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Solar Energy -- Architectural Alternatives for Home Building

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by Georgia Redonet

Introduction

"*The will to act — that's a renewable resource — let's do it.*"

Al Gore, February 25, 2007

Former vice president, Al Gore, made the above statement when accepting an Academy Award for his documentary *An Inconvenient Truth*. It is a point well taken. Humans posses the energy and ability to affect change and that energy is a limitless renewable resource. Whether our ideas are big or small, they can all add up to a change in how we live, which can improve the world in which we live. The issue of global warming bypasses any questions as to how much petroleum energy is left for the world to use. CO_2 emissions must be reduced and every individual can play a role in that reduction. The focus of this curriculum unit will be on architectural alternatives in home construction using solar energy. Our studies will culminate with a look at Earthships. These homes present what appears to be the most all-inclusive use of alternative applications using solar energy.

Solar energy is a topic that I think will grab the imaginations of my students. As 7 th graders who, for the most part, live in apartments, the discussion of houses heated and operated by the sun will be a totally new topic. Once our study begins I anticipate difficulties getting them back on track for the rest of our regular studies. That's fine. We will have sparked an interest in a field that is the next "dot.com.>" era as they consider future career choices. President George W. Bush mentioned renewable energy in the 2007 *State of the Union* address. Some of the large energy companies, such as Shell Oil and BP (British Petroleum) are actively involving themselves in renewable and alternative energy research. In fact, Shell Oil is using Shell Energy and Shell Global Solutions to describe their corporate structure. The purpose of this unit is to use architecture to introduce my students to this topic of renewable and alternative energy, which is quickly becoming a part of our mainstream dialogue.

Objectives

By the time my students reach their maturity, knowledge and acceptance of renewable and alternative energy solutions will be essential, even in Houston, Texas, the so called "Energy Capital of the World". My seventh grade Texas History classes study the emergence of the petroleum industry in Texas, the products it produces, and its importance to the economy of Texas and the nation. We also consider career options provided by this industry which is the biggest employer in the Houston area. This unit will provide a continuum to that study. An objective of this unit is to apply concepts that they have already learned in their science classes to the application of architectural alternatives using solar energy for living on and off of the grid. Examples of this would be transference of energy, thermal mass, the seasonal position of the earth in relationship to the sun, basic electricity, and the environmental impact of CO_2 emissions on the environment. Another objective is to continue with an ongoing goal to expose students to new professional options in a changing marketplace. We will focus on examples of how individuals can impact the need for change and the global implications of that change.

At least one-third of the world's population does not have access to electricity. Exponential human population growth and the accompanying increase in energy consumption by developing nations is expected to cause global temperatures to increase between 2 and 5.8 degrees C over the coming century, according to the *Intergovernmental Panel on Climate Change* report issued in 2001 [1]. A change of a few degrees may not seem that drastic. But this type of temperature increase does not appear to have occurred during the human habitation of the earth. These changes will impact our planet's weather throughout the Earth's ecosystems. Increased levels of drought, flooding, and storms as well as the impact of melting glaciers and changes in temperature will impact every continent. Therefore, a new way of thinking about energy efficiency, affordability and alternatives is necessary within our society. An informed public can encourage the growth and use of energy alternatives. What can we do at a personal level? Another objective of this unit is to have my students begin a dialogue centered on these issues.

This unit is aimed at 7 th grade, second language learners. Before beginning this unit, my students will have viewed and studied Al Gore's video, *An Inconvenient Truth.* This will prepare them for understanding why it is not enough that we conserve energy. They will have considered the necessity for renewable and varying sources of energy. I expect my students to become knowledgeable about new ideas, so that as adults they will be prepared to encourage and accept alternative energy solutions. The objective of this unit is not to teach new construction methods or delve into highly technical explanations of solar energy processes. I suggest that teachers of higher level classes involving technology, engineering, architecture, or construction read the books listed in the bibliography. They are interesting and full of valuable information, specifications, and worksheets. These areas are too broad a topic for this unit which is intended to grab the attention of students and prepare them to accept new innovations in the field of energy as it relates to architecture. The lessons I propose to create in this unit will be aimed at simpler, individually based alternatives to begin the process of creating a public willing to consider changing how we live to improve the way we live. "The key to reversing climate change is action. The key to generating clean energy is education [2]."

Background

My interest in creating such a unit was spurred in 2005 when I traveled with a group of Texas teachers to China. This experience had a huge impact on me. Questions as to where the energy and water will come from for cities of 30+ million people were constantly confounding me. What about trash disposal? People are leaving the countryside in huge numbers for what appears to be a better way of life in the cities. The Chinese government is trying to discourage this migration. When our group traveled to a mountain village to visit the local school I noticed that there were few large trees in the area. I also noticed that the homes that we visited were built of mud: adobe as it is called in the American Southwest. Some of the homes were set back into hillsides and we even visited people who were living in caves.

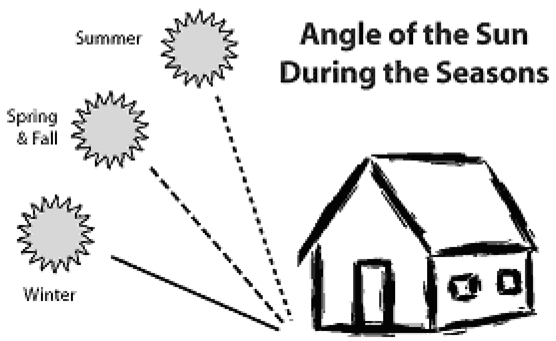
My mind was reeling with ideas. I have long been a fan of the Earthship houses created by Michael E. Reynolds of Taos, New Mexico. These homes use limited wood products. A large portion of the building material is soil. The village we visited experiences extreme cold in wintertime. Earthships can operate off of the grid through the use of solar energy. No fuel is required for heating, thus preserving limited wood and petroleum resources. Passive solar energy heats the homes. There are various alternatives for producing electricity within the Earthships including battery stored energy through the use of photovoltaic cells and wind turbines. The back and side wall mass of the structure is created by packing earth into used tires. China, with its millions of people turning to the use of automobiles, will have an enormous environmental problem when it comes to discarding used tires. Areas of northern and central China are very dry. Earthships are designed to collect water from the sky for household use. I came back wanting to share my experiences and impressions with my students.

My trip to China stimulated new ideas as to how to approach the study of energy. Energy availability and its attendant problems such as sustainability and pollution are issues of importance around the globe. Not everyone can afford to buy or build a home. This is the world my students will inherit. Through this unit they will be introduced to various architectural alternatives, including the Earthship, which address these issues. My classes will be asked to consider which ideas are feasible and which need improvement. Which of these housing alternatives would they be willing to try? Do they think they would work in the countries their families come from? We have a large immigrant population at our school. While the majority of our students are of Mexican and Central American background, we usually have between thirty and forty countries represented each year. I want them to understand the implications these changes could have, not only in the industrialized USA but, in emerging and third world nations.

Using Solar Energy

To understand how a solar home functions it is first necessary to review some basic information about the sun. We all know that it provides heat and light. We also tend to take that for granted without thinking about what that really means. According to William H. Kemp, in his book *The Renewable Energy Handbook*, all energy is solar. The sun's rays enter windows and create heat. It miraculously turns into electricity when striking a photovoltaic cell. Air that is heated by the sun begins to rise and wind is formed which causes a wind turbine to spin eventually creating more electricity. The heat of the sun causes water to evaporate and form rain clouds which will supply streams and rivers with flowing water. That water might flow through a water turbine creating more electricity. These are all renewable sources of energy which come to us from the sun [3]. The fossil fuels upon which our society depends so heavily were products of the sun's energy through photosynthesis.

