The background of the cover features several thick, wavy yellow lines that curve from the top left towards the bottom right, set against a light yellow background.

Sharon Cornet

**DIY Solar Oven, Solar
Water Distillation, Passive
Solar Home Design, & No
HVAC Air Conditioning
Earth Tubes**

**Passive
Solar
Energy
House
Projects**

Passive Solar Energy House Projects:
DIY Solar Oven, Solar Water Distillation, Passive
Solar Home Design, & No HVAC Air Conditioning
Earth Tubes

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AUTHOR BIOGRAPHY



Sharon Cornet

My background in solar energy projects really started when I was flipping through the yellow pages one late summer day in El Paso, Texas at age 19. I came across the 'solar energy' section and happened to see the *El Paso Solar Energy Association* (EPSEA) listed there.

To my excitement, EPSEA (epsea.org), which was and is the longest running solar association in the United States, had monthly meetings with special speakers on various topics at the time, which was free to attend at UTEP (University of Texas at El Paso). I suddenly had exposure to people who had built steam cars, or solar room heaters out of used materials, learned how to make solar ovens for cooking food, built solar water distillers, made designs of solar homes, and heard how others built homes out of alternative construction materials such as adobe, rammed earth, rock, cob, or even log homes.

I was speedily asked to become a volunteer and later to join as one of the members on the Board of Directors. By the following year I was voted in as Secretary and also wrote articles on solar topics as I learned about them. I was to stay in that Secretarial position for

another two and a half years before moving away to Nebraska to build my own passive solar home.

Because corn and wheat fields were abundant, I decided to build indigenously with local materials—a straw bale house. I joined SBAN (Straw Bale Association of Nebraska) and became the Library Committee member. I signed up for *The Last Straw* Journal (excellent resource out of Colorado at thelaststraw.org) and learned everything I could about how to build a house out of bales.

The house was passive solar in design, and utilized mostly used/recycled materials. We built a composting toilet, had a greywater system, and made earthtubes for natural passive cooling.

By 1999 we sold the house and moved back to El Paso, Texas. I rejoined the Board of Directors for EPSEA and in 2001 was voted in as Vice-President, newsletter editor, and by 2001 was both the EPSEA President and Project Manager for two bi-national mini-grants (\$10,000 each) and a \$100,000 EPA (Environmental Protection Agency) grant to install solar water distillers in local and rural unincorporated communities (called “colonias,” which means colonies) along the US-Mexico border, including west Texas, southern New Mexico, and Mexico.

By 2002 I dropped the fancy titles and sat on the Board of Directors before phasing out of my non-profit endeavors, opting for selling small e-books and booklets on how-to topics. I went back to school at UTEP (University of Texas at El Paso) in 2004 for cultural anthropology. I also worked on grant writing and as the Organizing Assistant for the non-profit organization, *Border Interfaith* (borderinterfaith.org) where my community surveys and associated report (the Canutillo Water Project) helped the local colonia get city water due to their contaminated shallow wells.

In 2008 I transferred my studies to Ashford University, and in 2010 I graduated with a BA in Social Science, with an Anthropology specialization, followed with a move to the greater Seattle, Washington area. I have found that solar energy, alternative construction, and natural living have phased in and out of my life, but always seems to come back.

In 2012 I compiled my small six solar energy related e-books (how to make a solar distiller, solar oven, passive solar home design, intro to photovoltaic (PV) and wind energy, hurricane and tornado resistant homes, and earthtubes for cooling) into one single book and published it on Amazon and Kindle as *Passive Solar Energy House Projects: A How-To Guide*.

In 2019 I decided that the original book needed updating so I chose to pull out the most popular books (solar ovens, solar water distillers, passive solar homes, & air conditioning earth tubes) and so greatly expanded them here in version 2. I hope you enjoy it!

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HOW TO MAKE A SOLAR OVEN

DEDICATION

This book is dedicated to my one and only beautiful daughter Kira, for helping me with so many projects that have come and go throughout the years. I love you and hope you can share these fun projects with your own children one day.

INTRODUCTION

I have discovered that a lot of people are fascinated with solar ovens, also called solar cookers. When at solar events or energy fairs people come up to a booth I'm manning and get to watch the cookies bake in a solar oven, or get to burn their lips on a hot steaming chunk of hot dog or other snack that was baked in the sun. People go away impressed, and want to know how they are made so they can make one too.

If you are one of those people who enjoy using free and abundant energy to cook, participate in science fairs, or if you are more practical and prefer to keep the heat out of the house during summer by cooking outside, doing your part to not use fossil fuels or pollute the atmosphere just to eat, or simply saving on your utility bills, then this book is for you.

There are numerous do-it-yourselfers in the world, but sometimes it is actually the kids and their science fair projects that come up, which is also an excellent reason to make a solar oven. Solar cookers, whether a simple box style, or something more complex, are usually inexpensive and easy projects that you can make at home with just a few simple tools like scissors, a utility knife, aluminum tape, non-toxic school glue, etc.

People who go hiking and camping a lot tend to love solar ovens as well as solar camping showers, in particular. You can put your food in the solar oven in the morning, go hiking for a few hours, and when you come back your food is hot and ready to eat! Also, if you have a nearby stream you can use a solar oven to pasteurize water to kill worms, bacteria, and microorganisms. This is also why survivalist types are also drawn to making solar ovens, because they are versatile, and can help you cook and stay alive by decontaminating water when there is no other fuel sources available, especially in remote areas.

Those who live in a green or eco-friendly way, or just prefer a simple and frugal lifestyle also enjoy cooking with solar energy because it is generally inexpensive to make solar cookers, and free to

use once made (no fuel costs), no pollution, no waste, no worries. Bachelors also love solar cooking because it is very hard to burn food in a solar oven. Kids also love it for the same reason.

To everyone who has a copy of this book in their hands, whether you are a little kid or a big kid like me, I hope you enjoy this book!

WHAT IS A SOLAR OVEN?

A solar oven, also known as a solar cooker (*I will use these terms “oven” and “cooker” throughout this booklet interchangeably*), is usually an insulated box-shaped container that uses the sun’s energy to cook food. There are a number of versions, but I will go into those later. For now, I will keep it simple so you can learn the basics first.

People who hate to cook love solar ovens because they are so easy to use. Also, people who don’t know how to cook well—such as kids or some bachelors—or even people who don’t have time to cook a lot, such as campers who prefer to hike all day and come back to a hot meal (without having to cook it once they get back), enjoy using solar ovens because of the ease and simplicity and convenience they provide. You can leave the food to cook in the sun and not worry about scorching or burning it, which is a real plus. They also need very little water in the pot to steam or cook the food.

How Does It Work?

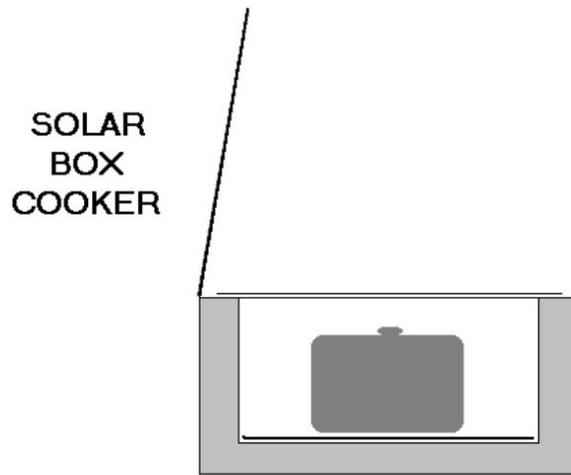
How a solar oven works is simple. Basically, the sun’s energy enters through the top of the oven (insulated box) by shining through a piece of horizontally or diagonally placed glass (or other clear item such as plastic or Plexiglas—thicker is better), or oven bags (cheap and can withstand higher temperatures than plastic wrap or other thin plastic), and heats up the inside of the oven, hot enough (150 degrees F minimum (66 ° C)) to cook the food safely and efficiently.

So the insulated box serves as the “oven” and has a piece of glass on top to allow the sun to shine in and heat it up inside. Temperatures inside the oven usually range between 180 degrees Fahrenheit (82 degrees Celsius) to 275 ° F (135 ° C) but can go over 400 ° F (204 ° C) in some manufactured models.

Almost anything you can cook in a regular gas or electric oven can be made in a solar oven, but since it works like a slow cooker (heating

the food at lower temperatures) it takes a little longer, so the food can take approximately 1 ½ to 2 times as long to cook, depending on the solar oven and the sun's intensity.

Please note that the low temperature setting on most electric crock-pots is only at about 160-170 degrees F (71-77 ° C) so if you compare cooking in a solar oven similar to cooking in a crock-pot then you already have the idea. However, some high-end solar ovens can reach temperatures of over 500 degrees F (260 ° C)!



I will cover the basic solar box oven next since that is the easiest to make and use, as well as probably being the least expensive. Plus the box ovens are great for kids' projects, such as for science fairs.

The Box Design

The design of the box is very important. It should always be *well insulated*, but NEVER use items such as fiberglass insulation (loose fibers may make the food harmful to consume), Styrofoam or other foam products, colored newspaper, or duct tape or other plastic tapes as these items can give off toxic fumes when heated up to the higher temperatures you'll find in a solar oven; this can make your food dangerous to eat.

Better items to use for insulation would be crumpled up black and white newspaper (excellent) or standard cardboard (also excellent). Both are recycled materials and can be gotten free if you look around. If you are in doubt of a particular insulating item you could possibly use then it is always best to be safe than sorry and eliminate any chances for a potential health hazard. Remember that if the insulation material you choose is on the inside of the box, or could gas off or particles could invade your food, then it is best to be safe and not risk health. However, if the interior of your box is completely sealed from the exterior or insulation area, and nothing could contaminate the space inside, then alternative or potentially "unsafe" (like fiberglass) exterior insulation could be utilized. I still do not recommend it, however.

For exterior insulation some people have used papercrete (cement mixed with cellulose, such as newspapers/magazines) that has been cured and they have found it to be a very lightweight and strong. It is an economical alternative to straight paper or cardboard, especially since it dries back out after it gets rained on, and becomes rock-hard again.

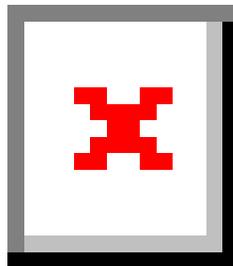
A standard solar oven box is usually about 10" high in the back and can be that high in the front as well (the "front" being the side that faces the sun... usually facing south if you live in the northern hemisphere of the world) but tends to work more efficiently if the front side is lower/shorter, so as not to create shadowing inside the box. Some boxes are longer (oblong) on the front and back sides, and some are simply square. The larger the box the better since more square feet equals more sunshine and more heat. Other cookers I

have seen include octagonal, round, or a host of other shapes. For simplicity, in this book, I will show you a design for a rectangular box, however it will have a lower/shorter front side (with sloped top) to allow more sunlight into the box.

Openings for Food Access

Some people add a removable/openable lid on top so the food can be set inside or taken out or checked on. Be sure to use hot pads as the pots/pans and food can burn you, as well as the heat which escapes out the top of the box when it is opened! Usually you will not want to open the box to check the food too often as solar oven-cooked does not typically require stirring, plus BE AWARE!... opening the oven causes most the heat to escape and it will have to reheat up all over again once you put the lid back on. It is better to leave it closed even though it might be tempting to open it.

Regarding the lid itself on the oven, sometimes the glass or plastic part is attached to the removable lid, and sometimes it is placed underneath a cover that just overlays the outer edges of the cooker. Keeping an openable lid cover is sometimes nice if it is propped up with a stick and string (to keep it taut or from moving in the wind) because you can glue aluminum foil (shiny side out) to the underside of the lid so that when it is propped open at a good angle, it can reflect extra sunlight down into the box through the glass/plastic top.



If you have an old toaster oven on hand that doesn't work anymore then the unit can possibly be altered and turned into a solar oven. The door itself can be used on either the backside of the solar oven to add or remove food (a side-opening door tends to lose heat less quickly than one that opens on top), or it can be utilized in the front (just be careful not to shadow the cooker too much when dealing with the food—plus having the glass in the front can help add solar gain to your cooker).

BOX MATERIALS

Some people make their solar ovens out of wood, metal, or other materials depending on their design criteria. For a permanent oven you may wish to use something other than cardboard or newspaper as these can wear out or get soggy if a sudden rain comes up, which can destroy your entire cooker.

On the other hand, cookers made out of recycled paper or cardboard are usually lighter, sometimes collapsible, and easier to transport if you like to take your solar oven with you on outings, school functions, or trips. The box-shaped ovens are handy in that you can store some of your non-refrigerated food items inside, put the lid on, and take the whole thing with you in the back of the vehicle when you go camping—kind of like a big picnic basket that stores everything inside that you need to make your meal(s). Make sure to stay away from using materials that may outgas or give off poisonous toxic fumes such as plastics. Plastics may also degrade and get brittle in the sun or from the heat.

Exterior Box Materials

This list of box materials is typically used on the exterior, but in some cases they can also be used on the interior of the box (a separate list of interior box materials will be covered later). Examples of box materials you can use include:

- 1) Cardboard (heavy duty or regular). The pros are that it is inexpensive or even free, lightweight, easy to manipulate and make the box. The cons are that it is not waterproof, and eventually bends or breaks down, although they can last for years if taken care of properly.
- 2) Wood (thinner is better). The pros are that wood can be fairly inexpensive (depending) or free if you find recycled wood, it will last for many years. Cons include that wood tends to be heavy, requires tools to cut, or it may have old lead paint on it (if the age is pre-1978 or so), which you would not want to be present in food contact areas such as the inside of the box.
- 3) Metal (aluminum, stainless steel, etc.). Pros are that sheet metal is generally lightweight, bendable in most cases, and can be cheap, recycled, or free. Cons are that some metals, like stainless steel (which is also less malleable than aluminum or regular sheet metal), can be more expensive. Also, it is debatable whether galvanized metal should be used as an interior-box material, but it is okay for use on the exterior of the box as long as the inside surface is sealed off with aluminum tape at the joints/seams. Also, always use protective gear (gloves/safety goggles) when cutting metals.
- 4) Plastic (exterior only). Pros are that this tends to be cheap or free if recycled, and may be cut more easily than metal or wood (usually a jigsaw will do the trick). Cons are that it can only be used on the exterior of the box since interior plastics would degrade quickly from the heat, plus gas off and possibly poison your food. Some might argue that food-grade plastic (or even silicone) that is heat resistant could be used on the inside, but I personally would not want to use these

and do not even cook in the microwave with plastics as I do not trust the dioxins or other molecule-exchange processes that occurs when different materials heat up that are in contact.

- 5) Glass (panes of glass, or objects made of glass). I am going to mix-up the pros and cons list on this one, because glass is versatile and a unique construction material in the case of solar ovens. I have seen some people use glass for 2-6 surface sides/top of the cookers, depending on the shape. If hexagonal or octagonal shaped boxes are utilized (similar to a round-ish shape cylinder style) then more than one of the sides being glass could allow more solar gain. Just be aware that glass is not insulated, plus restricts solar gain if sunlight hits it at an oblique angle, so if the surface is not 90 degrees (perpendicular) to the sun's rays then it can be losing heat (causing your cooker to cool down) rather than gaining heat. In my opinion it is simpler and more efficient to have one flat glass surface on the south-facing side of the box and just turn the cooker often to keep facing the sun (or use a tracker like some people do—I have also seen people set their solar box cooker on top of a swivel device or turntable and just turn it every 15-60 minutes). Also, concerning the use of glass on the top of the cooker, more than one angle can be utilized here; I have seen cookers with the top and front all glass, plus a 45-degree angled (diagonal) piece in between on the southerly facing side to allow more sun into the cooker. These tend to work well. Also, making the south-facing/glass side of the box wider than the back/north side also allows more sunlight into the box and creates less shadows, plus utilizes the open-angled sides to reflect more light onto the pots of food inside, which helps things heat up nicely.
- 6) An old toaster oven can also be modified; you will need a metal-cutting blade in a jigsaw or other power tool to make any cuts in the top for the glass—don't forget to wear protective gloves, and especially safety goggles because you do NOT want metal flecks flying into your eyes! Keep the

glass door as your south-facing side, make sure to pick an oven that is dark-colored inside (or sand it and paint it with black woodstove paint and let the fumes burn off BEFORE you ever use it), and be careful when cutting the top off. You will need to cover and seal any joints or exposed insulation away from the food area with perhaps cardboard and/or aluminum tape.

- 7) Hemp board or any other natural fiber board (especially if they are weather-proof). These, like wood, can be a boon to making a solar oven, depending on price and how easy it is to manage working with the material(s). Again, like any of the materials above, make sure food contact surfaces are protected, and that nothing used gasses off. Also be sure that it is not prone to warping or falling apart if it gets wet from rain or food.
- 8) Cement board (you need special blades on a circular saw to cut these, and be sure to wear a protective mask and safety goggles) is also a possibility. The pros on this are that it will last for many, many years, does not gas off (to my knowledge), can be painted or surfaced inside with any product that is food-safe, can hold the heat (thermal mass) once it warms up, and is good for a permanent type of cooker. The cons are that it can be somewhat expensive, takes special blades to cut, may be harder to fasten together (depending), is quite heavy, and takes a while to heat up the cooker, causing a lengthening of cooking time (you will want to set this cooker in the sun early to allow it time to heat up if using cement board on the inside of the box); this is a moot point if the cement board is only used on the exterior surface of the box.

Inside the Cooker

On the sides of the solar oven's interior you will need to add a reflective surface in order to bounce and reflect the sunlight around inside the box for better efficiency in cooking. This is especially true for the inside of the back and sides of the box. This is usually done by gluing several layers of aluminum foil or placing a lightweight reflective surface such as aluminum sheeting on the inside walls of the oven.

