inch thickness of material. The R-value of a wall can be calculated by adding together the R-values of each material used in the wall system. When calculating the material's total R-value, remember to multiply the materials thickness (in inches) by the R-value per inch.

<http://www.coloradoenergy.org/procorner/stuff/r-values.htm>

<http://www.kie.berkeley.edu/ned/data/E01-950509-004/E01-950509-004.html>

Things to remember: 1) earth wall systems have low R-values. Their ability to insulate depends on their thermal mass, and 2) straw bales have an R-value around 2.7 per inch.

New Mexico Content Standard 8: Students will know and understand the properties of fields, forces, and motion. Student will apply knowledge of the constancy of energy in the universe and the forms that energy takes to real-life problems and situations.

### Activity # 3: Soil Test for an Earth Wall

Two activities can be used (websites listed below). Both involve making adobe bricks. I would recommend that the students gather soil from their home or an adjacent lot to determine if the bricks can be made on-site (as if it were an actual building site). Be sure that the students remove the top three to four inches of soil to remove any organic matter in the sample. The bricks constructed in all classes can be used to construct an adobe wall. The wall can then be used to further explore passive solar heating using Trombe Wall technology, weather resistance and/or thermal mass transfer. For an activity plan to build a simulated passive solar structure visit:

[http://www.nmsea.org/Curriculum/7\\_12/Passive\\_Design\\_Lab/passive\\_design\\_laboratory.htm](http://www.nmsea.org/Curriculum/7_12/Passive_Design_Lab/passive_design_laboratory.htm).

To have the students investigate which type of mixture is best for adobe bricks visit:

<http://www.hwr.arizona.edu/globe/globe3/mud2bricks503.html>. They also provide a complete activity guide. For a more general activity introducing adobe brick building visit:

<http://www.girlscoutsofsc.org/ea2000/cadettebvt.pdf>. For Activity 2 – Option Two: Making adobe bricks, start on page 6. On page 5, the introduction to "Earth Friendly Building Materials" begins.

New Mexico Content Standard 5: Students will acquire the abilities to do scientific inquiry. Student will evaluate, design, and use the most appropriate equipment, tools, techniques, and information sources to improve scientific investigations and solutions to problems.

#### Activity # 4: Solar Orientation

Care must be taken to affix a PV System in a place that receives maximum solar exposure and which is oriented facing solar south. Solar south can be easily located by placing a stick or pole in the ground, consulting the local paper for sunrise and sunset times, and calculating the midway point between them: this is solar noon. At solar noon, the shadow cast by the pole will point to true north; the opposite direction will be solar south (Klein). Another way to find solar south is to subtract or add (depending on location) the magnetic declination of your area. In Albuquerque, NM, magnetic declination is approximately  $11.5^{\circ}$  east. This means that you would add  $11.5^{\circ}$  (rotate the compass dial counterclockwise). The index line on the compass baseplate will now point to solar south (true south) when the red magnetic needle is aligned with the red orientation arrow. For more information on using Map and Compass visit:

<http://www.princeton.edu/~oa/manual/mapcompass.shtml>. This activity can be supplemented with a small unit in astronomy, particularly focusing on the apparent movement of the sun.

New Mexico Content Standard 13: Students will know and understand basic concepts of cosmology. Student will predict changes in the positions of objects in the sky based on knowledge of current position and patterns of movement.

#### Activity # 5: Build a Solar Panel

Using a copper sheet, a heat source (Bunsen burner or hotplate), and some wires, students can make a simple solar cell that works. If you want to use a hotplate and look at complete instructions to make this solar panel visit:

<http://www.angelfire.com/ak/egel/solcell.html> If you would like to use a Bunsen burner and read general procedures and where to buy a book on making homemade solar panels visit: <http://pub30.ezboard.com/foch74837frm8.showMessage?topicID=20.topic>.

Be sure to visit both sites!

New Mexico Content Standard 9: Students will know and understand the concepts of energy and the transformation of energy. Student will apply knowledge about energy and energy transformations to problems both within and outside the school environment.

## Activity # 6: Concepts Behind Electricity

All electrical devices use amperage (amps). The more watts a device uses, the more amps it requires. If there is too much power (watts) on one circuit in a home, the breaker will trip (blow a fuse). The electrical wire and circuit breaker could not provide enough amps to meet supply and demand. Each circuit breaker in a home is labeled as to how many amps it can supply. Power is measured in watts.  $\text{Watts} = \text{amps (current)} \times \text{voltage (volts)}$ .