From their science classes, my students will know that the earth tilts on its axis as it orbits the sun. In the Northern Hemisphere, the sun is lower in the sky during the winter and higher in the sky during the summer (see Figure 1). For this reason, a home with south facing windows will receive direct solar gain in the winter as the sun's rays extend directly into the windows. If there is thermal mass in the home, it absorbs the sun's heat and releases it at night when the sun goes down. *Thermal mass* is a term for any mass used to hold or contain temperature. During the summer, the rays of the sun approach the house from a higher angle and are deflected off of the front of the home. Without the direct gain from the sun, the house remains cool. "The amount of energy received by vertical south-facing glass in December or January is almost triple the amount received in June [4]."



SOURCE: *Power With Nature* book by Rex A. Ewing. © PixyJack Press

Figure 1. Reprinted with permission of the publisher from *Power With Nature* by Rex A. Ewing: PixyJack Press.

Thermodynamics is the movement of heat. Heat tends to move from the hotter place to the colder. "The hotter will lose energy and the colder will gain energy until a state of equilibrium is attained. Cool mass walls will absorb the sun's heat, but when the sun goes down and the air in the room cools, the heat will slowly be drawn back out of the walls [5]." A good example of this phenomenon would be the way a roadway gives off the heat it has collected all day into the cool nighttime air [6]. *Conduction* is the process by which heat energy moves through a material. For example, the sun heats the south side of a mass wall and the heat moves through that wall to the room on the north side of the wall [7]. These terms are essential to understanding how passive solar energy can heat a home.

The Trombe Wall

A Trombe Wall is a solar heat-collecting wall. It can be made of concrete or adobe bricks, stone, or can even be a wall filled with water. The wall is placed behind a south facing glass window. The energy of the sun passes through the glass and heat is stored in the thermal mass of the wall. Often times the wall is painted black for better heat absorption. As the wall warms, the air in the space between the window and the wall heats up and rises. Vented openings in the top and bottom of the wall allow the heated air to rise and enter the living space behind the wall. As the air cools, it drops and flows back into the air space in front of the wall where it is reheated, rises and returns to the living space via the top vent. This type of air movement is called thermosiphoning or thermal looping [8]. As we learned above, heat moves towards cooler spaces. Ideally, at night, the Trombe Wall releases its heat to the interior of the home. But unless the vents are closed off, it would be more typical for the heat from the room to gravitate towards the glass windows and cooler outside air. Remember, heat likes to conduct itself to a cooler place.

So, while the wall might work in the daytime, it will probably lose most of its heat to the cooler outside air at night. Besides, it is rather odd to drive up to a beautiful house with large "picture" windows and see a big wall right behind the glass. But the use of the Trombe Wall helped lead to new ideas. We didn't go right from stone tools to computers and the use of solar energy in the home was and still is evolving. The Solar Slab represents the next step in that evolution.

The Solar Slab Heat Exchanger

James Kachadorian opens his book *The Passive Solar House* with the following statement: "All houses are solar [9]." If a house has windows and the sun is shining, there is an opportunity to gain free passive solar heat. But, not everyone avails themselves of the opportunity. As a home builder, Kachadorian acknowledges that "home building plans were typically insensitive to the position of the sun. Our prefabricated home packages were labeled simply 'front, back, right side, left side,' not 'south, east, west, north.' We offered little or no advice on siting [the position of the home in relation to the sun], except that we needed enough room to get a tractor-trailer to the job site [10]." He describes how potential home buyers showed little interest in the insulating qualities (R-values) of their homes and were less interested in energy efficiency than the attractiveness of the house. After oil prices rose in the 1970s, he acknowledged that the home buyer, contractors, and design team must all work together to provide a more comprehensive plan for home construction and energy efficiency [11].

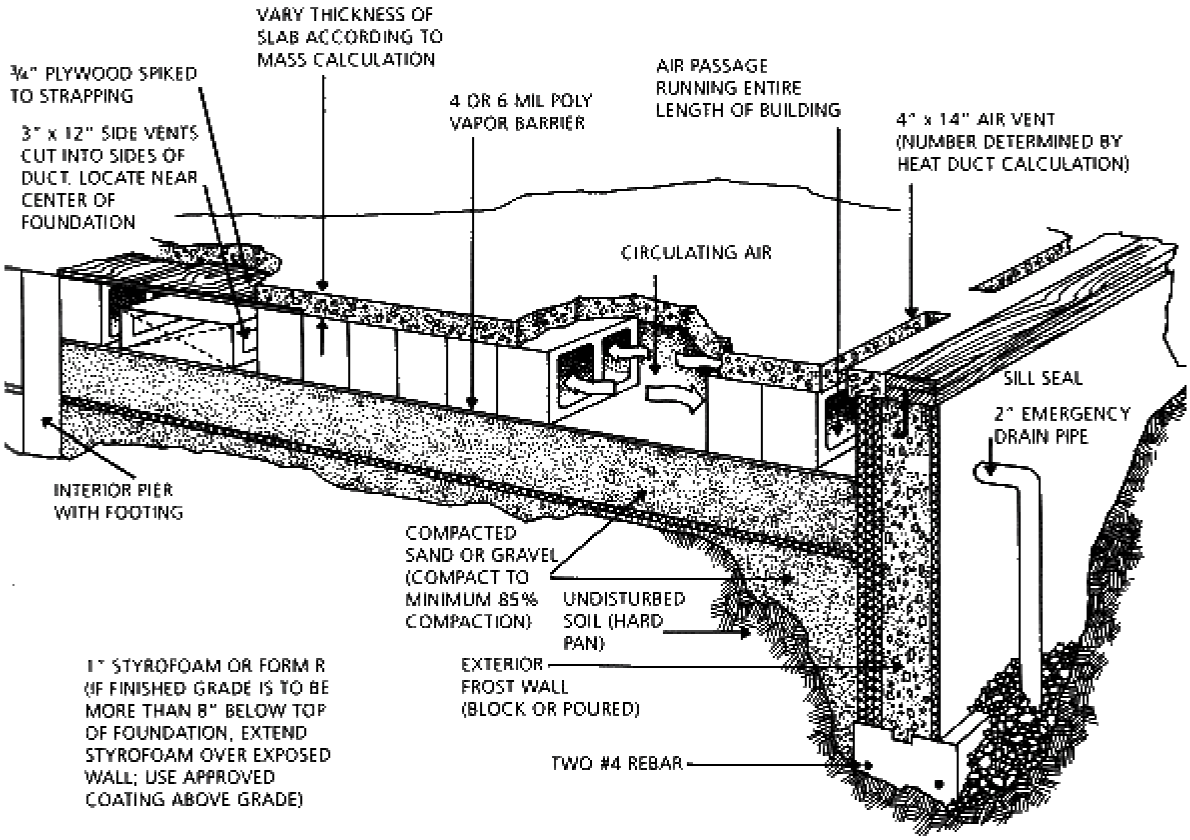
In January of 1976, Kachadorian opened Green Mountain Homes, the first company in the United States to focus on the design and manufacturing of solar homes in kit form. His company created simple changes in construction which invited the free energy of the sun into the home. He did meet resistance. People were afraid the house would become too hot or too cold. They feared it would have to be weird looking, use strange fickle gadgetry and materials, and require huge expanses of glass [12]. His designs are far from that. They incorporate traditional designs and use the materials required for normal construction. The only downside is that a basement cannot be included in the home as a ground level foundation is necessary for the absorption of heat into the slab.