Aluminum sheets can usually be obtained for free, or for mere pennies, from any printer company (such as for newspapers) that tends to have tons of these sheets on hand as scrap or waste (other manufacturing places might also give some scrap metal away free). Leftover newspaper printing sheets have one side that will have printing on it, and the other side you can use as your clean reflective surface. The students at New Mexico State University (NMSU) created a box that had a large Plexiglas front at a 30-35 (approx.) degree angle that had a slightly conical interior with a flat bottom. They had to ruin a few aluminum sheets in the first prototype attempts, but eventually got a form and cutting method that worked well.



Prototype—if you look you can see the crumpled aluminum sheeting on the left where this one did not turn out as well as the NMSU students hoped.

A small but simple cabinet looped handle on the top made this cooker easy to carry around. I used one of these as a sample cooker for many solar fairs and events where we baked cookies for the general public to taste. Make sure not to cook directly on the aluminum sheeting as it may not be healthy to ingest food that has been in contact with non-food grade aluminum.



Solar Cooker

**built by NMSU students.
Cookies are baking inside, waiting to be eaten
by my son Jeremiah Eby-Martin, Earth Day 2001**

Interior Box Materials

Some of the best interior surface materials may include:

- 1) **Cardboard with aluminum foil** glued on (half water and half school glue mixed together and painted on, then the foil pressed on to dry). Heavy duty cardboards are stronger but may need to be scored with a utility knife before bending, but be careful not to cut it through. Use aluminum tape (only) for the interior of the box to keep the sides reflective and because regular tape will break down and fall apart plus could gas off.
- 2) **Aluminum sheeting** (sometimes these can be gotten from leftover newspaper printings).
- 3) **Stainless steel sheets** (though these may be tough to cut or bend, plus add weight)

On the bottom of the cooker you will also want to glue on aluminum foil or sheeting, and on top of that you will want to put a cookie sheet or flat metal pan painted black (use BBQ black spray paint and then let the oven “run” for a day to burn off the paint fumes before using the oven to cook food the first time) or else a seasoned or well used—or even a broken piece of—cast iron griddle in the bottom of the box. This serves as your heating plate for which you will place your pots and pans (full of food) on top.

Cast iron takes a little longer to absorb the heat from the sun, thereby making your initial preheating time a bit longer in your oven, but once going it retains the heat better in case you have to open the oven to check the food, or if the sun goes behind the clouds for brief periods. Cast iron also cooks more evenly than aluminum or cookie sheets do. I would like to recommend the cast iron as the primary bottom (cookie sheets are pretty standard though), and a long griddle available at many stores or cooking shops and an old one you already use is even better because it will already be black. Black cast iron (or any cast iron for that matter) will not, and should not have to be painted at all. TIP: Buy your bottom sheet before you make your

cooker so you can build the cooker around its size, otherwise it may not fit well.

A black or dark colored marble bottom is great for directly baking pizzas on, especially if you have a well-designed oven that gets very hot. I have never cooked a pizza in a solar oven as they usually are not hot enough (usually requiring 425 °F (218 °C), but a manufactured or superior design could easily do it.

Of course, since we are talking about the bottom of the cooker, we should also talk about the top. Covering the top of the box should be your glass, which allows sunlight into the box, but also is utilized to hold the heat inside as much as possible. Try not to let it leak air or let it open very often, if at all. Most people use either regular glass, Plexiglas, or even used car windows or similar recycled materials.

TYPES OF SOLAR OVENS

Now that you have a good foundation for what a solar oven is, and how they work, and how a basic solar cooker can be built, you are ready to expand your choices. There are many types and forms and styles of solar ovens out there in the world but most of them fall under three main types – direct gain, panel, or parabolic cookers, plus I will go into hybrid types.

Box Cookers

Direct gain “BOX” cookers are the most simple and easy to make, and often the cheapest style of oven to create. This involves the insulated box and a piece of glass to cover the cooker (allowing the heat in and keeping it from escaping, as you learned earlier).

The direct gain style cooker is the one we’ll be teaching you how to make next, complete with pictures from one I made recently as a display model at public functions. You can place food in these simple cookers and set it “ahead” of the sun, so that the sunlight can “catch up” and then pass it later on (much like the sun timer—I will cover this later) so there will be even cooking and less shading throughout the day.

These are the types of cookers that campers like to use, or kids, or bachelors (since they don’t burn the food), nor do they require much attention in order to cook the food. Temperatures are more constant and lower in these types of cookers, ranging from 160-325 ° F (71-163 ° C).

Panel Cookers

Think reflector panels! Panel cookers are basically a direct gain cooker with added Mylar, aluminum, or other shiny reflector panels all around the outside so as to reflect added sunlight into the cooker, therefore decreasing cooking time by increasing temperature by around 25-75 degrees F (14-41 ° C) on average. Chances are that if it has reflectors on it, it is probably a panel cooker, or a hybrid thereof.

Paabolic & Paraboloid Cookers

Parabolic cookers utilize a parabolic-shaped surface, and paraboloid “compound” cookers and are more complex in their design. They typically use fixed and perfectly angled mirrors or other shiny (Mylar or aluminum) rounded (concave/parabolic) surfaces/reflectors all aimed towards a central focus point so as to cook the food in an area that now has concentrated sunlight.

These cookers **MUST** be turned on a swivel pivot **OFTEN** (every few minutes) in order to keep up with the movement of the sun and keep the heat on the food/pot, otherwise the temperature will drop significantly and the oven will not work. Parabolic type ovens cook the food at much higher temperatures and also cook it much faster than traditional cookers. Some people put their parabolic ovens on solar trackers. Temperatures usually range from 200-500+ degrees F (93-260 ° C).

WARNING! Something important to note about parabolic ovens are to be careful where you put them, and how you store them. I had a friend in southern New Mexico who had a parabolic oven stored behind his shed. It fell over and the sun concentrated and burnt down his entire shed and its contents! Luckily his house was far enough away that it did not catch fire.

Hybrid Ovens

There are some very simple hybrid ovens that combine the direct gain system along with parabolic ideas in order to make the cooker more efficient.

Richard Wareham of the Sunstove Organization (now retired) developed just such a solar cooker. He had placed thousands of these cookers all over in developing countries to aid the people in cooking without costly fuel.

Mr. Wareham had some NMSU students build some of these, using the old printing aluminum sheets I mentioned earlier, so they could be distributed by the El Paso Solar Energy Association (www.epsea.org) to people in Colonias (poor rural unincorporated communities along the US/Mexico border where health issues abound) during their Solar Water Distillation Projects.



Cookies baking inside the panel-box (hybrid) oven

As Project Manager of these projects I put in many hours of teaching people how to use both the solar stills as well as the cookers. The southwest area of the country is now spotted with many of these hybrid type solar ovens, which have been a boon to many.

The Sunstove style of cooker (remember the picture earlier of my son Jeremiah?) uses the direct gain type of system with parabolic sides *inside* the cooker so as to reflect the light toward the pot/pan in the middle. All of the sides, therefore, are angled gently but not focused to a specific point (making it a modified paraboloid-panel-box cooker). This allows the sunlight to be distributed evenly within the cooker instead of shining on one small section that would otherwise make a “hot spot.”

Also, the front is lower and the back is higher, making the glass mounted at a tilt, for optimum solar gain and no shadowing. This is by far the most simple yet effective type of cooker I have ever used without getting too complex or expensive.



View from the back side of a paraboloid-panel cooker (the people are looking at a solar water distiller)

I displayed one of the Wareham-NMSU hybrid panel-box cookers at events such as solar fairs and energy fairs. My business, SunStar Solutions (www.sunstar-solutions.com) had a booth where we educated the public about solar ovens and other solar energy topics.



SunStar Solutions booth with solar oven baking cookies in foreground

CARDBOARD SOLAR OVENS

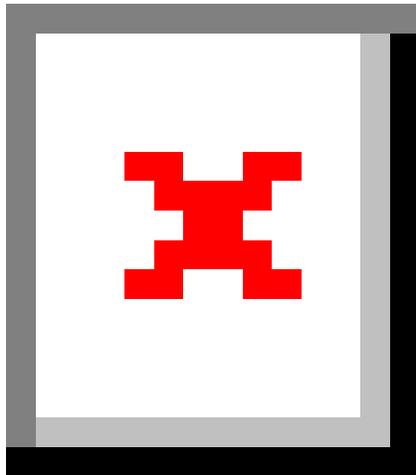
The Simple Box Cooker

By far, the most simply made direct gain solar cooker (with one possible foiled lid flap as a reflector) is the box-within-a-box type of oven, with insulation; this is also simply referred to as a true box cooker. Although it is the easiest it to make, it is also the least efficient in North America due to the high front, which can cast a shadow inside the box. However, it is very simple and cheap to build, and you can add reflectors to make it more efficient.

For a standard box oven the outer box should not be more than 10" high all around. Several long triangle-shaped "tubes" made out of cardboard (taped together so they keep their shape) are spaced evenly in the bottom for strength.

Wadded up black & white newspaper (small pieces wadded tightly is best) are then placed in the bottom between the triangle tubes. Center the second inner box on top of the triangles/insulation and then fill in the sides all around between the inner and outer boxes with more newspaper (I have heard one should not use colored newspaper as it could give off toxic fumes, at least while it is new).

Mix white school glue 50/50 with water and paint it on the inside walls, pressing aluminum foil flat against it. Cover the top with more cardboard and tape it in place. A foiled lid may also be made to serve as a reflector. Place a black painted cookie sheet in the bottom, an oven bag cut open, or glass, or Plexiglas can be used horizontally to allow the sunlight in and trap the heat. You are now ready to cook!



Cut-away view of box solar cooker

This solar oven is a simple box cooker with a detached reflector, made out of scrap boxes and cardboard, aluminum tape, scissors and a utility knife, school glue (50/50 with water) with paintbrush and a cup, extra-wide aluminum foil, leftover packing paper, a cooking pan, and since Plexiglas was not available I used a sheet of hard plastic that usually serves as a large fluorescent light fixture cover (not my favorite choice, but it will do in a pinch).

Visual Instructions for Simple Box Cooker

I have included below some pictures as a visual tool for those who like to see how the cookers are made. This version uses multiple layers of cardboard to insulate the sides rather than newspaper.



Fig 1 - Gather your materials



Fig 2 – Crushed paper inside the lid and taped in; this will insulate the bottom inside the box once it is wrapped with foil and set inside the box



Fig 3 – Back side

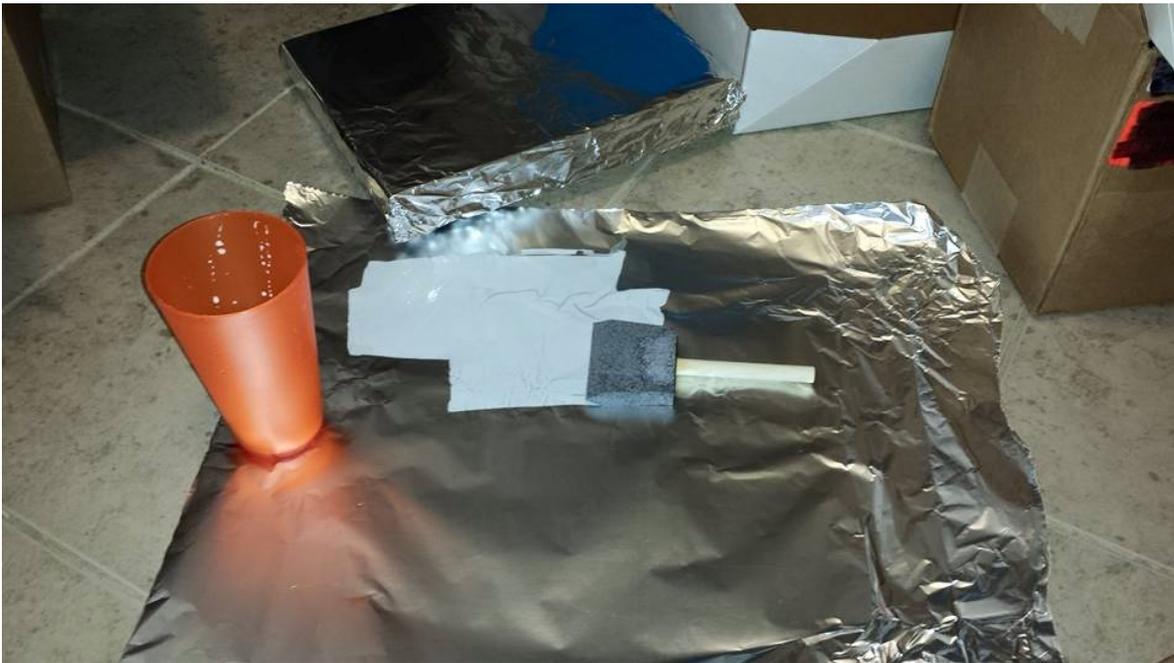


Fig 4 – Elmer's school glue mixed 50/50 with water in a cup or bowl, paint it on the aluminum so it will stick to the cardboard



Fig 5 – Wrap foil over box and press flat (repeat for multiple layers)



Fig 6 – Tape in reverse so it's sticky on the outside



Fig 7 – Stick the aluminum-covered (and insulated) lid to the bottom inside the box. This is just one version of many ways to make these...



Fig 8 – Double cardboard. Cover with aluminum foil next to make the inside of the cooker sides (1 of 4)



Fig 9 – Tape two layers of cardboard together



Fig 10 – Cover cardboard with aluminum foil and glue it on



Fig 11 – I inserted the foil-covered side on the right interior “wall” portion of the box



Fig 12 – Added an interior side to the left this time (2 of 4)



Fig 13 – This image shows all four interior sides done with aluminum foil. Notice between those and the exterior of the box is crammed with several layers of straight cardboard? That will act as insulation to keep the box hot when the sun shines in to heat it up later. Ideally this should be 2-3” thick on the sides



Fig 14 – Cut the flap so it will fold over in between the edge of

**the cardboard fill and the foiled
interior side sheet**



**Fig 15 – The left side is folded over to make a top to the
insulated side of the box cooker**



Fig 16 – Two sides done...



Fig 17 – Three sides done... I was playing around with the fourth one to try something new but I scratched the idea



Fig 18 – All four sides are done, but then I used aluminum tape (do NOT use anything but metal tape!) to reinforce the sides at the top



Fig 19 – Taped all around the top and inside all the seams within the box so it does not leak and appears seamless and "pretty"



Fig 20 – Be careful taping the inside seams... a bit tricky!



Fig 21 – I used this too-small lid and created a makeshift lid next...



Fig 22 – After fitting the lid so it is snug (keep slightly loose so it comes on and off easily, but you don't want it to leak air either) I added the plastic transparent "glass" (Plexiglas is best--I was forced to use a fluorescent light cover, which I cut with a utility knife and taped onto the lid)



Fig 23 – Top of my makeshift lid. This has one piece of plastic

"glass" on it, but I will add another one on top so it will be "double-paned" later



Fig 24 – An old pan inside will work well... black is BEST! This is what I had on hand



Fig 25 – Here's the pan that I cooked food in in the solar oven.

Don't open the cooker more than once every couple hours at most or the heat will be lost! This is a slow cooker.... it can go all day and should not burn. Just use a little extra bit of water in the pan if you have veggies, rice, etc.



Fig 26 – Late in the evening after cooking food in the solar box cooker (solar oven)... the reflector is the rest of the non-Plexiglas I had left over, covered with aluminum foil



Fig 27 – Dinner from a solar oven! The sun did all the work and kept the heat out of the house on this hot day! (95 F / 35 C plus humidity)

Please note that this cooker above was a small model version, mostly used for display at events, which I made specifically for that purpose, mostly to show how solar water pasteurization can be done. If you make this cooker be sure to make the bottom and (note that I will explain solar water pasteurization in a later chapter) the sides thick enough, packed with cardboard to at least 2-3" in width, or else it will not heat up or cook well. Also, the opening should be fairly large so as to allow enough sunlight in (perhaps 18"x18" or 18"x24" at the very least).

While cardboard is the easiest and probably the most versatile material to use, it is certainly not the only way to make them. Real sheets of aluminum (recycled from a newspaper printer) or even stainless steel have been utilized, as well as wood or cement board to make it more waterproof. There is no rule, but keeping it inexpensive helps the pocketbook, and keeping it lightweight keeps it transportable.

Some people desire a permanent structure they can use year after year without having to move it, so decide what you want and then

make a plan, collect your materials and go for it!

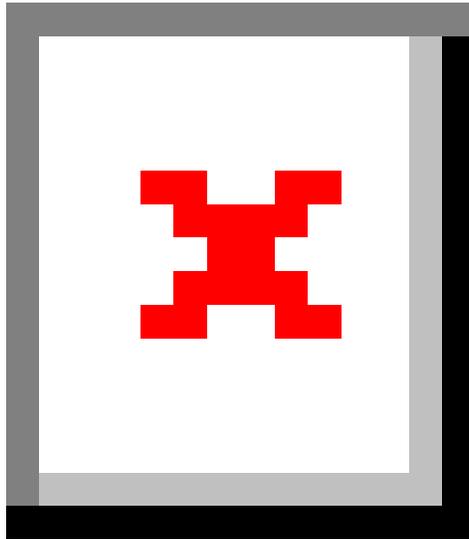
Panel-Box Cooker

This next oven is the one I have been leading up to. It is both simple and inexpensive to make and yet works very efficiently. With a one-piece aluminum foiled reflector set on top it becomes a panel-box hybrid type of solar oven. It utilizes cardboard pieces for the insulation, all glued together, so the walls of this cooker are still lightweight although stronger than one with newspaper as the insulation material. The front (south facing) wall is short and the back wall is higher so it has less shadowing inside the box.