Students can determine how many amps they have on the circuits in their home. The easiest way to do this is to turn off the circuit breaker, then go around the home turning on and off the electrical devices. A list of the devices affected by the circuit is compiled. The students then add up the amps of the electrical devices. The students then determine if the circuit has enough amps to carry more loads (amps). Not all devices have the amps listed. Using the equation  $\text{Watts} = \text{amps} \times \text{volts}$ , apply algebra to get  $\text{amps} = \text{watts/volts}$ . A standard voltage of 110 is used unless the appliance uses a 220 outlet; electric stoves, heaters, and dryers are examples of a 220 appliance. For example, a 60W lamp uses .54 amps ( $\text{amps} = 60/110$ ). For a detailed explanation of amps, volts, and watts please visit:

[http://www.nmsea.org/Curriculum/4\\_6/Electricity/dc\\_electricity.htm](http://www.nmsea.org/Curriculum/4_6/Electricity/dc_electricity.htm).

New Mexico Content Standard 7: Students will know and understand the properties of matter. Students will explain how atoms interact with one another by transferring or sharing electrons that are farthest away from the nucleus.

## Activity # 7: Calculate Your kWh Usage

The first activity in this section is Meter Reading (<http://www.ase.org/educators/lessons/MeterReading.html>). It will teach students (and many adults) how to properly read an electric or gas meter. The second activity, The Electric Hook-up (<http://www.ase.org/educators/lessons/hookup.htm>), is a great activity to teach students how to calculate kWh's and gives a short review of how to read electric meters. I would suggest doing both, starting with Meter Reading.

New Mexico Content Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will quantify the transformation of energy and matter in a system; employ typical high school mathematics skills to explain a given problem or situation.

## Activity # 8: Energy Transformations

The activity, Energy Transformations (<http://www.ase.org/educators/lessons/e-trans.htm>), will help students understand BTU's, Kcal, calorie, and other various terms commonly found in discussions on energy. The math involved may give some students difficulty if introduced early in the school year (depending on grade level). The activity mainly compares the energy of non-renewables. Before introducing the activity, go to the New Mexico Solar Energy Association's (NMSEA) website at

[http://www.nmsea.org/Curriculum/Primer/energy\\_physics\\_primer.htm](http://www.nmsea.org/Curriculum/Primer/energy_physics_primer.htm),

which has great information on "energy physics." Another NMSEA website that is worth reading is at

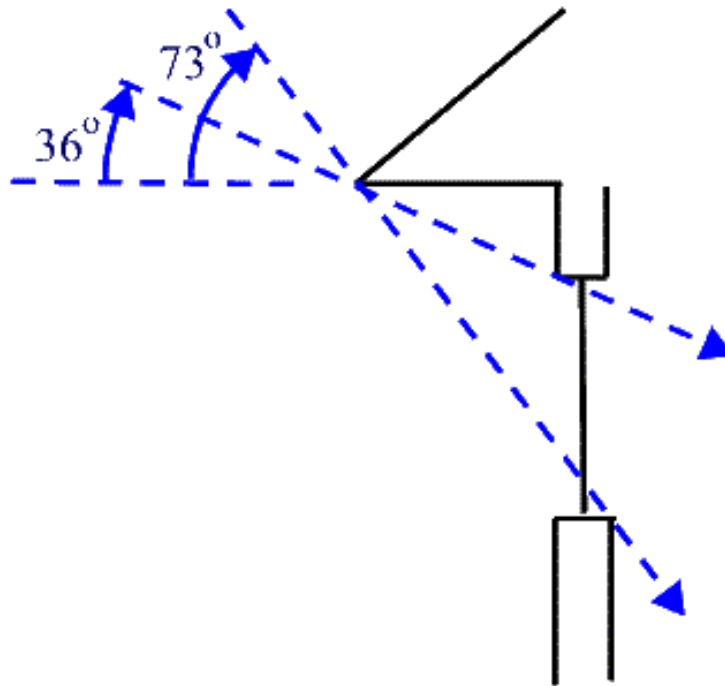
[http://www.nmsea.org/Curriculum/7\\_12/The\\_Solar\\_Resource.htm](http://www.nmsea.org/Curriculum/7_12/The_Solar_Resource.htm). This

website answers the following questions: 1) Could solar energy power the United States? and 2) How does this compare to coal? Just make sure you have the time to think through the questions!