It was stated earlier that traditional home building kits did not mention the orientation of the front of the house: south, east, west, or north. This becomes the first step in building any home which will use passive solar heat. The major windows at the front of the house should face south to grab the rays of the sun. The back of the house, with few windows, will face north. According to Kachadorian, solar principal #1 is to orient the house properly with respect to the sun's position as it relates to the building site. "Use a compass to find true south, and then by careful observation site the house so that it can utilize the sun's rays from the east, south, and west during as much of the year as possible [13]."

The best solar gain design for any construction style presents as much surface area as possible to the sun. This is achieved when the longest axis, which is usually the front of the house, is facing true south [14]. For example, a house in Hartford,

Connecticut facing true-south will have a 100% solar benefit at high noon. If the house is rotated 22 1/2 degrees to the southeast or southwest, there is a 92% solar benefit. Rotating from true-south by 45 degrees provides a 70% solar benefit and a rotation of 67 1/2 degrees results in a gain of only 36% [15]. Staying within the range of a 20 degree shift from true-south would still provide ample solar gain while giving some leeway as to the orientation of the front of the house. If possible, a windbreak of some type is desirable on the north side. This can be provided by an outcropping, hillside, or group of evergreen trees to protect the house from north winds [16]. Deciduous trees on the east, west, and south provide shade in summer and, after the loss of their leaves in the fall, allow the sun's rays to penetrate into the house during the winter. We know that the sun's rays are angled above the front of the house in summer, thus lowering the amount of solar energy directly entering the front windows. This does not hold true for the sun as it rises in the morning and drops in the afternoon. Therefore, houses in warmer summer climates may need less east and west facing windows as they will not stop performing as solar collectors in summer [17]. Another option would be to plant deciduous trees or use insulating window coverings.

James Kachadorian's Solar Slab is constructed with concrete blocks (cinder blocks) and poured concrete (see Figure 2). This slab is easy to build, reasonably priced, and provides an effective thermal mass to absorb heat from the sun. A layer of 1" Styrofoam is first laid on the ground. This is topped with 12" of compacted sand or gravel which is covered with a poly vapor barrier. Next come the concrete blocks which make this slab unique. They are laid so that the holes in the blocks line up horizontally forming air passages running north and south. Finally a rebar enforced slab is poured over the blocks [18]. It is this slab which will absorb the solar gain and conduct it into the air passages of the cinder blocks. At the north and south ends of the slab, wooden spacers are inserted before pouring the slab to create air vents. These vents will allow the circulation of air between the house and the concrete "radiator" slab [19].



The Solar Slab concrete heat exchanger: a section drawing.

Figure 2. Reprinted with permission of the publisher from *The Passive Solar House* by James Kachadorian: Chelsea Green Publishing.

This is how it works. Light rays from the sun, which are short-wave energy, pass through transparent glass. As soon as the light rays strike an object, for instance the floor covering above the slab, light changes form to long-wave energy or heat. The concrete slab's temperature rises as heat is absorbed and the air in the vents of the cinder blocks is warmed [20].

During winter days, the south wall will be warmer than the north wall. Heated air along the south wall will rise. As it rises, it pulls warmed air up through the floor vent from the slab. Cooler air along the north wall will drop down into the floor vent where it circulates through the slab, is warmed and rises back into the house at the south wall. This is another example of the thermosiphoning circulation of air which was first utilized in the Trombe Wall [21].

But, not all days are sunny, and we want our homes to be warm at night when the sun is not shining. Heat storage is accomplished by using thermal mass to capture the heat of the sun during the day. "Thermal mass is comprised of building materials that absorb heat effectively, charging up like a thermal battery and then yielding this heat back into the home's living space through periods of time when the building is not actively gaining heat from the sun or from some other source [22]." In simple terms, the heat stored in the mass of the slab radiates back into the home during times when the sun is not shining. When discussing solar heating it is important to remember that heat wants to move into the cooler spaces. As the temperature drops, the slab radiates energy back into the house. It acts like a battery being discharged. The next day when the sun returns, the slab is recharged and another day of heating begins. If backup heat is needed, it is only necessary to provide the difference between the thermal mass temperature and the desired room temperature, thus saving on energy bills [23].

Photovoltaic Cells and Wind Turbines

Gaining passive solar energy to heat our homes is a fairly basic endeavor. In its simplest form, we can open our curtains and let in the sun's energy. Gaining electrical energy from the sun is not so easy. There is a misconception that going solar means energy is "free." To gain electricity from the sun, there are a whole series of components that are necessary and they come with fairly high price tags. The pay-off will come later when not paying monthly utility bills that will probably rise for on the grid users. There is also the important pay-off that results from knowing that energy blackouts won't affect one's home, and from not contributing to CO_2 in the atmosphere. For every kilowatt hour of electricity produced at the typical power plant, twenty pounds of carbon is released into the atmosphere. For every watt used in one's home, approximately nine watts are lost in the transmission lines [24]. For people moving into the country where there are no utility connections, the solar option can be immediately cost effective as utility companies usually charge a high premium to run lines to a new building site.

Photovoltaic cells are usually grouped together in modules. They convert sunlight into electrical charges. The charged electricity then travels through wires to storage batteries in the home. This is the major difference in living off of the grid. We are accustomed to switching electricity on and off as it enters our homes from the power lines. Off-grid users must store their energy in batteries or it will be lost. These batteries look like the ones we use in our cars, but are a heavier, deep-cycle version.

Now things get tricky. At this point, it is a good idea to remind students that they are studying electricity. This is not something to go home and play around with. The first step is to assess how much electricity (wattage) is going to be used. More usage requires the purchase of more photovoltaic (PV) panels (arrays) and storage batteries, which can significantly raise expenses and affect maintenance issues. More batteries will also affect construction cost, as they should be stored in a separate room inside the house. So, how much energy will you need? First, calculate your current usage. Consult your electrical bills and divide the kilowatt hours from the bill by the number of days in the billing cycle. The average home will probably be in the range of 15 to 30 kilowatt hours per day (without air conditioning) [25]. "Consider that the modules for a solar array will cost you somewhere in the neighborhood of $3.50 to $5.00 per watt [in 2003] (and each of those watts will give you, on average, .004 to .006 kilowatt hours per day, which is to say that a 1000-watt array will yield 4 to 6 kilowatt hours on a good day) [26]."

Obviously, conserving energy will be cost effective. Calculate the amount of electricity that is essential and then look for ways to eliminate usage. Older appliances are energy hogs. Look for newer, Energy Star-rated models to save wattage. Don't use items such as plug-in clocks when wind-up or battery operated will work just as well. Eliminate phantom loads. The modern home contains several items that are always "on," even when they are turned off. The television is the best example. It comes on instantly, because it is waiting in an "on" condition. Other examples are VCRs, DVD players, cable boxes, laptop computers, and electronic chargers [27]. These items should be unplugged when not in use or plugged into a power strip that can be turned off. Switching from incandescent to compact fluorescent light bulbs will save wattage. Every bit helps and reduces set up cost. Once the system is up and running, there are other wattage saving measures that can be undertaken. Don't use big energy consumers at night or on cloudy days. Wait for days when the sun is out and constantly charging the batteries.