The pan inside can be a cookie sheet painted black, an aluminum sheet painted black, or even aluminum foil painted black (use black poster paint as it doesn't give off fumes, or else use black BBQ spray paint and let the cooker "run" for a day before cooking in it to burn off any fumes).

In this case I prefer to use a well-seasoned or used cast iron flat griddle as they are easy to clean, cook evenly, plus hold the heat well, even though it takes a little longer to preheat the oven. Try to find your pan or griddle first and then get a box (or make a box) to fit it so there won't be wasted space and to make sure your pan will fit. **Important Note:** *Make sure the pan/griddle fits inside the box with about 2 ¼" to spare all the way around, and make sure your pot will fit as well.*

Plexiglas (thick) or an oversized oven cooking bag can be used as the glass. I tend to shy away from actual window glass in cookers because it is easy to break glass and cause an accident. For the same price Plexiglas is much better.



Side view of the panel solar cooker

STEP 1:

Once you have your griddle and right-sized box (width and length at least 2" wider/longer than your pan) then cut (if necessary) the back of the box down to 10" in height and the front side down to 6" in height.

STEP 2:

Take white school glue mixed half and half with water and set it aside. Use a 2" wide (or so) cheap paint brush to paint on the glue on the bottom of the inside of the box.

STEP 3:

Press down (over the glued bottom) a piece of cardboard equal to the size of the bottom of the box. Make sure there are no gaps. The piece, or pieces of cardboard should fit just right to evenly cover the entire bottom. Paint more glue on this upper piece of cardboard and then place a new piece(s) of cardboard on top again. Keep doing this until the entire bottom of the box has about 2-3" of cardboard on it.

STEP 4:

Repeat these same steps for gluing the cardboard to the front, back, and sides so they are all 2-3" thick as well. Make sure the angle of the top of each side is shaped right to hold on the "glass"... shave or trim this off, if necessary, with a utility knife to the shape shown in the picture above. The "glass" should fit flat on the upper surface of the cooker all the way to the top to the outer edges of the box.

STEP 5:

Put glue on bottom and sides and stick on heavy-duty aluminum foil all around (inside, and outside too if you like). Repeating this step several layers thick inside is best, but not absolutely necessary. Make sure aluminum covers the top edges of the cardboard insulation/walls as well (where the "glass" will lay onto because moisture may collect here). Finish off all inner edges/corners and the top edge with strips of aluminum tape (available at hardware stores for several dollars) to seal the corners and give added strength, if needed. This also protects the cardboard walls from moisture or condensation that could build up inside the oven.

STEP 6:

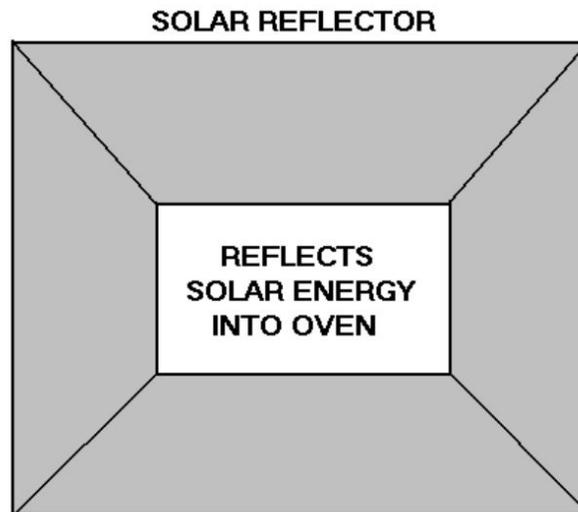
Place griddle/pan inside the cooker and put Plexiglas on top. A box lid with a window cut out in the middle may be made to fit over the glass to help hold it down and reduce leakage of inside air to the outside, and to keep the glass from sliding off.

Optional: Instead of Plexiglas you may also create a rectangular-shaped "ring" made out of three pieces of glued cardboard the same

width and length as the top part of the oven. Place the oven cooking bag around this ring, gluing it or taping it tightly in place with aluminum tape. You now have a double-paned “glass” which can withstand high temperatures, is food-grade, and will help hold in extra heat due to the air space in between the sheets of the bag. Don’t forget to make a lid as stated above on Step 6.

STEP 7:

Take several pieces of cardboard (one for each side of the cooker) and make a reflector, taped together with aluminum tape and then aluminum foil glued onto the inner surface of it to act as a one-piece (foldable and collapsible) reflector for the cooker. The top-back piece should be taller/higher than the lower-front piece. The reflector should be made to sit on top of the oven lid, or can be attached to the lid itself. Consider the angle of the sun to help determine what angles to cut the reflector panels at for optimum solar gain.



**Top view. Also see picture just before
STEP 1 for side view**

STEP 8:

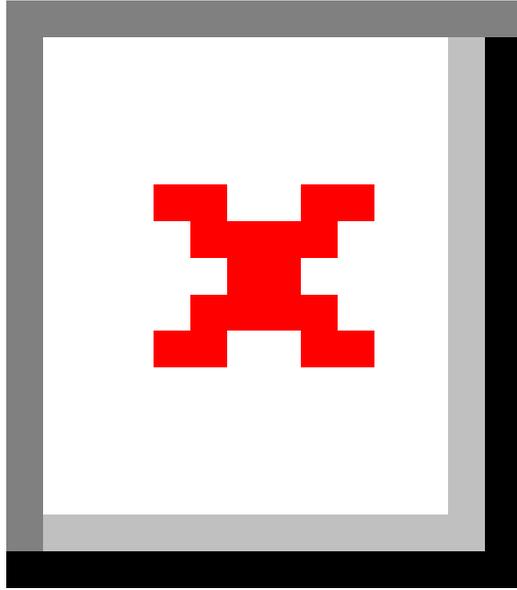
Place a pot of food on the griddle/pan in your cooker, place the “glass” on, then the lid and reflector and set in the sun. Use a sun

timer and an oven thermometer if you like. Once the food is done... enjoy!

Example of the Same Cardboard Oven (PICTURES)

I made this oven in the summer of 2013 when I hosted a “How to Build a Solar Oven” workshop in Sultan, Washington. Adults and I made this oven while the kids made Pringles can cookers (I will show you that and pizza box cookers next).

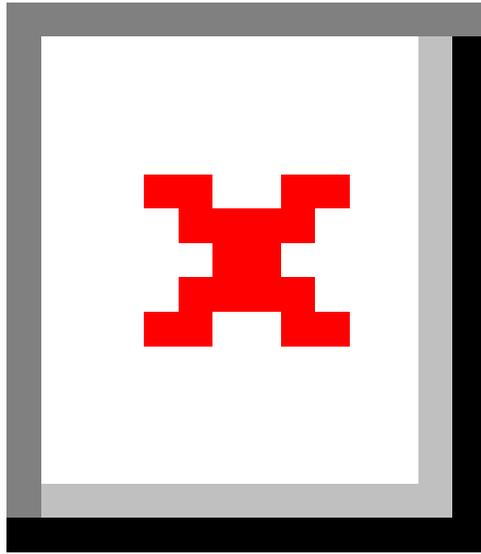
The picture below shows cardboard triangular tubes taped together with aluminum tape and placed into the large outer box to make a solid surface for the inner box that will be placed on top of them. This is done so that when a heavy pot of water or food is placed in the cooker it does not bow down or sag in the middle.



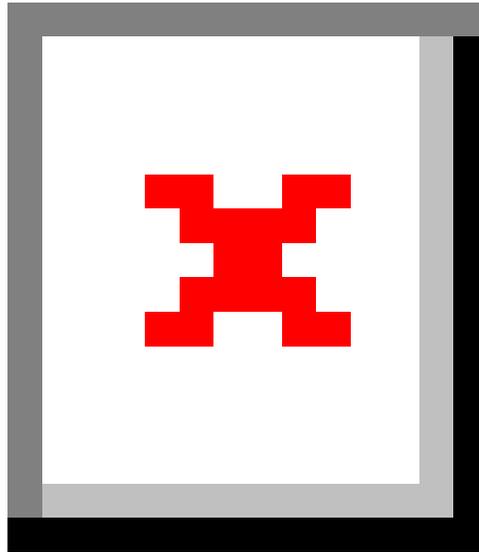
Next tightly wad up lots of newspaper around the triangle tubes to fill the bottom.



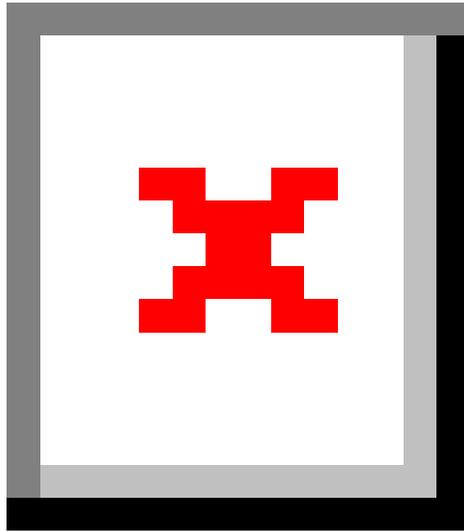
Add a smaller inner box, wrap the box flaps over and cut to fit. Do not tape shut yet as you are just sizing it all for now.



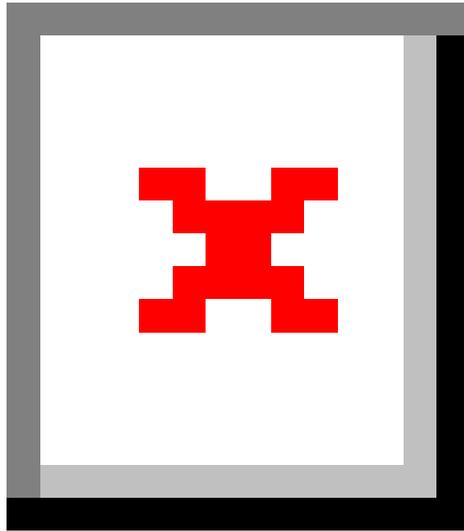
Another front view of the same step...



Fit the last flaps over as top edges. Cut only through half the depth of the cardboard (not all the way through) to make it easy to fold it over.



Make sure you fill the inside between the inner and outer boxes with more newspaper—pack it in firmly!



Lastly, tape it all together so it is solid and strong. **ONLY** use aluminum tape as plastic or other tapes not only gas off, but the glue will give out in time with the heat. Aluminum tape is made for HVAC ductwork so it will last through the heat and over time.



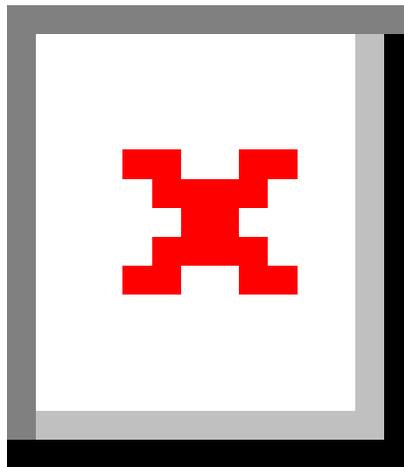
Just glue aluminum foil inside, add food, put on your windowed lid, and start cooking!

SOLAR COOKERS FOR KIDS

Two simple cookers, which younger kids love to make for science fairs, include the pizza box cooker and the Pringles can hot dog cooker.

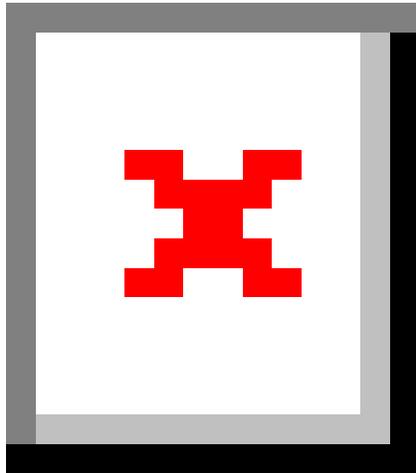
Pizza Box Cooker

For the pizza box cooker the lid is raised, foil attached all over the inside (including the lid), black paint or black construction paper placed inside on the bottom, and saran wrap over the top (to serve as glass, although an oven cooking bag is better and food-safe in the heat). This will warm a pizza but not “cook” it per se, but it is a lot of fun to do and to teach the basic principles of solar oven cooking to kids.

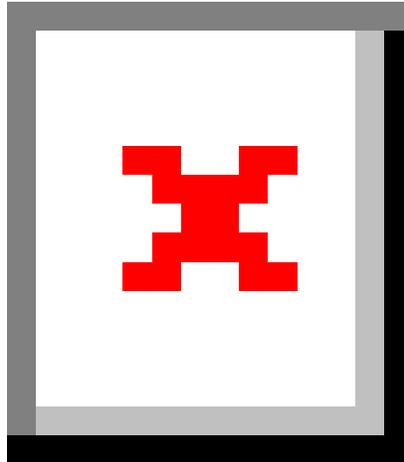


An oven bag will serve as the “glass”

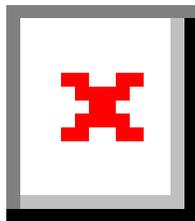
An extra-large oven cooking bag (turkey sized) can be used as “glass” for simple cookers. If you wrap it over the lid ring (only) it will keep the moisture away from the cardboard and serve as a “double paned” window.



Large tri-folded cardboard—add aluminum foil and you have a reflector!



**Solar pizza box cooker with a large reflector.
Pieces of hot dogs are cooking!**



**Pizza box
cooker made
by children at
Earth Day in
Deming, NM
2001**

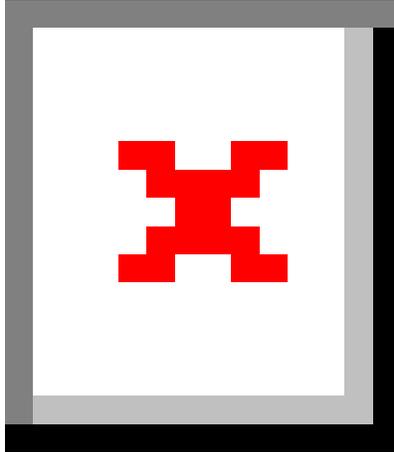
You can also make the pizza box cooker more efficient by using two large and one medium pizza boxes and insulating them... fill the first large pizza box with tightly packed balls of black-and-white

newspaper and seal it shut; this will be the insulated bottom. Place it underneath the second large pizza box (which you open up the lid on top). Then, on the third medium-sized box, cut off the lid. Then place the medium pizza box inside the second open box (center it and tape it down with aluminum tape) and pack more newspaper around the sides in between both boxes.

If you close the lid of the large top box you'll see you need to cut a hole to allow the sun to shine through to the medium box inside; only cut three sides so it can lift up and make a reflector flap on the back. Use an oven cooking bag or plastic wrap for "glass" and attach aluminum foil on the reflector flap. Now you have a much more efficient pizza box cooker!

Pringles Can Cooker

The Pringles can hot dog cooker is also very simple. Half of the side is cut out (keep the ends intact). Then a metal coat hanger (or simply use baling wire instead) straightened and burned clean over a flame and stuck through small holes made at both ends of the can (bottom and through the lid). Plastic wrap over the open side of the can, and a larger L-shaped reflector made out of cardboard and aluminum foil finish it off. Put the hot dog on the rod, place the can in the bend of the L-shaped reflector, face the sun and it will heat the hot dog in about 15 minutes. These cookers do not actually cook the food either as they are very small units with no insulation but it will warm the hot dog enough to eat. These are also very popular among kids and science fairs. It is important not to keep the food in these little make-shift cookers too long as the temperatures are not high enough to “cook” or kill bacteria growth.



Pringles can solar hot dog cooker

(Source: <http://p2.utep.edu/watts/projects/cook.cfm>)



Pringles can solar cookers with reflectors, placed on chairs—the advantage was the chairs held the reflectors up and kept the wind from blowing them down. Solar oven workshop I taught in Sultan, WA 2013

Materials for Pringles Solar Oven

To make a Pringles can cooker you just need a few things:

Empty Pringles can

Aluminum foil

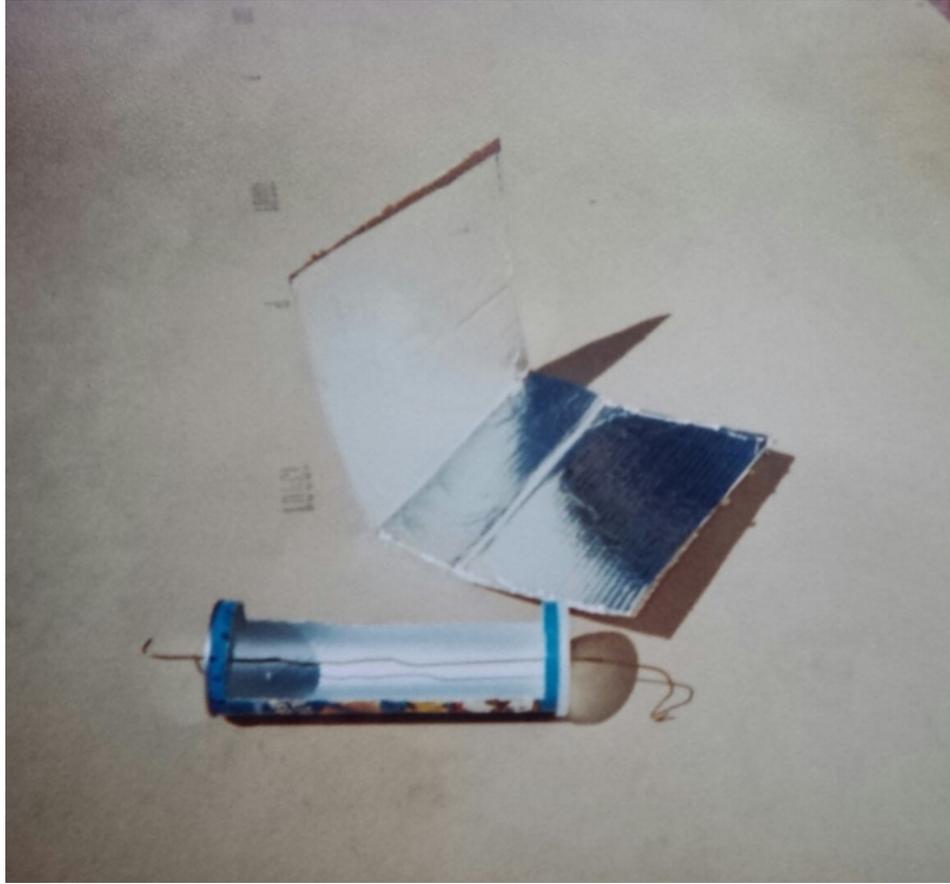
Glue stick (or school glue)

Utility knife

Metal coat hanger (available at some dollar stores) – make sure you burn off any plastic coating in a hot fire so you do not poison your food!