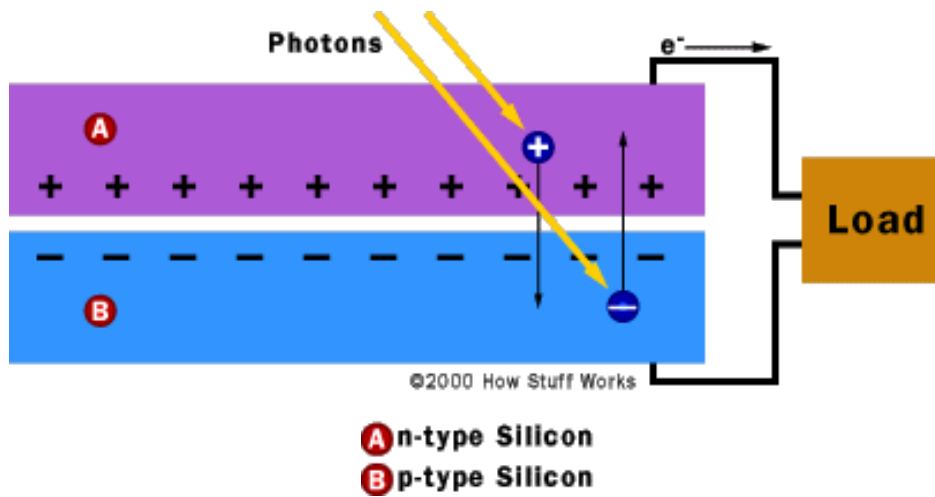
When presenting the Energy Transformation activity, remind the students that the sun puts out 1,000 watts per hour per square meter ( $1\text{kWh}/\text{m}^2$ ) which is equal to 3,410 BTU's (3.41 kilo-Btu's).

New Mexico Content Standard 4: Students will understand the physical world through the concepts of change, equilibrium, and measurement. Students will quantify the transformation of energy and matter in a system; employ typical high school mathematics skills to explain a given problem or situation.

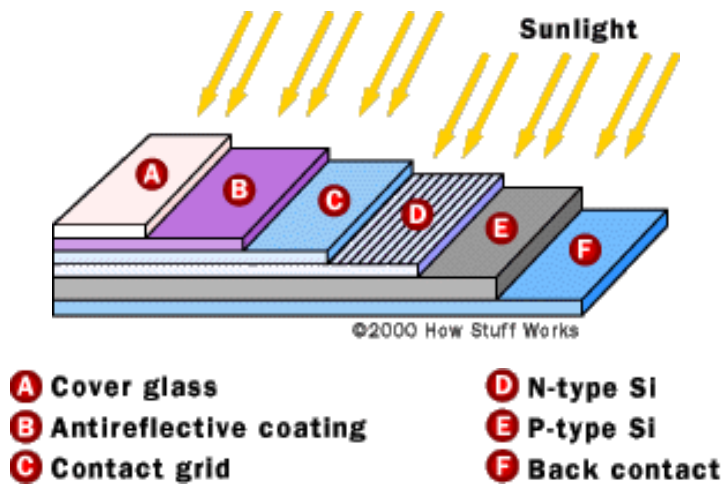
### Illustrations



**Figure 1:** Overhangs are strongly encouraged for south-facing windows and Trombe walls in Northern New Mexico. The following overhang angles were suggested by Doug Balcomb. These angles are not the angles specified in most books regarding the winter and summer solstices. Rather, they have been adjusted by five degrees or so for the climate of New Mexico, such that they provide six weeks of full solar gain in the winter (as opposed to just on the winter solstice), and a full six weeks of shade in the summer (as opposed to just on the summer solstice). The seventy-three degree angle represents the summer sun angle. The thirty-six degree angle represents the winter sun angle. (Courtesy of the New Mexico Solar Energy Association.)