It might seem that having extra PV cells and batteries would just be easier, despite the cost. But, that is not necessarily true. With too few batteries you will be wasting available solar and wind energy. With too many, the batteries themselves will suffer due to maintenance issues [28]. Sulfates can accumulate on batteries that are not brought to full charge. This will lessen the life of the battery. So, the batteries need to be taken to full charge (filled up with energy) on a regular basis. Too many, and that may not be possible [29].

The solar array of PV cells should be oriented towards the sun in the same manner as a house utilizing passive solar energy. There are several components necessary to bring solar electric energy into the home. Energy from the PV cells needs a charge controller to ensure that the electricity is the appropriate DC current for storage in the batteries. American homes operate off of AC current, so an inverter is needed before the energy can be put to use. Meters are useful for monitoring usage, and fuse or breaker boxes are needed to regulate energy to the outlets. If including energy from a wind turbine, that electricity will also have to flow through the charge controller, or converter, for storage in the batteries (see Figure 3). This all serves as a reminder that the start-up costs of "free" solar electricity are more than those associated with contemporary construction.

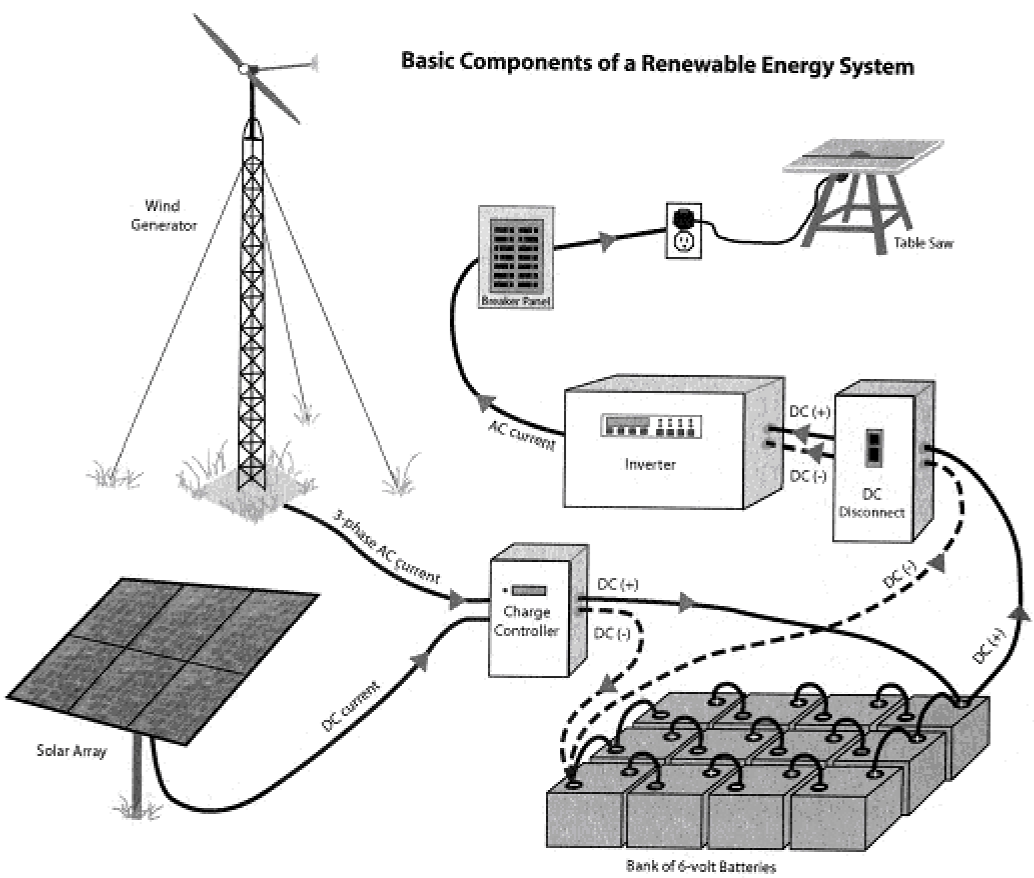


Figure 3. Reprinted with permission of the publisher from *Logs Wind and Sun* by Rex A. and LaVonne Ewing: PixyJack Press.

Wind turbines can be large or very small. Check *YouTube* for numerous variations in style. The advantage of using wind energy is that it supplements solar production when the sun is not shining and at night. Of course, for this to work, wind is necessary. A turbine requires wind speeds of between 8 to 10 mph to produce electricity. It is wise to monitor wind velocity in an area before investing in a turbine system. Since wind speed increases with height, most turbines are raised on towers. Here again, there is more start-up cost. The turbine should be free of any obstacles that can limit wind access such as trees, buildings or geographical formations. In his book, *Logs, Wind and Sun*, Rex Ewing recommends that the blades of a turbine be mounted at least 20 feet higher than the highest point within a lateral radius of 300 feet [30]."

Earthships

When my students enter high school they will begin to study contemporary issues. Energy availability is and will continue to be of high importance. But other issues will come to the forefront as they mature. There appears to be a widely held assumption that water, not oil, will soon become the most valued resource on earth. Underdeveloped and immerging nations such as China will require more energy and in the process produce more trash. How will the world handle these issues? With the background knowledge gained through this unit of study, my students will be prepared to make realistic decisions regarding the future of the world. Earthships were mentioned earlier in this unit. They came to mind as I considered the problems facing modern China and the impact that China's growth will have on the rest of the world. We will culminate our study of architectural alternatives by investigating this innovative structure called the Earthship. Almost every aspect of modern living is adapted to renewable energy in this sustainable system.

Michael E. Reynolds of Taos, New Mexico has created a design for home building which is affordable and innovative. He accomplishes this by using recycled trash and earth as building materials. Reynolds sees garbage as a renewable resource. By using such items as used tires and beverage cans for construction he is able to use one problem to solve another. "Garbage is a renewable resource-and we don't have to worry about raping the Earth to get it [31]." These Earthships can operate off of the grid and are designed to be totally self-sustaining. An Earthship provides its own heating and cooling, water, and sewage treatment. Electrical power is generated through photovoltaic cells and wind turbines. Food can be grown year round in the interior, no matter what the climate.

How does he do this? A brief description was given in the introduction; now I will give more detail. I strongly recommend pulling up pictures or videos from the bibliography when studying these homes in your classes. To take advantage of the free solar energy, Reynolds chose to create walls in his homes with a capacity for high thermal mass. This is where tires come into the picture. Thermal mass is any substance which can contain temperature. Earth, adobe and other bricks, rock, concrete and water are all thermal mass materials. Concrete is not renewable and comes with a price tag. That price can be calculated in dollars and CO_2 emissions. "Roughly 7% of greenhouse gas emissions worldwide stem from the manufacture of Portland cement — a major component of most concrete mixtures [32]." With bricks, there is also the issue of transport, cost, and the environmental consequence of brick making. The energy equivalent of one gallon of gasoline is needed to manufacture eight common building bricks [33].

Water is the best material for thermal mass. It is used in radiant floor heating in contemporary construction. Hot water runs through tubes embedded in a slab. The heat radiates upwards towards the cooler air. It is a good system, but it does require the use of fossil fuel and mechanical technology for it to work. I have seen water used to retain the heat from solar gain. Friends had a huge cylinder of plastic (about six feet across) reaching from floor to ceiling in the entryway of their home. It absorbed the sun's energy and radiated it back into the house after the sun set, as the air in the house cooled. Unfortunately, this cannot be devised as an aquarium as the fish could not take the variations in temperature. A huge water tank, with the possibility of leakage, may not be the route most people would take to heat their homes.