Materials for making a Pringles can cooker

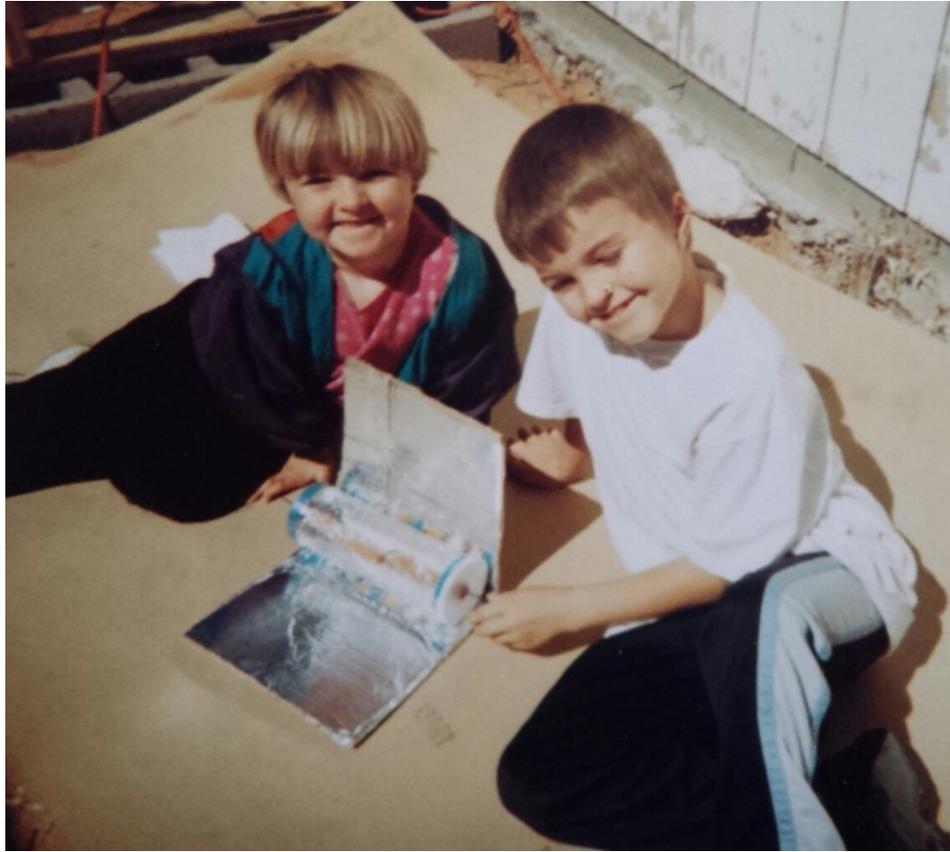


Finished cooker and reflector



My son Jeremiah putting hot dogs onto the rotisserie made from the metal clothes hanger





**My daughter Kira with Jeremiah
proudly displaying their cooked hot dogs**

Bernard Solar Panel Cooker

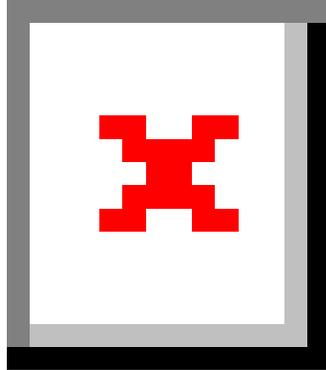
Probably the most SIMPLE & PORTABLE solar cooker known is the Bernard solar panel cooker which utilizes these few materials in which to make it:

Cardboard, scissors, ice pick, glue, aluminum foil, a large jar with lid, a large turkey-sized oven cooking bag, black poster paint, twist tie

Cut the cardboard into a T shape (as shown in the picture below), glue the foil to it and create the necessary bends in the cardboard so it will reflect as needed. Use the ice pick to poke a hole in the jar lid (this serves as a steam vent so pressure doesn't build up in the jar), paint the OUTSIDE (only) of the jar black and let dry.

Put food to be cooked inside jar, put on the vented lid and stick the whole thing inside the oven cooking bag (blow up the bag with air and twist tie it shut). Set jar in bag on the reflector. Tabs may be kept on the upright side panels of the reflector so rocks or something heavy can weight it down so the wind doesn't blow it down.

Aim it all towards the sun, keep watch on it, turning it towards the sun if necessary and soon your food will be ready to eat!



Steve Cook at the Energy Center of the University of Texas at El Paso with “Bernard solar panel cooker”

Another form of a Bernard cooker is this one, displayed by Steve Webster at The Grove in Newton, BC on July 18, 2015 where a film crew was filming the movie “The Secret of Change”, which is a UK documentary series that discovers and explores communities along the west coast of Canada and America that are involved in grassroots efforts for changes related to the tools/methods/framework called Transition (the Transition movement). I was at this event and was one of the many people interviewed, but we will see which edits are made and what makes the cut in the end.



Bernard style panel cooker (wrap an oven cooking bag around the black-painted jar to make it more efficient!)

PARABOLIC/PARABOLOID COOKERS

Where the simplest solar oven is the true box cooker with glass laid flat on top, probably the most difficult to make or complex solar cooker is the parabolic cooker, which I will briefly explain next.

The Parabolic Cooker

Parabolic cookers use simple curves (its cross section is a parabola so they require extremely accurate angles), while paraboloidal cookers use compound curves (sometimes made using many small mirrored or reflective surfaces, also very precisely angled but in wider, flatter sections).

An example of a *parabolic surface* is an old round TV satellite dish that is completely smooth. An example of a *paraboloid surface* is an umbrella with the rounded pie-shaped or wedge-shaped sections.

Kits or parabola charts for either can usually be found on the Internet (a simple Google search will find you a ton of information and pictures, none of which I want to reproduce here), which I highly recommend since these tend to be complicated and are more for advanced solar cooker builders. There are numerous types and sizes of cookers, and all with varying efficiencies in temperature capabilities.

People have actually used satellite dishes and umbrellas, which they resurfaced by adding mylar or aluminum tape/foil, or similar reflective materials to make these types of solar cookers. Others have used materials to make a parabolic reflector or reflector dish or elongated trough. The Pringles can cooker is actually a simplistic version of a trough cooker to heat up the hot dogs.

As a side note, people have even gone so far as to scoop out a rounded parabolic shape into the snow during winter and use the surface to reflect light toward the center where they have melted snow in freezing temperatures, mostly for drinking water or such, but not really for cooking.

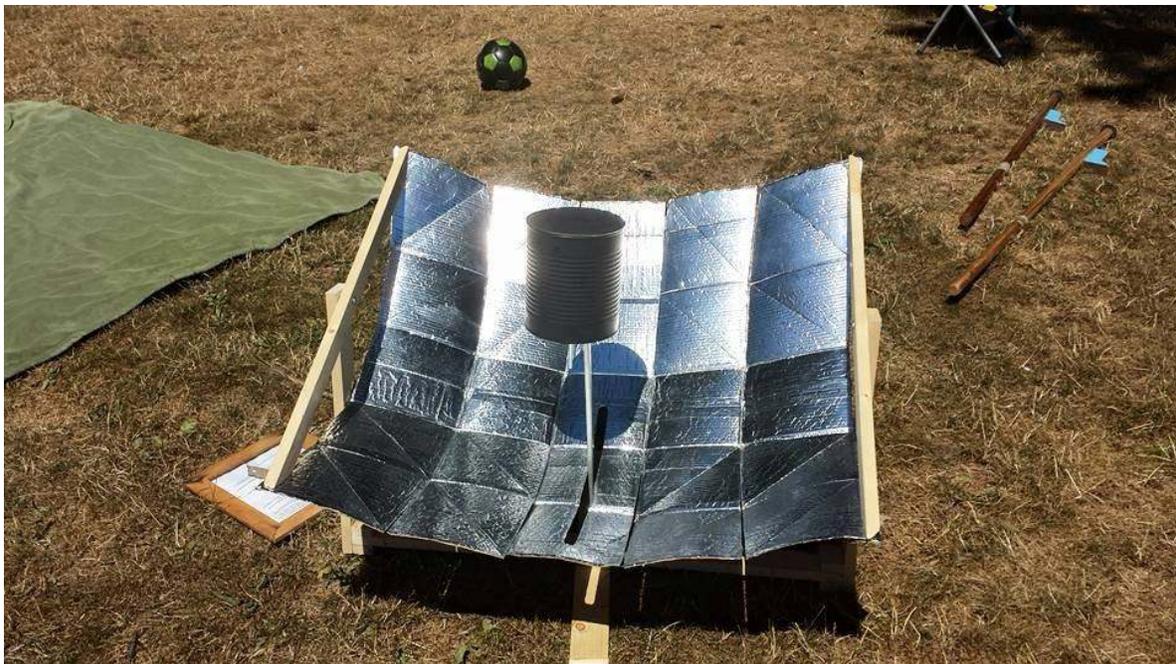


Parabolic/Paraboloid solar cooker
(photo source: Wikipedia)

Below is a picture of a gentler version of a parabolic/paraboloidal cooker, which was displayed in Surrey, BC. This is a “loose” parabolic reflector, designed out of cardboard with aluminum foil glued onto the surface of each of the cardboard reflector pads, which hang on the wooden frame and all point or reflect light toward the center black-painted coffee can (on a small post) in the middle. The can is mounted firmly, but the metal lid is openable (use hot pads as this gets VERY HOT!). Inside is placed a jar (with a small vent hole poked into the lid) or very small pot of food.

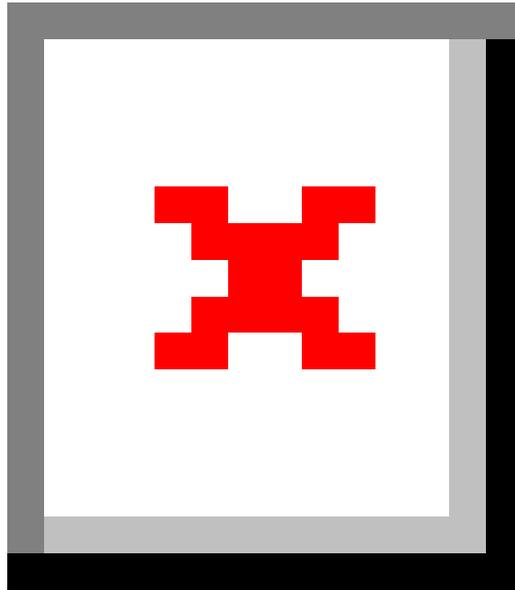
The angle of each of the parabolic reflector pads is extremely important so that it shines onto the can, and the whole contraption needs to be moved fairly frequently to make sure the sun continues to shine on it... as the sun moves the light source will go off the can making it cool down rather quickly so you have to keep watch on this type of cooker!

I personally recommend buying a kit or already-made parabolic cooker because they can be complicated to make, unless you like a challenge! I have no plans for them here but they can be found readily on the Internet.



Parabolic style solar oven displayed by Steve Webster of the Village Surrey Transition Initiative

Although this next one is considered a parabolic cooker, I think it is technically a panel cooker (like the Bernard cooker), but it uses nothing but a windshield shade to make this solar funnel cooker. One could argue that it is a parabolic/paraboloid cooker as well.



Windshield shade solar funnel cooker
(photo source: Wikipedia)

As parabolic styles go (or panel cookers for that matter), you can't get much simpler than that! I still say that placing a turkey-sized oven cooking bag around a black-colored thin-walled pot with a tight fitting lid heats things up a little faster.

Now that you have a solar oven here are a few tips and then some recipes that you can try out...

TIPS FOR YOUR SOLAR OVEN

Here are some tips for your solar oven, regardless of which one you make. Some of these tips may work better with certain types of ovens or cookers than others.

Difference Between Oven and Cooker

First of all, is there a difference between an “oven” and a “cooker” for solar cooking? Well, and this is solely for your information... although these terms are actually most often used interchangeably, it is generally called an “oven” if you put the food inside the insulated walls of the box, similar to a regular kitchen oven. Also, it is generally referred to as a “cooker” if it, like the parabolic or panel cooker, does not have an actual box-body to place food in, but rather some alternative method... but again, these ‘rules’ are pretty loose and I have heard experts over the years refer to them as either/or on a continual basis.

Build Based on Where You Live

If you live on or near the equator the sun in summer will be straight above you, so a simple box cooker would be perfect. If you live in latitudes that are further away from the equator, such as North America or Europe, then you may want a sloped top-front glass since the sun will be coming in from a side angle rather than straight over your head. This can affect the efficiency of the cooker. Consider materials that are local and inexpensive, including recycled materials. This keeps cost down and keeps it easy. If you live in hot or equatorial latitudes you will probably need less insulation and less cubic feet

inside your oven (or less reflector panels) than in areas that get cooler temperatures.

Best Type of Panel Reflectors

Generally the best type of reflector panels are made from super shiny material that is rigid, well-mounted, extra-large in size, and is splayed out like an array, similar in shape to a parabolic cooker, except that the panels are usually placed on a box cooker and therefore referred to as a 'panel cooker'.



My good friend Chuck Reel—the original Reel solar guy—with a panel cooker (this oven gets hot!)

The box cookers are easier than parabolic cookers to make, yet they have a similar open and wider-at-the-top funnel shape that bounces the light around into the box. When you add more light, you automatically add more heat. Heat is what you want! In the picture above, and of all the cookers that I saw Chuck Reel use at the solar

events we attended, this one—outside of a parabolic cooker—was often the hottest and could get up to as high as 375-400 or so degrees F (191-204 ° C), as I recall.

If you make a box-panel combo cooker, be sure to increase the panel size if your box opening is smaller than 18"x18" (18"x 24" is best). A large opening in the box allows more sunshine in, and larger reflectors make up for smaller box openings by adding additional heat.

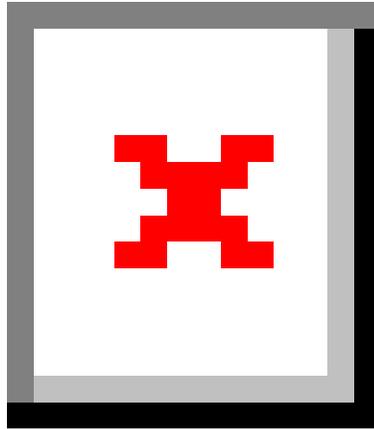
Some people also use mirrors or other mirror-like surfaces for reflecting light but they tend to be heavy and are better for permanent structures. If you do use mirrors then you may want to build the box body out of something that is made of solid materials such as wood, so it can be strong or the lid folded closed to protect the mirror(s) from getting broken or the wind causing it to fall over.

Easy Pivot for Turning Your Oven

If you choose to place your solar oven on a pivoting or swivel chair then you can turn it easy, or you can just set it on the ground (keep dogs or other animals away from it). I would recommend finding a way to stop the random pivoting of the chair or turntable (i.e. "Lazy Susan") in case a gusty day ensues as the wind may turn your cooker away from the sun, instead of towards it.

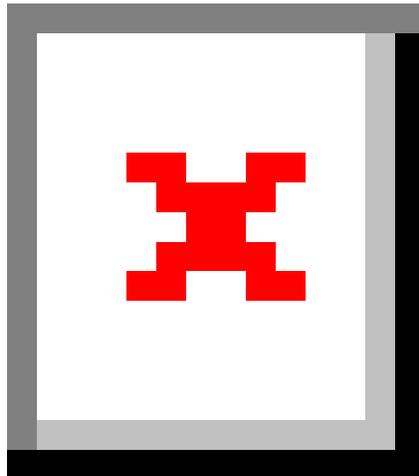
Make a Timing Dowel

An option for timing the cooking of your food (especially when you are out camping or don't have a watch or clock available to check the time) is an hourly **timing dowel**. If you place a small piece of a skinny wooden dowel into the top of the cooker (vertically) then the dowel will cast a shadow. The shadow produced, not unlike a sundial, will move as the sun tracks through the sky.