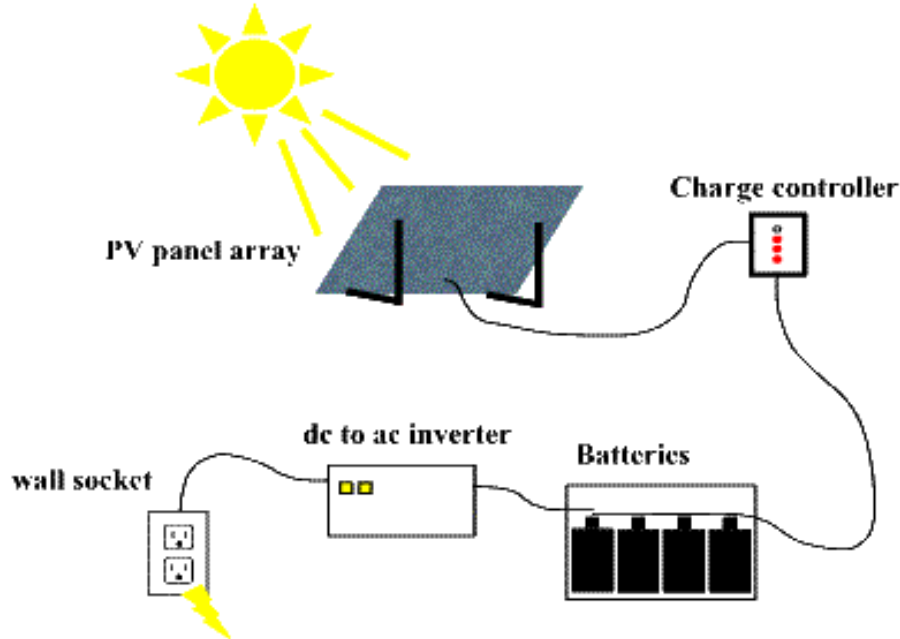


**Figure 2:** Interaction of photons and a simple silicon solar cell. (Courtesy of Scott Aldous, 2001)



**Figure 3:** Typical construction of a solar panel. (Courtesy of Scott Aldous, 2001)

## Components of a PV System



**Figure 4:** Components of PV system.

Sun shines on the panels to produce electrical power. That power is routed through a charge controller to the batteries. The charge controller regulates the charging of the batteries - the voltage on the batteries needs to be increased slowly, because charging them too fast or routinely overcharging the batteries quickly degrades them. Next, the inverter converts the dc (direct current) electrical power from the batteries into ac (alternating current) electrical power at 110 volts. This can then be fed to household appliances via a wall socket. (Courtesy of the New Mexico Solar Energy Association, 2001.)

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Villa, Bob, Norm Abram, Stewart Byrne, and Larry Stains. *This Old House: Guide to Building and Remodeling Materials*. New York, NY: Warner Books, Inc., 1986.

#### *Other Suggested Websites*

Architecture Solar Virtual Reality Native American Archaeology

<http://www.taosnet.com/architectVRe/html/SolarDesignb.html>

Experiment with a Passive Solar Design Laboratory

[http://www.nmsea.org/Curriculum/7\\_12/Passive\\_Design\\_Lab/passive\\_design\\_laboratory.htm](http://www.nmsea.org/Curriculum/7_12/Passive_Design_Lab/passive_design_laboratory.htm)

NCPV Home Page

<http://www.nrel.gov/ncpv/pvmenu.cgi?site=ncpv&idx=3&body=infores.html>

NMSEA Curriculum Outline <http://www.nmsea.org/Curriculum/Listing.htm>

NMSEA Solar Design Competition

[http://www.nmsea.org/Design\\_Competition/contest.htm](http://www.nmsea.org/Design_Competition/contest.htm)

Passive Solar Architecture and Energy Efficient Houses – The Australian Renewable Energy Website [http://renewable.greenhouse.gov.au/home/passive\\_solar.html](http://renewable.greenhouse.gov.au/home/passive_solar.html)

Photovoltaic Solar Cells and Panels <http://www.plastecs.com/forms/index.htm>

Sandia Natl. Voltaic Laboratory Photovoltaic Systems Project

<http://www.sandia.gov/pv/main2.html>

Solar Educational Resources and Projects

<http://www.nmsea.org/Curriculum/resources.htm>

Solar Electric House Kit

<http://www.jademountain.com/International/International/greenstar/g8079.html>

Solar Energy Network <http://www.solarenergy.net/>

The Solar Resource [http://www.nmsea.org/Curriculum/7\\_12/The\\_Solar\\_Resource.htm](http://www.nmsea.org/Curriculum/7_12/The_Solar_Resource.htm)