Earth is free and readily available. The ever increasing number of tires in need of disposal is a world-wide problem. Think back to the beginning of this unit. It was the thought of all those automobile tires that will eventually become trash and the fact that some type of sustainable housing in the Chinese countryside could stem the flow of people into the already overcrowded cities that launched my desire to create this unit. To quote Reynolds, "You've got dirt and tires. Here's structure, here's mass and here's a heating system — and it's free. . .Thermal mass is usually expensive. Traditional houses have no mass [34]." While insulation helps to keep heat inside houses, it does nothing to store heat. Because it does not hold temperature, we continually heat or cool the air. This results in higher energy and emissions costs [35]. Reynolds decided to pack or ram earth into used tires. He knew that a denser thermal mass would hold and provide more heat [36]. This part of the construction is very labor intensive. Sledge hammers are used to pound an average of 300 pounds of earth into each tire [37]. They are then laid in courses just like those used to lay conventional bricks (see Figure 4). These tires are used to build the interior and back walls. At a width of 30 inches, they provide stability and thermal mass. This thick anchoring mass will absorb solar heat during the day and release it at night.

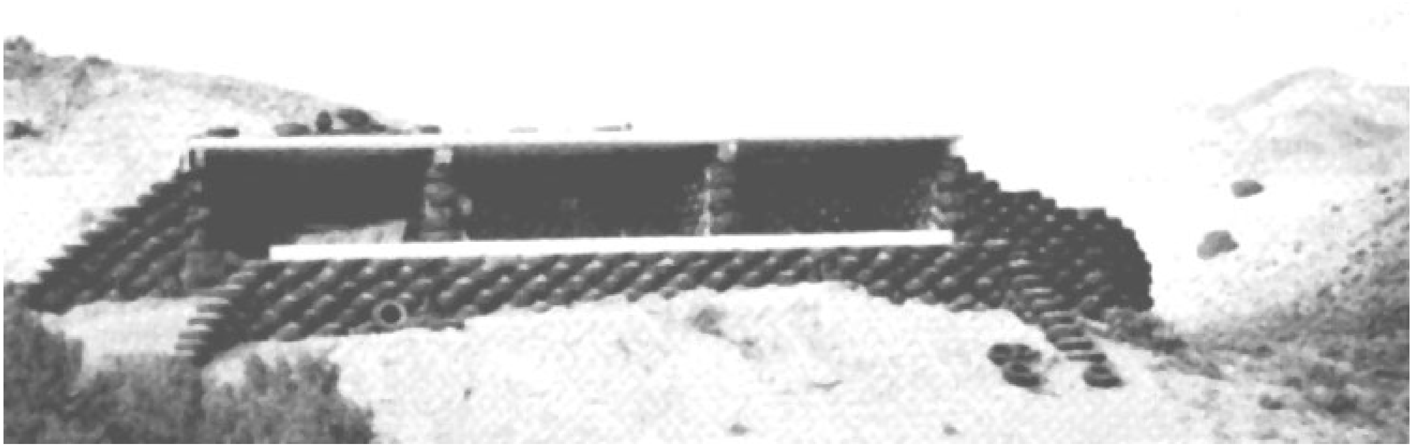


Figure 4. Reprinted with permission of the publisher from *Earthship, Volume I: How To Build Your Own* by Michael E. Reynolds: Solar Survival Press

To increase the heat retaining capacity of the house, it is bermed into the earth. The

house ends up looking like it is partially buried from the back towards the front. This, however, is not an underground home. Earthships are airy and open to the outside. By burying the sides and back, or north side, of the house, the thermal mass of the home is increased. By placing the foundation, which is hard-packed earth, below the frost line, the house can maintain a constant temperature no matter what the weather is like outside. At a depth of approximately four feet, the thermal constant of the earth is between 55 and 60 degrees F. For this reason, the tire walls are not insulated away from the earth. "By tapping into this natural thermal constant, the Earthship is consistently comfortable, because this is only 10 degrees away from the North American comfort zone of 70 degrees F [38]." In winter, the solar gain warms the house to a higher temperature if desired during the daytime. Meanwhile, the walls are recharging like a battery. If the house becomes too warm, there are air vents which are used to control temperature. At night, as the house temperature cools, the walls release stored heat. After several cloudy days, backup heat can be provided by a small propane heater or fireplace if desired. But the temperature in the house will not drop below the earth's thermal constant temperature. In summer, this constant temperature helps to keep the house cool.

In the spaces between the tires, where they curve towards each other, beverage cans are inserted as filler along with mud. The mud is used in the same way that cement would be used. Here again, the earth provides a free, renewable, and nonpolluting building material. Electrical wires are run between the courses of tires before plastering begins. Stucco wire covers the tire walls and they are plastered over with plaster, stucco, or mud. If using mud, the same traditional technique used to plaster over adobe bricks is used. The mud is stabilized with sand and bits of straw and can be painted. A flat roof is placed over the structure and a greenhouse is added to the front, or south facing wall. Vertical or angled glazing (glass windows) covers the front of the building where the solar gain will take place. As stated earlier, it is important that the longest axis of the house faces south. Through the use of its space and thermal mass provided by the tire walls, the entire house serves as a battery to store heat in winter [39].

An important aspect to building an Earthship, or any type of home heated by passive solar energy, is to provide enough thermal mass to heat the living space. Therefore, Reynolds recommends that rooms not be larger than 18x26 feet [40]. His layouts use oval or U-modules to form each room. If the living area is too large in relationship to the thermal mass of the walls, then the home may not be able to retain and later radiate enough heat to make it through the night when the sun's energy is not present. Each room acts as a battery storing and releasing heat. The open end of the U faces south, allowing the sun to warm the interior during the day as the walls absorb and store heat. Access between rooms is through an open hallway along the south wall fronting the greenhouse area and south facing windows.

Now the fun begins. The exterior may look like something from *Star Wars*, but the interior of an Earthship can be quite beautiful and creative (see Figure 5). The curves provided by the tires mean there do not have to be any sharp edges along the walls. Old bottles (more recycling), tiles, and stone can be embedded in the plaster to make beautiful

Figure 5. Reprinted with permission of the publisher from *Comfort in Any Climate* by Michael E. Reynolds: Solar Survival Press.

works of built-in art. While a single story is the most efficient and least expensive design, it is possible to build multi-level homes. By using cement and recycled beverage cans as bricks, interior walls and stairways take on curved and exotic shapes. Videos of a Taos home called Angels Nest and actor, Dennis Weaver's Colorado home, listed in the bibliography, are excellent examples of how creative one can become with this type of construction. More conventional Earthship designs can be viewed on the Earthship Biotecture web site. This site also has plenty of interior photographs.

With beauty comes function. Reynolds has incorporated all aspects of modern life into the Earthships. It is possible to be totally disconnected from the grid and still have all of the modern conveniences. The following paragraphs describe water systems. While this discussion strays from the solar functions, it describes an important aspect of total sustainability. Other solar innovations will be studied in detail as a part of our classroom activities.

Water from our homes generally flows into a sewer system or septic tank after it is used. Not everyone can hook up to a city sewer system. Septic tanks are expensive to install and have to be periodically cleaned out. There is the hidden danger that water tables close to the surface may become contaminated. There are areas of the world where it is difficult to live due to the scarcity of water. Earthships are capable of capturing water from the sky and reusing it for maximum efficiency.