Hourly timing dowel causing a shadow

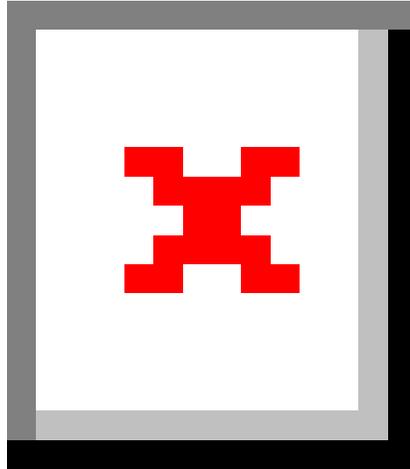
Make a mark on a piece of paper or cardboard where the shadow is at noon, and then where it falls in one hour, two hours, three and four hours, etc., without moving the cooker dowel. Once done then lines drawn the same distance in the other direction (the other side of the dowel) will also show the hourly progression.



Sample sun timer (not to scale)

Although this is a seemingly simplistic or archaic way of timing the cooking of your food, it is extremely easy and very worthwhile in the long run. Just make sure to mount your timing dowel (also called a “timer” or “sun timer”) to a permanent place on the front or back top edge of your cooker so it will not move.

Using ink or paint that does not fade easily, and getting it laminated against the weather might also help make it last longer. You could also make it out of wood and engrave it or paint the inside of the engraved areas black so you can see it easily and still remain fairly weatherproof.



Placing your dowel timer on the solar oven

What Can You Cook in a Solar Oven?

The foods you can cook or bake in a solar cooker are almost unlimited. The general rule of thumb is that you can cook in a solar oven whatever you can cook in a regular oven, except that it will just take a little bit longer. Usually the length of cooking time is about 1 ½ to 2 times that of a standard oven.

You may need to preheat your oven by setting it out in the sun about 30 minutes before you start cooking. Rice dishes and soups or stews do particularly well. Having a lot of food requires a lot of extra heating time just to warm the food up before it starts cooking, so keep that in mind before trying to do an entire roast complete with potatoes and vegetables that are cold straight out of the refrigerator. Cutting things into smaller bites also helps the cooking process along.

Tips for Cooking

Pots and Pans

Make sure to use black pots with tight fitting lids. Black is best because the dark color absorbs more of the heat and does not reflect it back out. Thick metal pots/pans take a little longer to heat up than do thinner metal pots and pans.

Many people prefer to use corning ware or Pyrex except that you may wish to place aluminum foil (although this may bounce some of the sunlight back off the pot, lengthening cooking time) or some other solid but flexible material on the outside of the lids to keep the sunlight off the food so it doesn't bleach out the color of the food. Some people cook in jars painted black on the outside (only—you do not want paint to touch your food!). Vegetables tend to fade quickly when they are cooked in the sun if not covered with something opaque. My favorite pots are those old fashioned thin-walled black camping pots with the speckles on them.

Vegetables

The nice thing about solar cookers is that it is almost like steaming your vegetables, as they need very little or no water in the pot. Too much water creates extra mass in the pot which has to heat up, and then can leach out the nutrients in the vegetables, much like boiling does. It is better to cook the vegetables themselves with the heat the oven provides rather than take extra time heating up water. Place harder-to-cook items (carrots, cut potatoes, parsnips, cabbage, cauliflower, etc.) in the oven first, and add vegetables which are more easily cooked (such as greens, asparagus, green peas, etc.) later on.

Potatoes

You can bake potatoes by placing them in foil, or putting them directly on the bottom of the oven, however large potatoes tend to take quite a while to cook. It might be better to either bake smaller sized potatoes or else cut the potatoes into wedges or smaller pieces and stick them in a pot with a tiny bit of water so they'll cook faster.

This goes for all kinds of brown, white, red, purple potatoes, and yellow yams or orange sweet potatoes.

Meat

All kinds of meats do well in solar ovens. You can roast a chicken or pieces of chicken for a casserole and I have even seen some people do their entire Thanksgiving turkey in a solar oven but it takes most of the day to do so, even with a higher-temperature oven. Roasts, stews, chili, and other meats you would let sit in a crock pot or just simply bake in your regular oven will do nicely in your solar cooker. Hot dogs only take about 15 minutes to heat up and no water is needed. You can even warm the buns for the hotdogs by setting the entire bun package in the cooker for about 5 minutes.

Breads

Breads and rolls can be heated, warmed, or even baked, although the breads tend to not brown as nicely in lower temperatures as they would in a regular oven. Some people baste on egg white or butter or oil on top to help it brown, even if only a little bit. Bread seems to do best in 1-pound dark coffee cans, or even a Dutch Oven (although the latter takes much longer to heat up). Keep the reflector off for raising the bread, and put it on for baking. For pizzas and pies, bake the crust first. Cornbread and muffins usually do well in a solar oven.

Beans

Dry beans may be cooked but we recommend soaking them overnight first and putting warm/hot tap or filtered water in the beans the next morning before placing it in the cooker to give it an extra boost and reduce cooking time by an hour or two. It may still take several hours or all day to finish cooking the beans as they are probably the hardest thing to cook in a solar oven; however, they are also one of the most popular items to cook. We went to a lady's house one time, at noon, and she had cooked split pea soup that morning for us in her solar cooker... it was delicious! I include that same recipe at the end of this chapter for you.

Miscellaneous

Cookies (a favorite) and other desserts such as cinnamon rolls do quite excellently, as do melting cheddar cheese on nachos, etc. Cakes and brownies do fairly well although cakes can sometimes come out a bit crumbly if the recipe is not adequate for slow cooking... but they still taste wonderful!

Drying foods

Like other vegetables you will need to keep the sun off of foods in order to dry them. It is important when drying foods to make sure that you have a good book on hand, or already have some knowledge about how to dry food. You will want to keep the lid/glass of the cooker cracked open so that the majority of the heat and moisture can escape, otherwise you will find that the food you place on your racks will COOK instead of dry out. You definitely do not want this to happen. Depending on the amount of sunlight, moisture conditions, how hot your cooker gets, etc. will determine how much you need to crack or open the lid/glass. You may also want to utilize a black cloth or shield to cover any food exposed to the sun so it does not bleach out or cook or over-dry.

Solar Water Pasteurization

In many developing countries solar cookers are not only used to replace expensive gas/propane/butane, electric (if available), or scrounging for firewood so they can cook their food, but solar ovens are also used to pasteurize water. If you are in an area where the quality of the water is in doubt then you may be able to pasteurize your water in your solar cooker; this is an alternative to boiling water. Here is how it is done...

Take a CLEAR GLASS jar or jug and place the water in it. This can also be water from a clear running stream if you are camping. Set the container in the preheated solar cooker in full sun. Make sure the water is not shaded as the Ultraviolet (UV) in the sunlight will kill off 99.9% of all bacteria and micro-organisms within 90 minutes (in FULL sunlight, otherwise leave it up to a few hours), plus once the temperature reaches 131 to 149 degrees F (55-65 ° C), then anything else left behind will automatically be killed off within a short time.

This process of solar pasteurizing water works great for contaminated water that has fecal coliform bacteria (a main cause of cholera and diarrhea in developing countries) or that has microorganisms such as giardia (commonly found in water) or cryptosporidium (often found in lakes or ponds).

Temperatures needed to pasteurize for these:
Microorganisms: 131°F (55°C) – Worms or protozoa cysts (cryptosporidium, entamoeba, giardia)
Bacteria: 140°F (60°C) – V. cholerae (or fecal coliform), E. coli, shigella, Salmonella typhi, rotavirus
Virus: 149°F (65°C) – Hepatitis A virus



It is important to note, just to caution you, that pasteurization of water does NOT remove solids such as sand, sediment, rust, nor does it remove minerals, arsenic, fluoride, chlorine, volatiles (like gasoline, kerosene, pesticides/herbicides), chemicals, or heavy metals. You would need a solar water distiller for that, or you could rig one up (if you have the know-how) to use the cooker as a water heater/pre-heater prior to distillation. I have a book on how to make a solar water distiller as well.

Recipe Ideas

These three recipes are some tried and true meals for using in your solar oven. Thanks to Peggy Chinkes for these!

Baked 3-Bean Casserole for Sun Oven

3 cans 16-ounce ea. of canned assorted beans, such as kidney, pinto, and pork & beans with salty packing liquid rinsed off. For one of the three, I like the pintos with jalapeños.

1/2 cup chopped onion
1-1/3 cup brown sugar
1-1/3 cup catsup
1 Tb. dry mustard powder
2 Tb. cider vinegar

Mix together in oven proof dish and bake until bubbly and onions are done.

Split Pea Soup à la Sun Oven

- 1 16 ounce bag of split peas
- 1 cup chopped carrots
- 1 cup chopped onions
- Red pepper flakes and/or Tabasco to taste

Combine all of above ingredients in oven-proof casserole with oven proof lid. Peas will soak up water while cooking. Keep covering them with water. Cook in sun oven for several hours or until desired degree of thickness. Keep stirring to mix veggies. It's often better when cooked a second day. When it tastes done, puree further by mashing contents with a hand-held potato masher or puree with a food processor. Chunks of cooked ham, salami, or Bacos may be added. Refrigerate leftover amount and add milk or more water to serve after it has congealed overnight.

Makes 6 servings.

Sun Oven Baked Rice

1 cup natural grain rice

1-1/2 cups of water or bouillon

8 X 8 inch Corning or Pyrex dish with oven proof lid

Mix rice with water, cover, and bake in oven at 250 degrees F (121 °C) for approx. 1 or 1-1/2 hrs. When done, fluff up with spatula. This method will not boil over as is often the case with rice cooked on a stove top. For Spanish rice variation, add ½ cup salsa to 1 cup of water or bouillon.

Serves 2.



Cooking hot dogs with toothpicks for passersby to taste at a solar energy fair. Photo courtesy of Chuck Reel

Notice the cookers in the picture above... the one on the right is a standard box cooker with all sides the same height. Do you see the shadow in the box covering 2/3rds of the food? Obviously this solar oven was being used at a higher latitude than the equator. A more efficient cooker would be to angle the glass and have the front edge (facing the sun) at about 6" height instead of 10" height.

Regarding the cooker on the left, notice the reflector is actually a mirror rather than aluminum foil? The lid is made of wood and held up by a strong dowel instead of a stick and string like the box cooker on the right. Additionally, the wooden box cooker on the left looks like it is made out of a drawer (thinner insulation too) and even has a handle on it, so when you close it up and latch it you can simply pick it up

and carry it anywhere easily. This oven also has a lower profile on the sidewalls, so less shadowing of the food is occurring here. Both solar ovens have thermometers inside to check how the temperature is heating up for cooking efficiency; these only cost a few dollars and can usually be bought at your grocery store or a kitchen shop.

I hope you have enjoyed this book on how to make a solar oven. There are so many resources on the Internet for other versions of cookers and solar ovens as well, so I recommend utilizing that free resource for your benefit.

Just to recap, solar ovens help reduce our dependency on fuel or electricity to cook, keeps the heat out of the house during summer, and solar energy is free and abundant! They are excellent for children or adults who do not like or know how to cook, plus are excellent for campers and survival-minded or frugal folks as well. Pretty much anyone can make and enjoy a solar oven—and you will enjoy the food you cook in it even more!

Have fun cooking with the sun!!!

HOW TO DESIGN A SOLAR WATER DISTILLER

DEDICATION

Dedicated to my oldest son Tyler for always being able and ready to help me install solar stills in the field in west TX, NM, and Mexico. So many times you have been there for me, to help me, including in the rehab real estate project in WA. Thank you. I love you son.

INTRODUCTION

By far the most popular topic I have ever written about has been that of the solar water distiller. Solar stills are in demand, I believe, because they represent the concept of PURE WATER to people, which is something that our society—even in developed nations—lack many times. City water is full of chlorine and sometimes fluoride (or other toxins) even though it is considered safer than in developing nations.

WATER IS LIFE, no doubt about it. Without water we feel quickly fatigued, and it even affects our ability to concentrate, and if dehydrated severely can cause health problems, including with our kidneys and other organ functions.

I am amazed at how many people in America do not drink water—*any* water—and only consume carbonated beverages, artificially flavored drinks, coffee, black tea, cow's milk that is full of hormones and other nasties, energy drinks or other sweetened drinks, when water is not only free or inexpensive (unless you buy it bottled), but FAR better for our bodies and health. We are a nation full of diabetics and cancer-ridden people, in part, because of toxins in our environment and food supply, but also our water, lest we not overlook that fact.

I happen to love water, and having come from the desert growing up—where water tastes saline and is full of hard minerals—I can say that having a distiller on hand, which can produce FREE purified water *without the need for filters or pumps or electricity*, sure comes in handy. This makes the initial cost, in comparison to those ongoing expenses with other purification systems, basically pay for itself in a relatively short period of time. It only costs a few hundred dollars (or less in some cases) to build a solar still, or several hundred if you wish to purchase a professionally made distiller, but over the coming years having one will pay for itself likely several times over.

So is it about health for you? Or is it about saving money? Or could it be that where you live has little to no potable water? Maybe your water just tastes or looks or smells bad? Perhaps there is a

medical purpose that you need to attend to? There could be a million other reasons to build a solar water distiller, and I will cover many of the problems and the solutions (a solar distiller of one kind or another) here in this book.

I do hope you enjoy my story and can find value in my experiences designing, building, teaching, and using solar distillers, and please check my website for updates on free ebooks on other solar energy and miscellaneous topics at: www.sunstar-solutions.com

SOLAR DISTILLER BASICS

The first question usually posed to me is, “What is a solar distiller?” or, “What is a solar still?” (note that I will use the words “distiller” and “still” interchangeably throughout this book) or, “How does it work?” or even, “Where do I place it?” I will answer these questions next...

What is a Solar Distiller/Still?

A solar water distiller or “solar still” is basically a simple, waterproof, insulated “box” with a piece of glass on top that uses the sun’s energy to purify water through the process of evaporation and condensation—just like how rain is made (the hydrologic cycle). You then collect the condensate and use it for cooking or drinking or other purposes.

That is the simple version, but you will see as we move forward in this book that although this is a simple process, it is also a very powerful process because it not only completely decontaminates/purifies bad water, but it also does so without the use of electricity or the need for city water (meaning water pressure).

How Does it Work?

To use a solar distiller your source water is placed inside, then the sun's rays heats the water and distills it passively. Solar water distillation that is "passive" means it has no moving parts, and uses no electricity whatsoever.

The purified or distilled water (called "product water") is then rendered safe for drinking and cooking, with absolutely no contaminants that are found in regular (potable or non-potable) water.

Raw sewage has been placed into these distillers as a test, yet pure and absolutely clean water is distilled as the final product (yes, confirmed by tests at a laboratory). Sound gross? It may, but it works! Bacteria and microorganisms simply cannot survive the distillation process, and everything (solids, chlorine, etc.) in the water is all left behind.

"Pure" water is the most clean water you can find on the planet, which means it is devoid of all contaminants, whether particulate or solid, microbial (bacteria or microorganisms or virus), or chemical. The only known exception are volatiles (like kerosene or gasoline), which can survive the distillation/evaporation-condensation process because, like distilled water, they are distillates also. I explain later how to deal with this issue easily, however.

Solar Distiller Plans

You may want or need construction plans to make a single basin still (cost usually runs between \$200 - \$350). Originally the full construction plans were available through the non-profit organization, the ***El Paso Solar Energy Association (EPSEA)*** website, but unfortunately their purchase page is no longer available as of this writing since EPSEA has been defunked for several years. I was their President in 2001, and had served on the Board of Directors for many years, during two different periods. I was saddened to see it die since it had held the title of the “longest running solar association in the United States.”



Homemade “EPSEA” style solar water distiller

Since the non-active status of EPSEA has been the case for many years The full still construction plans are only available through

SolAqua (I provide information for them at the bottom of this book), which is a company that was started by friends of mine in the solar energy field. They have a still construction kit available (it comes with the construction plans), as well as full construction plans by themselves.

You do not absolutely have to have detailed construction plans to build a solar still. You can build your own still with the knowledge you glean from this book, without the construction plans, although some people need or prefer step-by-step instructions, which is why I mentioned SolAqua above (I do not make any money if you buy from them). Construction plans are not necessary if you are handy with simple tools and have a logical mind for projects of this nature or scope.

Read to the end of this book before deciding whether you feel it is worth the effort in making this still versus buying one, or whether you think you need step-by-step plans or not.

Where do I Place it?