Where does the water come from if a home is not connected to the utility grid? Digging a well is a possibility. This is another major expense and there is no absolute guarantee that one is going to strike water. Pumping the water up from the well involves more expense and electrical usage. In his book, *Water From the Sky*, Reynolds details options for collecting and storing rain water and snow melt. For people living in dry areas or in underdeveloped nations his ideas present viable options for leading a sustainable life. Based on Reynolds calculations, it is estimated that in the United States the average water usage per person/per day is 52 gallons. This is based on toilet usage, showers, faucets, dish washer, washing machine and a small amount of leakage [41]. By using the techniques he has developed for the Earthship, an individual's daily water consumption can drop down to approximately 19 gallons. In areas of water scarcity, that is a substantial savings. These savings are achieved by using some of the water more than once.

In an Earthship, the roof area acts as a catchment system, funneling the rain water and/or snow melt towards the first filtration step which is a silt catch device. This will take out any debris which has gathered on the roof. From there it flows into a cistern for storage. The cisterns are usually constructed of tires and located next to the house. This forms a circular structure which appears to be an artistic and integral part of the Earthship. From the cistern, the water flows through a series of filters where it becomes potable and on into a pressure tank. This is the same type of pressure tank used when bringing water up from a well and will require a small amount of electricity. From the tank, it flows through to the conventional system of pipes and faucets [42].

Water used in the home is separated into greywater and black water. The water from a toilet is considered black water. It cannot be reused. For homes not connected to a sewage system there are composting toilets available for purchase. Some of these do use a small amount of electricity. You learned earlier that eliminating even the smallest electrical usage is important. Reynolds has developed a sun powered composting toilet which can be built by the owner. The sun heats solid waste (without smell entering the home) until it turns to ashes which can then be added to a flower garden. This may not seem appealing, but it eliminates the need to dig a septic tank and makes it possible to live in areas with little water. The high temperatures of the process kill off microorganisms. This type of low-tech treatment could go a long way towards improving public health in third world countries.

Greywater is what comes from the sinks, shower, bath tubs, and washing machines. In an Earthship this water is reused. This is why it is possible to live in a dry area, such as the mesas of Northern New Mexico with an annual precipitation of perhaps 8 inches per year, and still have enough water for domestic usage. Here again, the implications for adaptation to underdeveloped countries is significant. Let's follow the greywater as it leaves the kitchen sink or shower. The water drains into a botanical cell which will usually be located in the greenhouse area. The cell is a rubber lined pit with layers of gravel, dirt and plants [43]. As the water filters through the cell, it nourishes the plants, some of which will provide food for the inhabitants, and eventually flows through a filter and into a pipe where it is reused to flush the toilet (if a composting toilet is not being used). The water can be used three times before being sent out to a leach field and or septic system [44]. With the solar, self composting toilet reducing human waste to sterile ashes, the need for a septic system is eliminated and the leach field becomes a minor expense. The plants in the interior botanical cell will grow lavishly, even in winter, absorb CO_2 and provide oxygen as they filter the air. This function helps to lessen the carbon footprint of the systems within the Earthship. By reusing the water, it is possible to parlay 8 inches of annual precipitation into a usable amount of 24 inches [45]. Because the black and greywater are separated, the greywater when it finally leaves the house can be channeled into another outside botanical cell adding a fourth usage to the water. It should be noted that some municipalities may not allow this type of system within their building codes. In such cases, the Earthship would need to hook into a septic or sewer system.

Earthships have been adapted for use all over the world. In sites where runoff, possible flooding, or a high water table are present, alternative plans are available for building on or above grade. In warmer climates, the large windows are turned north, since heat gain is not an issue. Air conditioning can be achieved by introducing warm, outside air into underground cooling tubes where the temperature is dropped to the earth's thermal constant before being circulated through the house [46]. Reynolds has also developed more contemporary designs, which can be viewed on his website, for those wishing to fit into the urban environment. In April of 2007, the city of Brighton, England approved plans for a sixteen unit development in the heart of the city.

Conclusion

I have had the experience of living in a house heated by passive solar energy. So, I know that it really does work. I understood how it worked at the time and that there were some areas of its use that could have been better. All I cared about was that on sunny winter days when the temperatures wavered in the 30 degree Fahrenheit range (which is the norm in Northern New Mexico) my house was warm. A wood fire was necessary at night, but since I worked evenings in a restaurant, I usually came home and went to bed without building a fire. By 10 AM, the house was warm again. I was happy and not spending my hard earned cash on cords of wood to stay warm. I have been a fan of passive solar heating ever since.

After doing all of the research for this unit, I now understand just how much was wrong with that house. Yet, it still worked. When I decided to add a greenhouse with large south facing windows to the front of the house, no thought was given to the degree of slope in the angle of the glass. I simply told the carpenter to just tie it into the porch roof that was there. There was not enough thermal mass. The front wall separating the house from the greenhouse was adobe and the cement slab was of normal thickness. The walls on the east, west and north sides of the house were of conventional framing with sheetrock interior and stucco exterior. Huge windows faced the north, east, and west. The back portion of the house had a high ceiling and clearstory windows. This is a plus in the daytime for adding heat and a minus at night for losing it. But the point is it still worked. It saved me money and cut down on my personal carbon footprint. In summer, the house was cool thanks to the slopping overhang of the greenhouse roof which shielded the sun's rays which were angled from a higher arc in the sky. Some people may opt to make drastic changes in the way they live and others might only institute small changes in their existing architecture. Individual changes in architecture and lifestyle may not seem significant, but on a global level they can make significant differences in CO_2 emissions and quality of life.

We are not going to tear down all of the homes in the world and start over. But as new construction is considered, I want my students to be aware that there is another way of doing things. In this way, they will become an informed electorate capable of choosing government officials whose policies can effect change. That change is beginning to happen. In April of 2007, the city of Houston hosted a symposium attended by representatives of American cities that have begun developing "green" building codes. These cities are also supporting efforts to lower the carbon footprints of their cities [47]. Petroleum will continue to be the mainstay of the Houston economy, providing excellent opportunities for employment. What I want my students to understand, as they study this unit, is that there are going to be innovations in the world of energy research and usage. Shell Oil is currently working with a European company to develop more cost effective PV cells. An ad appearing in the August, 2007 *Texas Monthly Magazine* announced that British Petroleum will be a title sponsor in the U.S. Department of Energy's 2007 Solar Decathlon. Universities will compete to design, build and operate an attractive and energy-efficient house that is entirely powered by the sun. Their houses will be built and judged on the National Mall in Washington D.C. in October of 2007. This is where the new challenges exist and these areas of research and development will provide the newest sector of employment choices. The implications for improving the lives of people in third world and developing countries through the use of alternative energy sources are enormous. It is my hope that by delving into solar energy and architectural alternatives, this unit will stir the curiosity and imagination of my students, encourage a deeper interest in science and contemporary global issues, and lead them into a more advanced study of other energy alternatives.

Lesson I: Following the Energy Grid

Objective

Before introducing my students to solar energy, I want to be sure they know where the energy they currently use is coming from, how it is produced, and its impact on society.

Materials

Computer lab and library.

Posters and art supplies

White board

Activity 1

We will start with a general discussion about the energy usage in their homes. They will be asked the following questions:

1. What type of energy do you use to watch TV, listen to music, or use the computer?
2. What type of energy do you use to cook?

3. How is your hot water heated?
4. How is your home heated in winter and cooled in summer?
5. Why do you have light in your house?
6. How does your doorbell work and what about all of the appliances?

For the most part, the answers will be electricity. But, in some instances the answers will be natural gas and for those living in the countryside, propane gas or wood. Students in the Northeastern United States will mention oil and others may mention coal for heating. The idea here is to make them aware of the various sources. At that point, we will break into smaller groups for the next exercise.