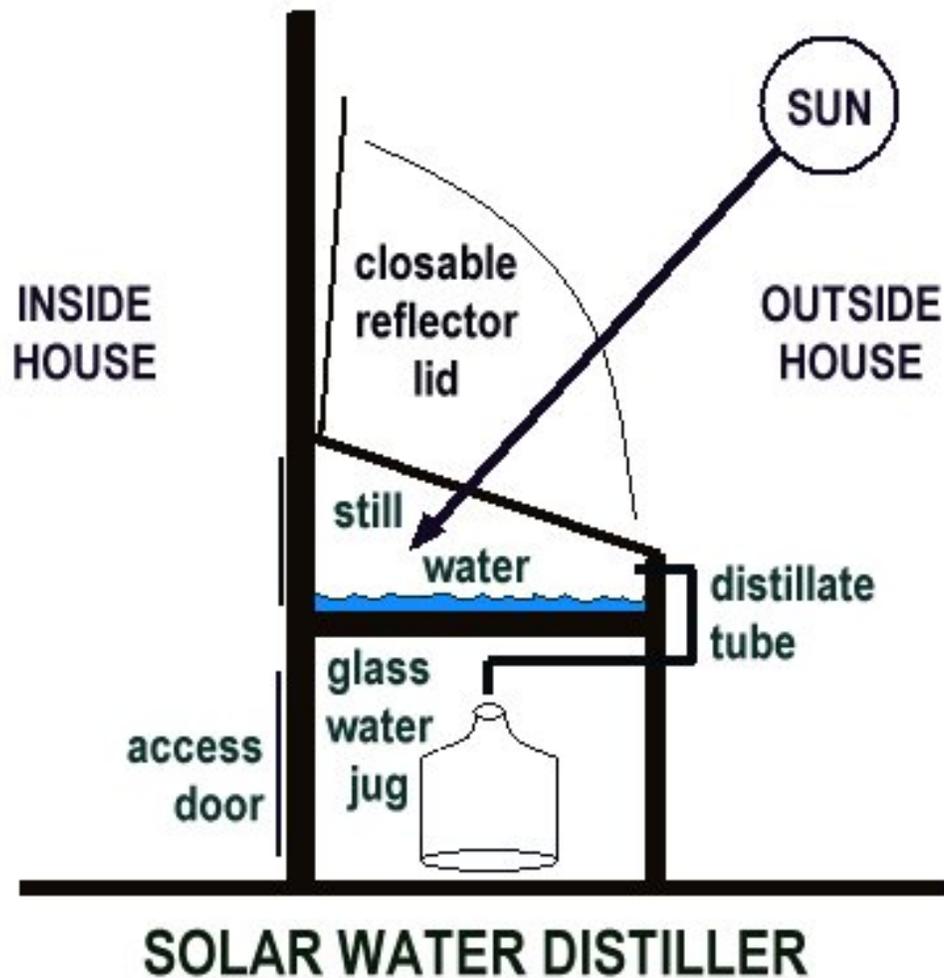
The short answer to this is “south.” But really, you will need to face the solar still to “solar south,” which is slightly off from magnetic south. I will explain in the next section, so for now just think “south” from your house or location.

This southerly-facing direction to aim the slanted glass portion of your still is for the northern hemisphere, of course. For the southern hemisphere the sun will actually be shining in the northern latitudes, so you will want to face your still to the north for optimum solar gain.

Since I am in North America, I am writing this book as if one is living in the northern hemisphere, so please just make adjustments as necessary.

You can install a still permanently to the side that has southern exposure or south-facing sunlight side of your house, and access the distillate from within the house. Be careful of overflows... you may wish to put in a floor drain or other method to deal with unattended distillate if you have distillate flowing into your house or building from the outside. If your still is high enough you can also simply put any overflow to go down your sink. I have installed stills on roofs that used this method for collection without the risk of overflow.

Alternatively, instead of having the product water flow into a glass jug or other container, you can collect it in a cistern or other non-plastic heat-resistant potable-water-safe container of a much larger size than just a few gallons. Below is a picture of a still attached to the solar-facing side of the house.

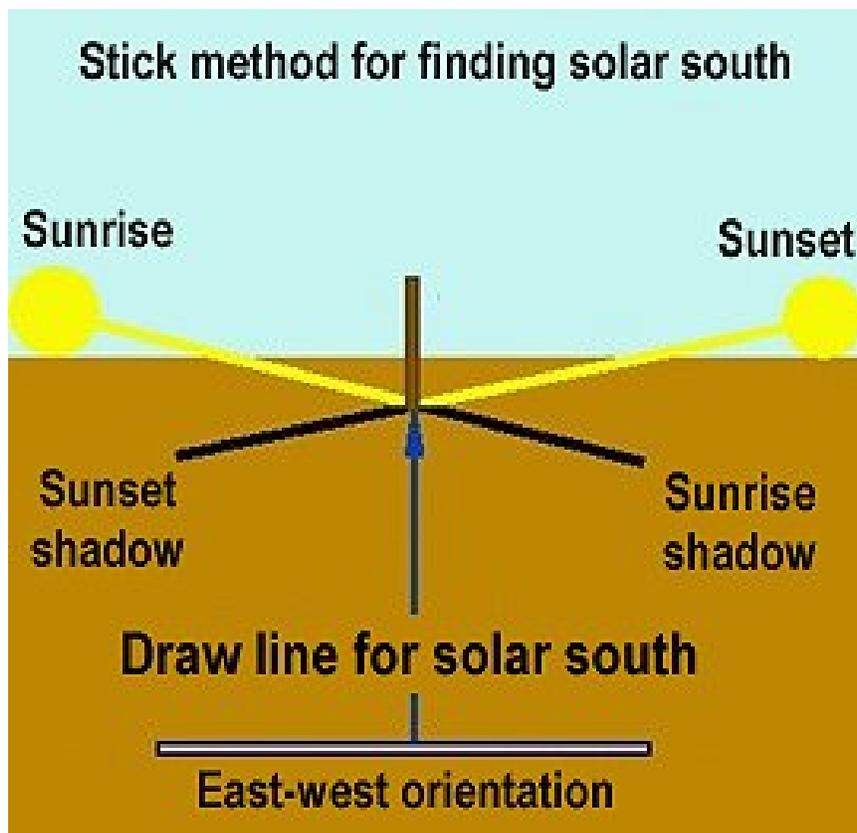


Most people build a portable still and keep it in their yard, but some people do not prefer to walk outside to check on the water or to retrieve it. If that is the case then there are other options, and really, it is up to you.

Finding Solar South

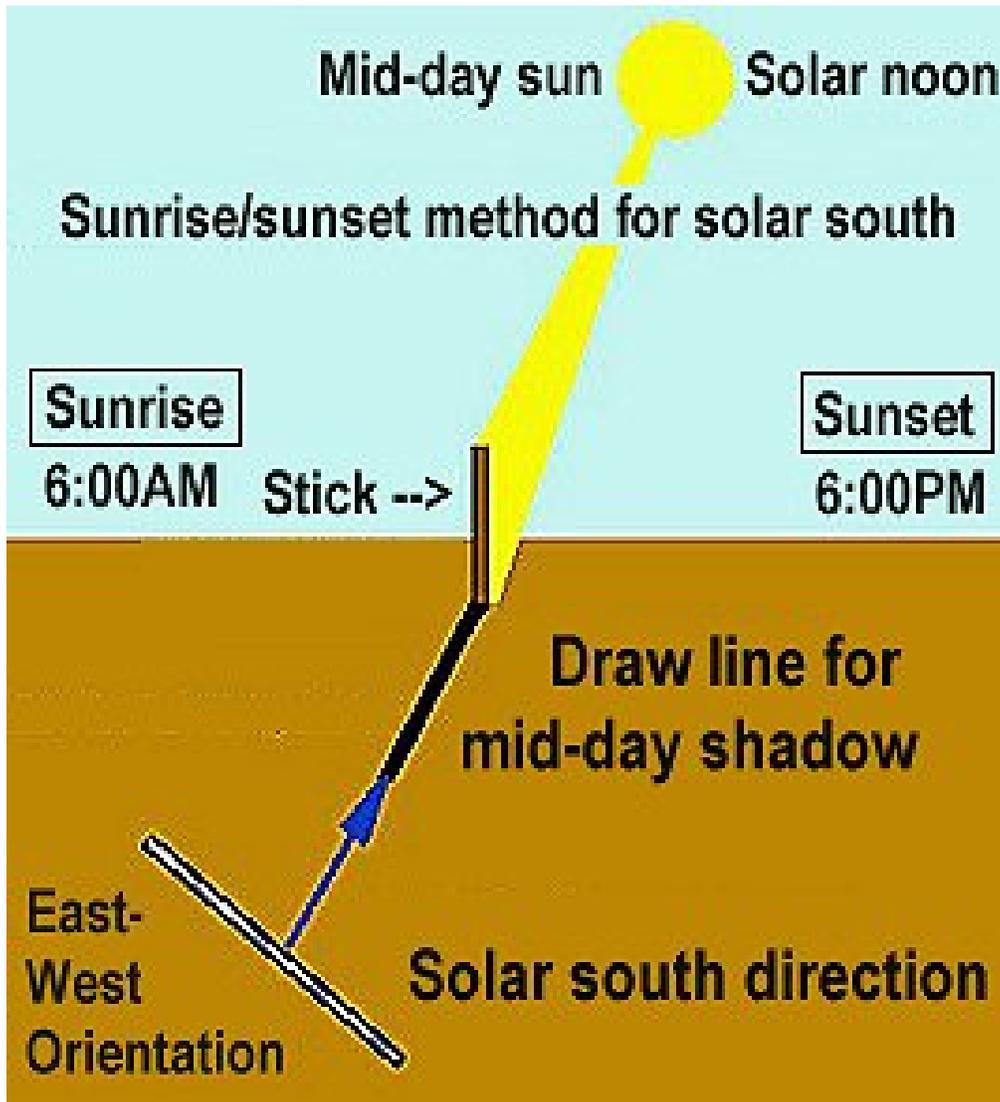
How do you find solar south? It is actually pretty easy, and there are a few different methods, which I will cover here. This information is borrowed from the section on how to design a passive solar house:

1. Place a stick straight up in the ground and draw a line on the shadow cast at sunrise. Then draw another line on the shadow cast at sunset. Directly in between the two shadow lines draw a third line (on the south side). This indicates the direction that the sun will be coming from exactly in the middle of the day (any time of the year). This should be south-southeast for most areas of the U.S.

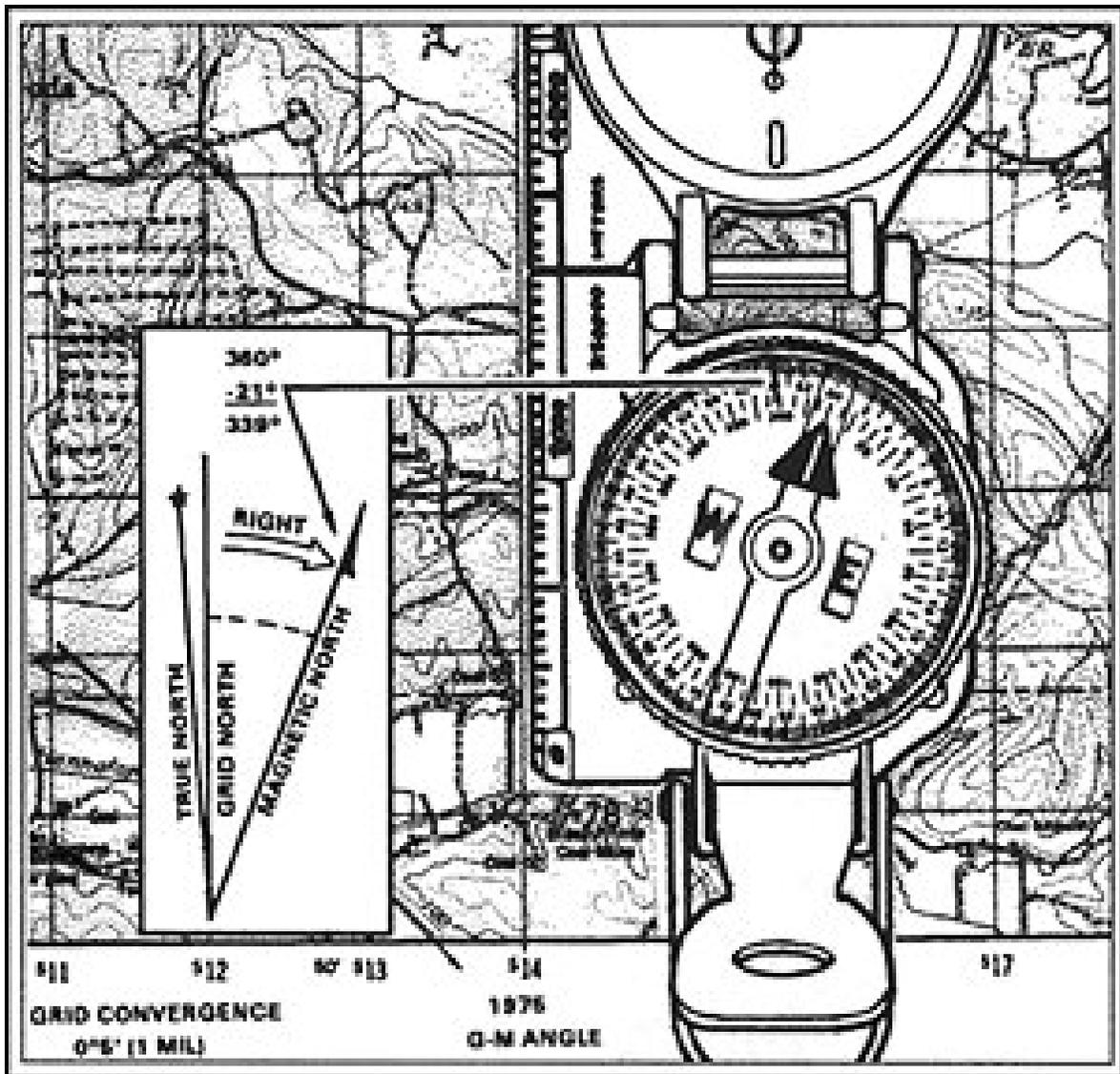


2. Watch the news on television, or check your Almanac and note the times of sunrise and sunset. At exactly in between

these two times, called “solar noon,” place a stick straight up in the ground and draw a line where the shadow is cast. Facing towards south (where the sun is) is where the line should point. This is solar south.



3. Find your location and see what the compass deviation (or angle of magnetic declination) is by looking on a topographical map.



Source: <http://www.globalsecurity.org/military/library/policy/army/fm3-25-26/image139.gif>

Compass deviation

Picture source: www.globalsecurity.org

Example #1:

For Lincoln, NE solar south is nine degrees *east* of magnetic south according to the deviation. The main solar heating hours for the Lincoln area are between 8:00AM and 2:00PM each day. Since so many of the hours to receive direct gain are in the morning hours,

many people choose to face their glass this extra nine degrees to the east side of south. But beware; anything facing more than 40 degrees off solar south (either way) starts to lose efficiency at a rapid rate.

Example #2:

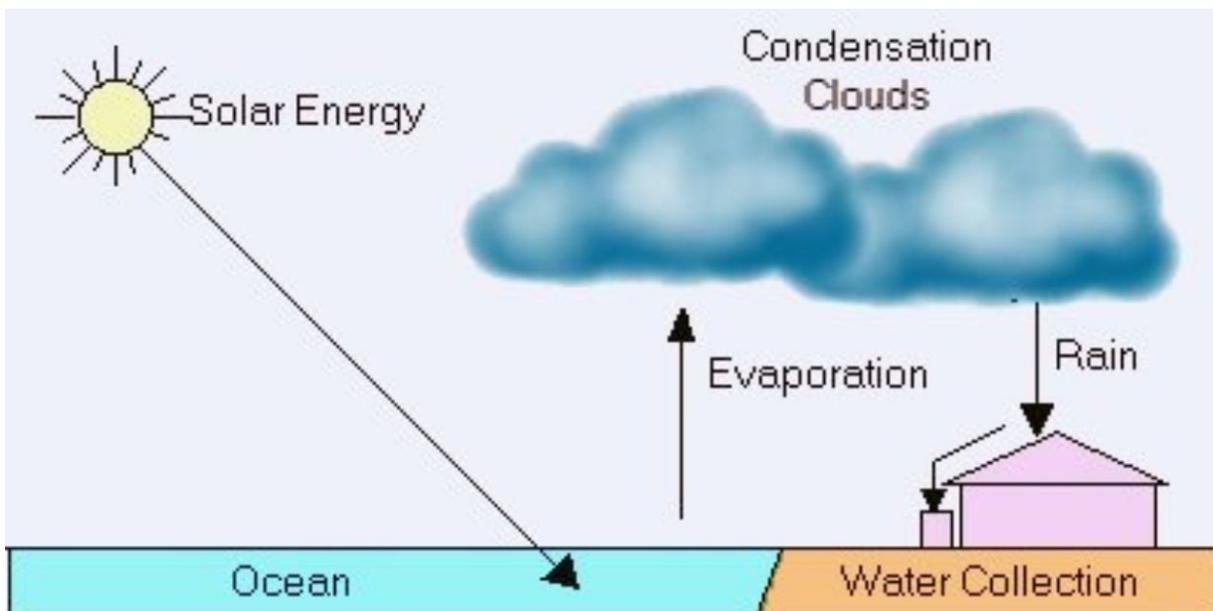
Another example is for El Paso, TX where solar south is 12 degrees *east* of magnetic south according to the deviation. The main solar heating hours for the El Paso area are between 9:00AM and 3:00PM each day.

Now that you know where to place your still and which way to face it, I will move on to the nitty gritty of how solar distillers really work.

HOW SOLAR STILLS WORK

Solar stills are basically just like making rain. In nature, the sun (solar energy) shines and heats the air and water (from the ocean and lakes, etc.) and causes the water to *evaporate* into the air as water vapor. Warm air can hold more vapor than can cool air. As it cools down it *condenses* and forms into microscopic particles that become visible as clouds in the sky, then when the conditions are right it finally falls as rain, or precipitation.

You can catch this water in a container to use for plants or other purposes. It is well known that rain water is the most pure water on the planet (unless it has been contaminated by pollution in the air from cities and factories). Plants LOVE rain water and thrive on it. Our bodies do too.