Activity 2

In my classroom, I have a whiteboard that stretches across the front wall. The students will draw their final charts on that board and describe them to the class. For assessment, the groups will also draw and illustrate their chart on a poster board.

Groups of four will be assigned an energy source: coal, natural gas, propane gas, wood, heating oil and electricity. Electricity will be further broken down under the headings of hydroelectric, nuclear, and coal. The groups will be given research time and must produce a chart which will look something like a timeline — running from left to right across the board.

An example for natural gas would start with the gas being drilled and piped to a refinery:

Gas underground —> Drill —> Transport in pipes —> Refine —> Pipe to home —> Plumb to water heater, heater, stove

The students, having more space, will add color, drawings, arrows and other graphics to their charts. As they describe the flow of their chart they will also be asked to discuss cost and in which regions of the country this energy source is most likely to be used. Is this a renewable or inexhaustible source of energy? Each group will report on the efficiency of using that particular resource and its approximate cost. The final segment of their presentation will include a report on the carbon footprint left by their energy source.

Assessment

Assessment will be based on each individual taking part in the group presentation. The group will split points from the poster chart based on accuracy and presentation.

Follow Up Activity

At the end of the unit another chart will be created showing the pathways used to produce electricity from solar and other renewable sources of energy, their costs, and carbon footprints.

Lesson II: Measuring the Earth's Constant Temperature

Objective

Because Earthship foundations are dug below the frost line, they are able to maintain a constant temperature. This activity will demonstrate how the temperature of the earth maintains a constant temperature below the frost line.

Materials

Soil — core drill

Graphing paper

Thermometer

Activity

As the students study the Earthship, they will learn that the temperature of the earth below the frost line maintains a constant temperature of approximately 55 to 60 degrees F. Using a soil - core drill, we will create a hole that drops approximately four feet into the earth. This will be placed in a location that sees no foot traffic. The opening will be small enough not to trip any passersby.

Using thermometers, the students will measure the temperature at the bottom of the core and the ambient air temperature once a month during the entire school year. This information will be placed on a graph.

Assessment

Graphs will be spot checked each month. At the end of the school year, a colored graph will be turned in for a final grade. It should have an accurate entry for each month.

Lesson III: Innovations for Living Off of the Grid

Objective

In this unit, my students will learn that producing one's own electricity necessitates the need for conservation. Otherwise, adding extra PV cells and storage batteries will become cost prohibitive. For those still living on the grid, using less energy is cost efficient and lessens the carbon footprint. This lesson will introduce students to various gadgets and devices that can lesson the energy load. The students will produce persuasive brochures and/or billboards to advertise these items and their benefits to society.

Materials

Computer lab and library

Posters and art supplies

Activity

For this activity, students may work individually or in pairs. They will be assigned an item, such as those described below, and develop an advertising brochure and/or billboard. Time will be allowed for research in the computer lab and library. Examples of products (and companies) to be researched and presented are underlined in the following paragraphs. Not all of the items are specifically solar, but they all provide alternatives to contemporary energy usage. I have provided a brief description. Websites for several of the items are included in the Bibliography.

William H. Kemp, in his book *The Renewable Energy Handbook: A Guide to Rural Energy Independence, Off-Grid and Sustainable Living*, provides an extensive list of items to be used when living off-grid or attempting to conserve energy. Shaken LED flashlights can provide approximately 20 minutes of light without the use of batteries. Radios and televisions operate off of sunlight or from hand cranked electrical generation. The Spheral Solar company produces lightweight photovoltaic panels that can be used to charge the batteries of a GPS, an MP3 player and other devices such as cell phones.

The Solar Cooker looks like a box with shiny flaps facing up to reflect solar energy. It needs no fossil fuel for cooking. Kemp calls it the "ecologically friendly version of the barbeque". The Sunpipe is basically a very small, tube like skylight that provides light to dimly lit areas without the heat loss of a regular skylight.

Solarwall is a narrow metal box with tiny perforations which allow the air on the

interior to heat up. It attaches to the outside of a house. As the air rises, it is taken into the house for heating. This Solarwall and the following Consolair are easy and practical retrogrades for existing structures. Consolair is a heat collector about the size of a sheet of plywood. It installs on the roof or south side of a house and provides solar heat gain.

Cell phones provide phone service to millions of people world-wide who did not previously have access. But even cell phones do not always provide service to remote or mountainous areas. Students should look for alternatives such as Fixed Cell Systems, Phone Service Extenders, Fixed-Point Broadband (Digital) Wireless Service, Radio Telephone Service and Satellite Phone Service. The same is true for the internet. Students can investigate Wide Area Wireless High-Speed Internet Service with Antenna, Satellite Internet Service, and Voice Over Internet Protocol Service [48].

Michael Reynolds has developed a Solar Oven and Thermal Refrigerator which are integral parts of the Earthship kitchen. The oven can maintain temperatures of up to 400 degrees F. During winter, cold outside air is admitted to the thermal refrigerator at night. This saves wattage for other functions during winter when there may not be as much solar gain for electrical usage. Reynolds has also developed a composting toilet that uses solar energy. Another option is a composting toilet developed by SunMar that uses small amounts of electricity. Neither requires a sewage hook-up.

Earthship Biotecture uses underground cooling tubes to introduce cool air from below the frost line into homes to provide air conditioning in warmer climates. The Building Circles Organization uses the same concept with a slight variation. The tubes have self contained water which circulates underground. Fans blow over the tubes and the cooled air is introduced into the home. There are several options for heating water including solar panels, batch heaters and coil heaters.

There are quite a few variations of photovoltaic cells and wind turbines. Building-integrated PV systems, developed by Uni-Solar, can replace roofing, thus eliminating bulky PV modules. They also produce other PV adaptations. *YouTube* has an incredible number of videos showing both large and small adaptations of wind turbines.

Assessment and Closure

The brochures and/or billboards are to be viewed as an advertising campaign aimed at educating and enticing consumers to buy new products. In a classroom presentation, each group should be able to explain how the prospective customer will benefit from purchasing their product.

Final assessment will be provided by a group of teachers who will judge the billboards and/or brochures for clarity, creativity, and persuasiveness.

Lesson IV: Other Examples of Alternative Architecture

Objective

In this lesson, my students will identify more examples of alternative architecture in both the private and public sector. They will use the information gained to create their own forms of alternative architecture.

Materials

Computer lab and library

Posters and art materials

Activity 1

Students will form groups and research various forms of alternative architecture. Types of construction that could be examined are straw bale, rammed earth, paper adobe, adobe, and underground. Examples of alternative housing can be found at Earthship Biotecture and Building Circles Organization. "Green" public buildings include the Conde Naste Building in New York City, and a new Shell Research facility in Houston. American cities such as Seattle, Chicago, and Houston are adopting "green" building codes in an effort to lessen CO_2 emissions. The Power to the People website provides links to sites showing works in progress and proposed plans for urban areas.

Each group will research at least two of the above categories. They will present their findings to the class in PowerPoint form. Each member of the group must participate in the presentation.

Activity 2

Most of my students live in apartments. Groups of five will be asked to use the

knowledge gained from this unit to create an alternative, urban, multi-use development.

Assessment

A group grade will be given for the PowerPoint. Individual grades will be given for the oral presentations accompanying the PowerPoint. They must discuss whether or not they would use the alternatives they studied and why. For the final assessment, each student will submit a paper and blueprint diagram of the group urban plan.