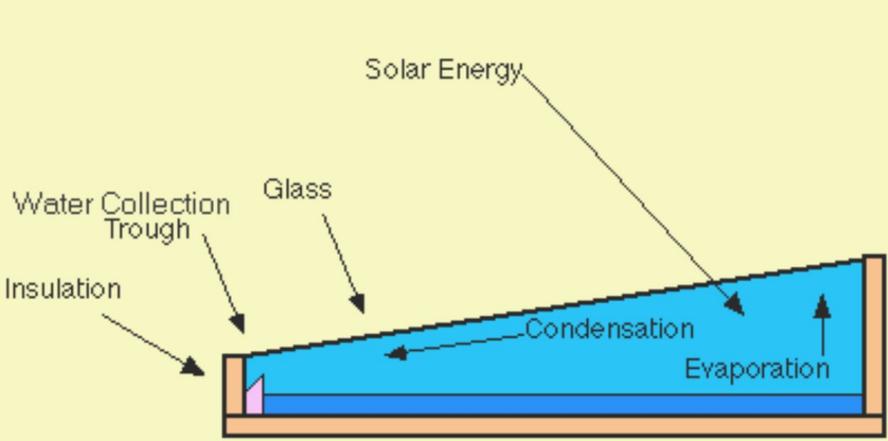


**How rain is made and used:
Evaporation, Condensation, and Collection**

A solar still, or distiller, makes pure water the same way rain is made. The sun's energy shines and heats the air and the water inside

the still causing the water to *evaporate* inside the still, and then *condenses* on the cooler glass above (the glass acts like a cloud). The water then drains down into a water-catching trough and out to a container.

This distilled water, or product water, can then be used for cooking and drinking or even bathing (some medical patients require pure water for cleaning wounds or due to other health problems).



How solar distilled

**water is made and used:
Evaporation, Condensation, and Collection**

How Good is the Water?

The water that is made in these stills is of superior quality than bottled water because it is purified using the distillation process. Distilled water is some of the cleanest, most pure water you can get on the planet. Why? Because there is nothing left in the water once distilled... it removes pretty much everything!

Additionally, because the water is slowly evaporated, instead of rapidly boiled, the water tastes sweeter due to the natural process, and is around a neutral pH (vs. "forced distillation" done by boiling the water, which tastes flat and metallic, and tends to be acidic).

When you buy bottled water you often get that "plastic" taste, and who said that the water that has been sitting in standard plastic jugs—after having absorbed some of the smells and potentially carcinogenic toxins/dioxins from the synthetic container it sits in—is still good for you?

Storing Distilled Water

The best storage container is by far a glass container. Stainless steel, although more expensive, is also good since you do not have to worry about the glass freezing and breaking in the wintertime, but make sure that it is high quality stainless steel because distilled water is so pure that it absorbs whatever it touches, and so can pit stainless steel over time.

This is why glass holding containers are recommended even though it is heavier and more fragile. Either way, the distilled water you get and store will be some of the best tasting water you will ever drink!

Beware of Bottled Water

Bottled water stored in plastic is iffy; for instance, distilled bottled water again has the plastic taste because distilled water absorbs the qualities of whatever container it is in, including toxins given off by the container.

Considering the continent-sized “island” of plastic that developed and circulated in the Pacific ocean for years before anyone really publicized it, people have since been made aware and are getting away from using as much plastic, many even abstaining from using any plastic products whatsoever, like many people did with Styrofoam in the 1990’s. There are still a lot of people who do not believe that these materials are necessarily healthy to use, at least not long term.

Distilled water is PURE H₂O and does not even have minerals so it potentially sucks up anything from its surroundings like a sponge. There is no evidence at all that it sucks nutritional content from out of your body, however. I have drank distilled water for decades without problem, as have my parents (they are in their upper 70’s now and in good health).

One interesting feature to note though, I have heard that drinking nothing but distilled water can cause electrolysis in your body, which makes you lose body hair over time, but interestingly, aging can cause the same thing, so I have some doubts in that hypothesis. Rain is also distilled water and no one I have ever heard of who drinks rainwater complains about losing hair either.

TIP: If your distilled water tastes flat because it has been sitting in a storage bottle, then to make distilled water taste fresh again is to shake it up to oxygenate it, just before drinking it, just like when raindrops pick up oxygen as they fall through the sky, which is what gives rainwater its amazing essence of life.

If you buy bottled distilled water also be aware of any possible pH issues (depending on how long it has been sitting on the shelves). I have personally drank boiled-distilled water from the stores that gave me heartburn due to the acid pH, so if I MUST have bottled water I

stay away from distilled water from grocery stores and choose spring water instead because at least it has minerals and a more neutral pH. Minerals can also be added back into your distilled water, if you so choose.

Also, beware, spring water you buy in jugs may also only be well water, and it may be treated in different ways, depending on the brand. If you get store-bought water that has the label "Drinking water" realize it may only be standard TAP WATER! That title only means it is legally fit for drinking, but not that it is purified in any way. It may even have chlorine in it.

I will not even go into the astronomical prices per ounce or liter of bottled water, let alone the potential environmental damage they cause (outside of the plastic island I mentioned earlier).

The Superior Solar Still

Regarding tap water, it is important to know that with potentially unhealthy additives like chlorine, fluoride, possible chemical and medical prescription drug pollutants, and other toxic substances in our in our sewers, water treatment plants/public water systems and environment, there are a good many reasons why you may want to distill your drinking and cooking water in your own backyard.

If you live rurally or go camping this is yet another reason to own a solar distiller. You can take river water, or lake water, or even water out of a muddy rain puddle, and distill it so that it is transformed into entirely pure H₂O fit for drinking.

“Purified water” means it has been run through some type of filtration or similar purification process (possibly including ultraviolet/UV light), but this does not always take out all toxins.

“Reverse Osmosis water” (known as RO water) is about as close to distilled water as you can get; however, it takes two gallons of water to make every one gallon of RO water. This means that for every 100 gallons of purified that another 100 gallons of “muck” (dirty waste) water has been drained away into the sewers as waste. This is an incredibly inefficient way to produce pure water! Very wasteful indeed, not to mention *expensive* because in RO systems there are specialized costly filters to replace, not including the expensive equipment, plus maintenance on the machine, and the people to pay to take care of it.

Solar distilled water, in contrast to RO, uses one gallon of water to make one gallon of distillate (basically no waste), on average.

Advantages and benefits of solar water distillers include:

- no filters needed
- no pumps required
- no fans necessary
- no moving parts to break down
- no electricity needed to run
- passive solar in design (utilizes free energy)

portable or permanent
made out of new or recycled materials
water tastes better than forced-distilled (boiled) water
neutral pH
removes ALL contaminants*
lasts 20+ years (if designed right)
works anywhere that the sun shines (versatile)
good for urban or rural areas
excellent after earthquakes or natural disasters
saves money
eco-friendly (no carbon emitted to use)
small applications (individuals or family-sized)
medium applications (business or small community-sized)
large applications (commercial-industrial, cities, military)

*except volatiles, which are removed by a small carbon filter

Solar distillation removes contaminants such as:

salts
chlorine taste and odor
heavy metals (like lead or mercury)
bacteria (E. coli, and fecal coliform (causes cholera), etc.)
microorganisms (giardia, cryptosporidium, etc.)
sediments
sand
debris
rust/iron
minerals
fluoride
arsenic
other particulates or toxins

Yes, some minerals are good for you, as long as it is not like water where I have lived in the desert, which is too saline and has far too much calcium and hard minerals that clog showerheads, lead to buildup on your faucets and fixtures and shower walls/tub, and can

affect health negatively over time (such as causing kidney stones). Minerals and the rest of these contaminants named above, and more, are all *100% completely removed* through the distillation process. You can also get minerals through your food, and through supplementation.

If you accidentally put in water that is contaminated with volatiles (gasoline, kerosene, etc.) then a simple carbon filter from the local hardware store can be placed on the still, rendering the water safe to drink.

WHERE STILLS ARE USED

Solar stills are appropriate technology for any geographical areas that have at least 5-6 hours of peak sunlight per day. They will not work as well in areas with less solar peak hours than that, such as extreme northern or southern latitudes.

Solar distillers also will not work very well on cloudy days or in areas that have a lot of rain. However, on sunny days they continue to work again.

You can use distillers at your home, at a cabin or your favorite camping spot, in border Colonias (unincorporated communities within 150 miles of the US-Mexico border) or other rural areas, in the city, survival situations, in the mission field, on a remote island, in the desert, and so on.

Stills come in different sizes. A smaller 2'x4' or 3'x3' sized (on average) still will produce approximately 1 1/2+ gallons (5 or so liters) of pure water per day in the summertime and about half that in wintertime.

The least expensive professionally manufactured still on the market that I know of is the **RAINMAKER™ 550** (which I will go into more towards the end of this book) and will typically produce most or all the cooking and drinking needs of 1-2 people (2 small stills, or 1 homemade larger (3'x6') still is usually enough for families). I know quite a bit about these stills because I used to install them in colonias in west Texas, southern New Mexico, and Mexico.

EPSEA Solar Still Projects

In the late 1990's and also in 2000-2002, The El Paso Solar Energy Association (EPSEA) had two \$10,000 grants from BorderPACT/CONAHEC for bi-national solar still installations, plus a \$100,000 grant from the Environmental Protection Agency (EPA). These monies were used to install over 100 solar stills in west Texas and southern New Mexico in areas that are challenged with water problems, specifically in rural border areas called colonias (meaning "colonies" or "settlements").

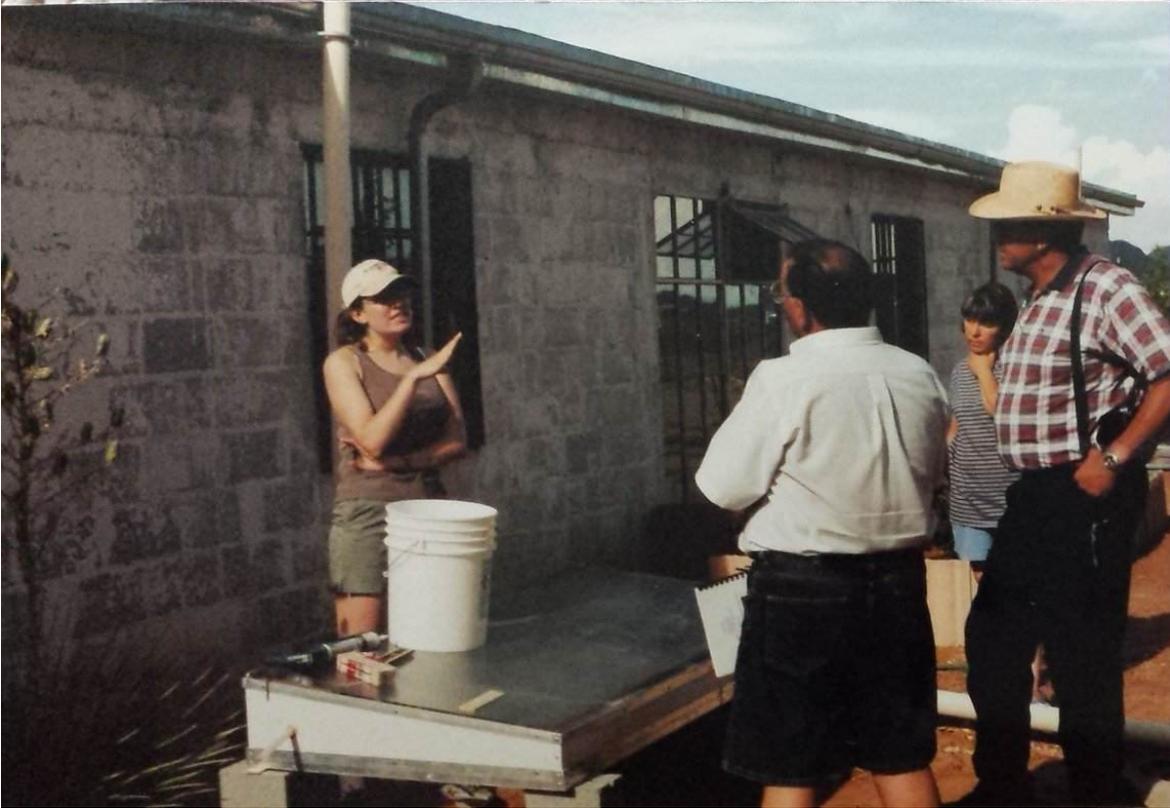
I was the Project Manager for those solar distillation projects, so I worked with EPSEA and collaborated with community leaders to target colonia families in need, especially the elderly and the sick, or those with children or who were either financially in need or lived in areas with known water problems.



This banner was hanging at the community center in a west Texas colonia and says things like “Yes for regionalization,” “Water for the colonias,” “Equal representation,” or “Water for 100 years”



**Peaceful march for water representation and rights for colonias
by colonia residents and supporters**



**My assistant Andrea Tirres explaining
how stills work in Spanish**

Besides health problems or lacking city water, people who received stills through these EPSEA solar still grant projects also may have lived in areas like Columbus, NM where unsafe levels of fluoride (naturally occurring, but over twice the safe national average) and high amounts of arsenic (from mine tailings in the area, which leached into the soil) were in the groundwater and city water supply.

Although an RO system was provided by Columbus to its residents, people had to go and fill up jugs, which was not always convenient, especially if residents did not have a vehicle or were ill.



**Sharon Cornet (formerly Eby-Martin) with still recipient “David”
in front of his fidobe (adobe and paper-cement (papercrete)
mixed block) house in NM**

Colonias and Developing Nations

Colonias are unincorporated communities within 150 miles of the U.S.-Mexico border that lack infrastructure—meaning no city water or sewers, although they do often have well water and septic tanks. Some areas—such as the one in the picture above—actually did have city water, but their water supply, although treated, still had other contaminants not removed by chlorine alone, so a solar still was their best option for on-site potable water.

Many of these rural areas/colonias, like other developing nations (what used to be referred to as “third world countries”) are plagued with poverty and poor health conditions, although in the US even ranchers, farmers, and people of wealth also choose to live in these rural communities because of numerous reasons, including that being their livelihood. So contrary to popular belief, not all colonia dwellers are poor, not all live in sub-standard housing conditions, and not all have unsafe water sources. However, many do.



My assistant DD Levine with still recipient in Mexico

Some of the diseases lurking in the poorer colonias may include hepatitis, cholera, and tuberculosis, but only in some areas, depending on the particular colonia and their unique situation—based on geography, geology, topography, political and social/cultural influences, access to medical care, economic opportunities (or the lack of it), etc.



Colonia in Juarez, Mexico - Note the large water tank in the background (obviously lacking city water is not the problem here)

Some of the homes in the colonias of Mexico are made out of pallets and cardboard and even dried mud or adobe blocks, or whatever cinder blocks or other materials they can get a hold of cheaply or for free. I have sat in some of these homes, eaten the food they offered, but selectively did not drink their water (they would offer boiled drinks like tea or coffee, however, or pre-bottled drinks, which I consumed).

I have spent plenty of time in Mexico and know the risks of drinking the water, eating the salad, having ice in your glass, or other rules that you know not to break. Nice restaurants serve bottled water, and even my dentist growing up was in Mexico, so I was familiar with the conditions of the city as well as the colonias when I began installing water distillers there.



Water faucet at the community center in Horizon City (east of El Paso), Texas where colonia residents can fill their water jugs free of charge.

You can see water draining from the sidewalk into the dirt from the faucet.



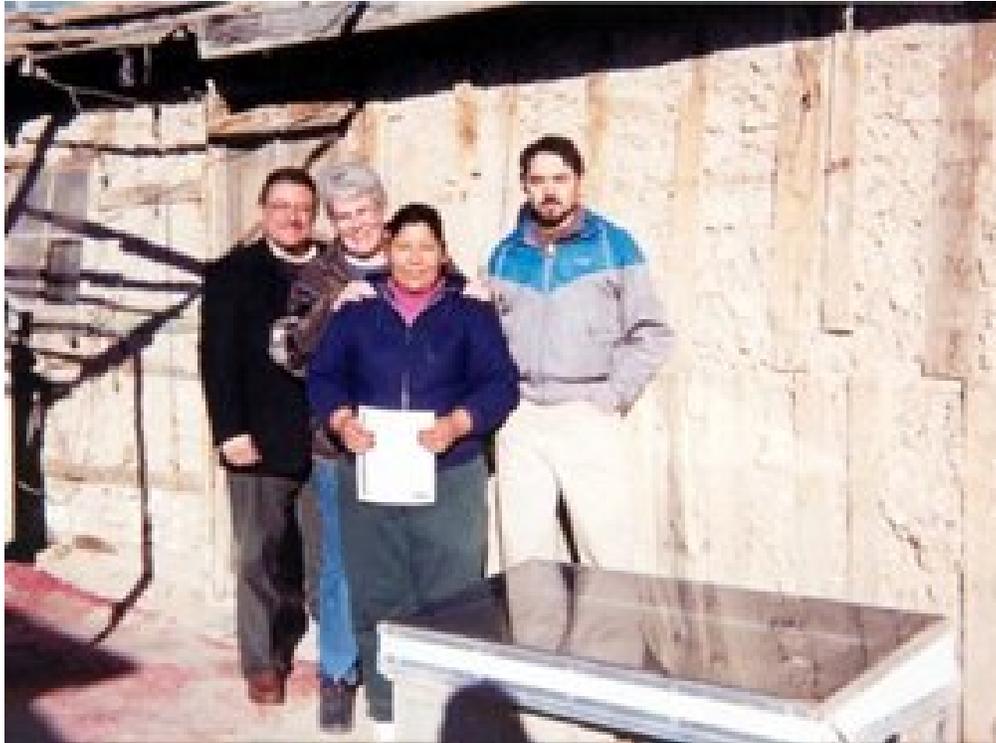
Vipin Gupta (right) handling blanket to keep still covered so it doesn't "run" while empty



55-gallon drums in west Texas colonia, used for all household purposes including cooking and drinking

The time and place where a problem with water comes in—regarding colonias on either side of the border—is when some or all of their water is either held in tanks, pilas (homemade cement block tanks), or other containers like used 55-gallon drums. Some of these may be contaminated, yet this is the water that these families drink and cook with on a daily basis.