Unit Follow Up Activities

As a conclusion to our studies, the class will hold a round table discussion in which they will consider how to prepare for new career options presented by the alternative and renewable energy sector. Please note that Pixyjack Press anticipates the publication of *Careers in Renewable Energy* in 2008. Judging by the other books published by Pixyjack, I think this will be a very useful tool for the classroom teacher.

Throughout the unit, classroom discussions will focus on the impact that innovations in alternative and renewable energy can have on third world and developing countries.

My students will be invited to come in after school and build an Earthship. It will be fashioned after the gingerbread houses which are popular at Christmas time. They will be asked to suggest materials. The most obvious one that comes to mind is lifesavers instead of tires. I think my students would enjoy this activity that would allow them to see some of the techniques used in this alternative architecture. I am hoping to create an energy club at my school, so this edible Earthship could be auctioned off as a fundraiser.

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Construction Handbook. New York: Princeton Architectural Press.

An easy to understand how-to book on straw bale construction. It also tells the

story of the Red Feather Development Group, a volunteer organization which

constructs straw bale homes for Native Americans.

Ewing, Rex A. (2003). *Power With Nature: Solar and Wind Energy Demystified*.

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An amusing and easy to understand description of PV and wind turbine usage.

Plenty of worksheets and formulas. Good diagrams.

Ewing, Rex A. and LaVonne Ewing. (2002). *Logs Wind and Sun: Handcraft Your Own* Log Home. . .Then Power It With Nature. Masonville, Colorado: PixyJack Press.

This is a very enjoyable and informative book about building self-sufficient log cabins that function off of the utility grid.

Kachadorian, James. (1997). *The Passive Solar House.* White River Junction, Vermont: Chelsea Green Publishing Co.

Written by the originator of the Solar Slab. Formulas and worksheets are included in this informative and useful book for anyone considering passive solar design. The revised edition includes a CD for help with doing calculations.

Kemp, William H. (2005). *The Renewable Energy Handbook: A Guide to Rural Energy* Independence, Off-Grid and Sustainable Living. Ontario, Canada: Aztext Press.

A comprehensive look at all forms of renewable energy for the home. Contains a helpful assessment of energy conservation which allows one to live within the boundaries of off-the-grid energy. Good list of product suppliers.

McHenry, Paul Graham Jr. (1984). *Adobe and Rammed Earth Buildings: Design and* Construction**.** Arizona: The University of Arizona Press.

Gives technical and historical information on building with earth. Contains lots of pictures of earth structures around the world.

Paschich, Ed and Paula Hendricks. (1995). *The Tire House Book*. Santa Fe, New Mexico: Sunstone Press.

This book is written by a contractor who specializes in building homes with tires and adobe. Lots of photos, diagrams, and interviews with tire house owners. Also provides a discussion of studies pertaining to earthquake resistance in Earthships.

Reynolds, Michael E. (2000). *Comfort in Any Climate*. Taos, New Mexico: Solar Survival Press.

This book gives a concise overview of the Earthship concept as described in Volumes I, II, and III. The author owns the publishing company and offers building plans, workshops, books and videos for sale on the Biotecture web site.

Reynolds, Michael E. (1993). *Earthship, Volume I: How to Build Your Own*. Taos, New Mexico: Solar Survival Press.

Gives the philosophy behind the Earthship concept and instructions for building this totally self-sufficient home from discarded tires rammed with soil. Highly informative and thought provoking.

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Describes creating a cistern system in an Earthship and grey and blackwater systems.

Scott, Ray G. (1983). *The Underground Home: Answer Book*. Blue Ridge Summit, Pa.: Tab Books.

This book is written in a question and answer format and answers hundreds of questions pertaining to building and living in an underground home.

Other Books

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Another book with detailed information concerning energy alternatives. Has an extensive glossary and bibliography.

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In this volume structural evolutions to the Earthship concept are discussed along with how to make a thermal refrigerator, solar oven and toilet.

Rounds, Glen. (1995). *Sod Houses on the Great Plains*. New York: Holiday House.

Well illustrated children's book which gives a wonderful description of the building and use of a sod house on the Great Plains. The author was born in a sod house in South Dakota. Students may find this of interest before investigating straw bale.

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Describes how the phenomenon of global warming developed. A good companion to the documentary *An Inconvenient Truth*. Very readable and informative.

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Program about paper adobes, straw bale houses and Dennis Weaver's luxurious Colorado Earthship. Gives a good presentation of the building of an Earthship. This particular home is currently on the market for over three million dollars.

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Narrated by Al Gore. Excellent, everyone should see this. Explains the issues behind global warming in an interesting and easy to understand manner. There is a companion picture book, but the bulk of the information is in the video.

Internet

American Council for an Energy Efficient Economy. Retrieved 25 May 2007.

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Publishes guides comparing the energy efficiency of appliances. This is useful information if one is planning to generate their own electricity.

Building Circles Organization. Retrieved 29 June 2007.

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This organization creates affordable, sustainable, and nature-integrated homes. Plans are available on the web site.

Composting Toilets: The Environmental Solution. Sun-Mar. Retrieved 5 July 2007.

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Sun-Mar manufactures and sells composting toilets. Informative, with pictures and diagrams explaining the workings and advantages of compost toilets.

EarthenSun. Retrieved 5 July 2007.

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Gives information on building or ordering kits to make solar ovens.

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Extensive web site with lots of pictures. Gives information on seminars and internships, publications, and ongoing projects around the world.

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Information about energy efficiency and conservation ideas. This site also provides links to sites detailing green building plans developed by other large American cities.

YouTube. Retrieved 13 June 2007.

http://www.youtube.com/

There are numerous clips about *Earthships*, *wind turbines*, and *solar energy projects.* Rather than site them individually, it is easier to go to the home page and type in a category. Try *Angels Nest* for an incredible, energy efficient home. The topics are endless. I had no idea, until I started working on this unit, that there are so many educational clips on *YouTube*.

Endnotes

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48 William H. Kemp. (2005) *The Renewable Energy Handbook: A Guide to Rural*
Independence, Off-Grid and Sustainable Living, 50 - 150.

Implementing Texas State Standards

In this curriculum unit the following Texas Standards will be met:

- SCI.7.02 Make wise choices in the use and conservation of resources.
- SCI.7.1.03 Plan and implement investigative procedures.
- SCI.7.1.07 Construct graphs and charts using tools including computers to organize,
- examine, and evaluate data.
- SCI.6.3.03 Investigate and identify energy transformations occurring during the
- production of energy for human use such as heat energy to electrical energy.
- IPC.3.03 Analyze the efficiency of energy conversions that are responsible for the
- production of electricity.
- SCI.6.3.08 Research and describe energy types from their source to their use and
- determine if the type is renewable, non-renewable, or inexhaustible.
- IPC.3.02 Investigate the transference of heat through conduction and radiation.
- IPC.3.04 Investigate, compare and evaluate the economic impact of various energy
- sources such as rechargeable or disposable batteries, and solar cells.
- SCI.6.3.05 Describe how electricity is produced.
- SCI.7.4.03 Relate the relationship between the tilt of the Earth on its axis and the
- seasons.
- SCI.7.4.10 Identify ways in which various resources can be recycled and reused.
- SCI.7.4.11 Make inferences and draw conclusions about effects of human activities on
- Earth's resources.
- TEXH.7.20 Use problem-solving and decision-making skills to pose solutions to
- problems related to the use of resources and technological innovations,
- scientific discoveries, and the environment.
- ENG.110.23b.2B The students will analyze and use persuasive techniques.

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