As Project Manager I met with leaders within the communities to help locate families in need. One of these areas included where some Catholic nuns ran an orphanage in Ciudad Juarez not far from the mountain. The old dump had been covered up, and people squatted and built their little homes of mud and pallets there. These were some of our first still recipients in Mexico.



Happy solar distiller recipient in Juarez, Mexico -BorderPACT grant funded EPSEA solar still project



Sharon (left of taller lady in middle) giving presentation on solar distillers to colonia residents at an orphanage that was run by nuns in Juarez, Mexico



Filling water bucket to gravity fill the solar distiller



**Solar distiller “team” with grant project collaborators/funders
(left to right): Unknown, Mike Cormier (EPSEA), Unknown, Vipin
Gupta (Sandia Labs), Sharon (self), Robert Foster (NMSU),
Unknown**



**Water purification message on a
building in Palomas, Mexico**

In the U.S. the colonias tend to be populated with mobile homes or simple (often uninsulated) concrete block or even adobe homes; but again, there are also exceptions depending on local and regional circumstances. Water problems and solar distillers seem to be made for each other, and a still is a viable solution in times of need.

IS CITY WATER SAFE?

Is your water safe? Do yourself a favor and do an Internet Google search for “boil water advisory” along with the name of your state. Do the same thing with your state and words like: E-coli, fecal coliform, giardia, or others. City water service I have paid for has had small pieces of black particles, and even tiny pebbles and sand and other debris come through the pipes of this “clean” city water. Imagine the things that are in there that you cannot see!

Even if you ignore the issues with places labelled as colonias, some say that the industrialized, developed nation of America has the cleanest water in the world! Yet we find all over the U.S. (not just in colonias) private wells are contaminated with bacteria, E-coli, lead, arsenic, pharmaceutical residues, or other toxic substances, some of which are removable with the use of chlorine, and many that are not. Environmental pollutants and chemicals from agribusiness and factory or manufacturing sources is a continual issue in many cities. Cities, in fact, can be more polluted than many rural areas with private wells.

City water is not necessarily “good for you,” is it? Do Americans believe that chlorine is even healthy? You might want to think about getting a chlorine-removing filter for your shower so you do not breathe in the chlorine gas that is dispersed during a hot shower, especially if you have respiratory illness or other health issues.

The chlorine in America’s water supply is similar to antibiotics, which is a product that *does not distinguish* between killing off living BAD organisms (bacteria, microorganisms) and killing off living GOOD organisms (necessary bacteria in the human body). Yet we are still told that it is perfectly fine to consume this potential poison... to ingest it long-term and that it is actually “safe.” Do yourself a favor and distill your own water, live healthy, and ignore what the mass

media tells you to believe. Here are some facts about city water you might want to know about...

- **A study by the California Department of Health** found that pregnant women consuming five or more glasses of municipal water had a 15.7% increased incidence of miscarriage. Doctors are saying drink eight glasses of water a day! *Source: Epidemiology report findings mentioned in the San Jose Mercury News, Los Angeles Times, and The Metro newspapers (Feb 1998) AND Pubmed (Savitz, Andrews, et al.):*

<http://www.ncbi.nlm.nih.gov/pubmed/7556013>

Too obscure? Perhaps it is outdated, or other variables were not considered since no studies with similar results have been done since then that I could find.

Consider this...

- **Fluoride is another issue.** Fluoride is an ingredient in toothpaste because it is said to help fight cavities, so does that necessarily mean that it is "safe" to be ingesting on a daily basis? I have known children who eat unsafe quantities of toothpaste regularly even though they are supposed to use a pea-sized amount and spit it out (they swallow instead).

Municipal water that contains fluoride has been accepted and also avoided in certain areas of the country because of this debate. The use of fluoride in water has been stopped, rejected, or banned/outlawed completely in many—if not most—industrialized and developed nations including: Austria, Belgium, China, Denmark, Finland, Germany, Hungary, Japan, Norway, Sweden, and The Netherlands, among others; America is behind the times.

Source: www.fluoridation.com/c-country.htm

The "safe" (highest acceptable - standards set in the U.S. by the Environmental Protection Agency (EPA)) level for ingesting fluoride is considered to be a count of **maximum concentration limit of 4 mg/L** in water tests. **Enamel fluorosis can occur when children are chronically exposed to fluoride at concentrations of 2 mg/L or higher.**

Children with fluorosis (fluoride poisoning) have bone strength problems (since fluoride actually leaches calcium from the bones/teeth, making them weaker, not stronger), developmental problems, health problems, and white spots on their teeth (mottled) and skin due to the unnecessarily high levels of natural fluoride found in the water table.

Children and adults who have had this problem were, amazingly, found only a 45-minute drive away from Deming, NM, where their (Deming's) claim is to have some of the cleanest and "best" water in the state! Due to geological reasons and old mines in the mountains, the village of Columbus, NM has high arsenic counts in their water. Plus Columbus has (found naturally) at least 200% higher than the maximum limit of fluoride concentrations (over 8 mg/L based on tests from 2001) in their groundwater.



Water Festival held in Columbus, NM



Greg Vogel and Mike Cormier carrying an EPSEA distiller for display at the Water Festival

The village, as I mentioned before, put in an expensive RO system for residents to fill up their bottles for drinking/cooking, but some of the residents, thanks to the EPSEA solar water distillation project, have solar stills at their homes so they do not have to travel to the town square to fill up their bottles with clean water and haul them back every time... they distill it on-site instead, which is far more convenient. Their solar stills remove ALL the fluoride and arsenic, as well as chlorine from the city water, thereby removing the danger of ingesting any of it unnecessarily.

The best reasons for having a solar still are not always just the practicality of on-site water purification but the reasons behind what drives us to want purified water in the first place.... our HEALTH is a big issue in our toxin-filled society today.

Next I will cover solar water purification for bacteria and microorganisms when there is no solar still available, then I will go into how to make a solar still.

SOLAR WATER DISINFECTION

Note that this next method, unlike distillation, does not remove volatiles or sediments/solids, minerals or other contaminants, but it will kill the bacteria and microorganisms found in river and lake water, contaminated city water sources after an earthquake or other disaster, and other similar scenarios. No book on solar water purification would be complete without this knowledge being presented.

Recently, when I went through my belongings that had been in storage the last five years, I came across an original paper handout that we at EPSEA used to give away to people about solar stills (back when I was still on their Board of Directors). This information has always been given away freely to the public, so I am happy to share it with you here so it is not lost in the annals of time. This is something that anyone can do, anywhere in the world, as long as there is direct sunlight.

“WATER PURIFICATION USING DIRECT SUNLIGHT

“The earthquake in San Francisco certainly made us more aware of the harsh situations that could develop during a time of disaster. One of these, and a most vital one, is the lack of good drinking water. The Energy Information Center in El Paso kindly gave us a simple method of water purification for drinking which we would like to share with you.

“Because the results have such unlimited potential for disease prevention throughout the world, during the first half of the International Water Supply and Sanitation

Decade (1981-90), five major institutions carried out extensive research projects to determine the role of violet and infra-red radiation in the disinfection of drinking water.

“The testing involved subjecting 1 to 3 litre capacity containers of contaminated water to direct sunlight for varying periods. Water samples were deliberately contaminated with municipal sewage to high levels not normally encountered even in rural areas where drinking water is untreated. They found that 99.9% of coliform bacteria were killed in 95 minutes.

“The time required to destroy 99.9% of the coliform bacteria by exposure to sunlight ranged from 70 minutes for colorless polyethylene bags to 1050 minutes (17.5 hours) for dark brown bottles. The mean value for all types of colorless glass or plastic containers was found to be 85 minutes. Colorless glass or plastic containers are the best choice whenever available.

“Storage for five days of disinfected water showed that the inactivated coliform bacteria failed to regrow at ordinary room conditions. To avoid recontaminations it is preferable that the water be kept in the same solar-sterilized container. To make it more acceptable for drinking, let it cool overnight as the water gets warm during sterilization.

“Dishes and similar tableware can be effectively decontaminated by exposure to sunlight for as short a time as 15-30 minutes. Containers should be properly spaced to avoid shadows.

“During cloudy days, all that is necessary would be to prolong the exposure period from a minimum of one hour to several hours. The routine procedure from morning to

afternoon would be more than adequate even on days with reasonable cloud coverage.

“The project’s overall findings are that in both summer and winter, the household water supply can be disinfected on a routine basis if clean transparent containers are put in the sun in the morning and exposed until late afternoon. Shading of the containers must be avoided, and turbid waters must be filtered or left to settle.

“This is a simple, practically costless method of disinfection which could be adopted by the vast majority of people in the world.

“Note: This information was taken from the text of a UNICEF manual.” - end

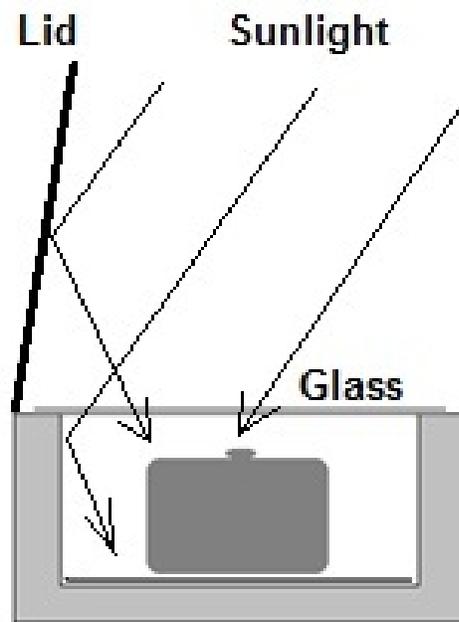
Note that this method of solar water purification/disinfection is also referred to as *solar water pasteurization*.

Solar Ovens for Solar Water Pasteurization

In colonias as well as many developing countries solar ovens/cookers are not only used to help pasteurize water in this same way, but also solar cookers replace expensive gas/propane/butane, electric (if available) for cooking, or the need to scrounge for firewood so they can cook their food.

A solar oven can be made from simple materials like recycled cardboard, aluminum foil, and school glue, then topped with a piece of glass (some people have utilized an old car window or Plexiglas).

Anything you can cook in a regular oven, Dutch oven, or slow cooker (crock pot) you can cook in a solar cooker.



Solar oven used for solar water pasteurization

As you have seen already, you do not really need a solar oven to solar pasteurize water, but if you are in an area where the quality of the water is seriously in doubt and microorganisms and/or fecal coliform bacteria (found in raw sewage) might be present, then you may be able to pasteurize your water just by placing it into a solar oven rather than just sitting the jug or glass jar in the sun; this is an alternative to boiling water.

Except for acid rain (or any rain contaminated by volcanic ash, etc.), rainwater is likely the most pure water you can collect outside of a known pristine source—even mountain springs can be contaminated with bacteria or microorganisms.

If there is no rainwater to collect from the sky, then you can wait until the muddy water in a puddle settles and carefully skim the clearer water off the top of it into your container. Once your jar or jug has the contaminated water in it, then place it in direct sunlight. This can also be water from a stream or river or lake or pond if you are camping or lost in the woods.

If using a solar oven, set the CLEAR container in the (preferably preheated) solar cooker in full sun. Make sure the water is not shaded or too cloudy as the Ultraviolet (UV) in the sunlight will kill off 99.9% of all bacteria and micro-organisms within 90 minutes (in FULL sunlight, otherwise leave it up to a few hours), plus once the temperature reaches 131 to 149 degrees F (55-65 °C), then anything else left behind will automatically be killed off within a short time.

This process of solar pasteurizing water works great for contaminated water that has fecal coliform bacteria (a main cause of cholera and diarrhea in developing countries) or that has microorganisms such as giardia (commonly found in water) or cryptosporidium (often found in lakes or ponds).

Temperatures needed to pasteurize for these:
Microorganisms: 131°F (55°C) – Worms or protozoa cysts (cryptosporidium, entamoeba, giardia)
Bacteria: 140°F (60°C) – V. cholerae (or fecal coliform), E. coli, shigella, Salmonella typhi, rotavirus

Virus: 149°F (65°C) – Hepatitis A virus

It is important to note, just to caution you again, that pasteurization of water does NOT remove solids such as sand, sediment, rust, nor does it remove minerals, arsenic, fluoride, chlorine, volatiles (like gasoline, kerosene, pesticides/herbicides), chemicals, or heavy metals. You would need to build a solar water distiller for that.

So that brings me to the next topic...

MATERIALS & TIPS

The great thing about solar stills is that you can “make your own rain” via evaporation and condensation within the still on any sunny day. Stills can be bought from companies (such as www.SolAqua.com, which is where we got some of our solar distillers for the EPSEA grant community projects) or you can build the still yourself using a variety of materials available to you.

Basically, there are three ways to make stills. The cheap way, the better way, and the best way, each with their own respective price tags.

If none of those options appeal to you there is always the option of buying one commercially made. Depending on whether or not you have some of the materials on-hand, just lying around your house or gotten free or cheap from a neighbor or friend, weighing out these factors may best determine if your still is going to wind up being less expensive or more expensive than purchasing a new one.

Typically larger stills can be made for \$350 or so. The process can be a bit time consuming, so if you are in a hurry for a school science project you may want to reconsider and make a solar oven instead.

If all you need is a quickly made emergency or demo-still please read “The Cheap Solar Still” section next. Those are also not meant for long-term use, nor are they necessarily healthy if plastic is used (in fact, perhaps the opposite of anything I would personally consider healthy).

Materials

Some of the materials you **may need** to make a solar still could include:

Plywood

Glass

Food-grade sealant (DOW-999A silicone—this is a special order item)

Nails

Screws

Nongaseous insulation

Wood (such as 2x4's, 2x6's, etc.)

Cement/concrete

UV resistant plastic or PVC (should not touch the product water as plastics give off toxins) for possible legs or for the box

CPVC for water trough or other water

Stainless steel

UV-resistant silicone tubing

PVC couplers/valves/connectors

Other miscellaneous items

Materials to Avoid

- *Rubber (toxic)
- *Non-UV-resistant and non-food-safe plastics (they degrade and become brittle in the sun plus can put toxins in the water)
- *Galvanized sheet metal (this will not last and the galvanization process/materials are not food safe).
- *Cork (breaks down)
- *Standard 100% silicone from hardware store
- *Polystyrene (bead board—it gases off and crushes with weight on it)
- *Any other foam or synthetic materials which are not food-grade or FDA approved as “safe” for food contact (especially if heated since stills can get quite hot!)
- *Any other material which you are unsure about

When in doubt, do some research and ask and find out... do NOT take chances! Do your research thoroughly.

Pay attention to volatiles:

Be careful about what goes into your still—not only the water source but also the materials you use to build it.

Volatiles like gasoline or kerosene are not typically in groundwater, city water, or other sources of water; however, if one is in a survival situation where your only source of water is a puddle that has a thin layer of an oily substance that has a rainbow-like sheen to it floating on top (skim off as much as possible—try NOT to put this into the still), or your source water is a water well that has picked up some volatiles from the environment due to a natural or polluted source, then it is important to know that volatiles (chemical compounds or elements that have a low boiling point) CAN survive the distillation process.

Why? Because they actually distill out of solution before water does. Water itself is actually a volatile (as is nitrogen, carbon dioxide, hydrogen, and others), but water is necessary for life on earth, whereas people only *think* that petroleum-hydrocarbon related

volatiles are necessary (our society in the future will surely rid our dependence upon most of these as a fuel source) when in reality the human race has lived as thriving civilizations for millennia prior to their invention.

Petroleum hydrocarbon volatiles (made from crude oil) can include things like gasoline, kerosene, diesel, or jet fuel, and anthropogenic (manmade) sources of volatile organic compounds (VOCs) can include paints and coatings, aqueous solvents, chlorofluorocarbons and chlorocarbons (occasionally found in old cleaning products/refrigerants but are now highly regulated or banned), fossil fuels, benzene (sinks to low-lying areas, found in stored fuels, car exhaust, volcanic eruptions (beware of water contaminated by ash fall) and forest fires (water contaminated by smoke), and tobacco smoke, plus benzene is used in the production of resins, synthetic fibers, and plastics—so do not use these products to make your distiller).

Additionally, methylene chloride (in adhesive removers or aerosol spray paints), Perchloroethylene (used in dry cleaning clothes), and MTBE (banned in 2004 in the US to limit contamination of drinking water, groundwater /aquifers), and formaldehyde (in paints, wall boards, adhesives, ceiling tiles, and wood products) are also VOCs that you should be aware of, which could contaminate the still or product water.

If this scares you, it should. Carcinogenic poisons can come from 1) improper materials you might use to build the still itself by gassing off and contaminating the air inside the still, therefore condensing out of the vapor into the distillate/product water, or 3) direct distillation of volatiles could end up in the product water.

If you place a simple carbon filter (these are very inexpensive and can be purchased at your local hardware store) at the outlet tube, between the exit water trough/tube and the collection vessel (usually a glass jug) then it will remove any possible volatiles in your water and render it safe for drinking. It is a simple and inexpensive solution that acts as insurance against possible contamination from numerous possible sources.

Mistakes People Make

There are a few pitfalls people fall into sometimes when trying to attempt the construction of a solar still for the first time, especially when they are unfamiliar with the process or materials, or in thinking that some materials are safe when they are not. Please read below and be careful not to make these mistakes:

- Using PVC instead of CPVC for product water (PVC degrades above room temperature and can put dangerous BPAs and toxins into the water)
- Letting the still run dry, causing silicone to gas off and make a film underneath the glass cover (clean with a green scrub pad and a weak acid solution or Liquid Plumber or similar product, rinse VERY WELL! Then let the still run for at least 1-2 days before drinking the water)
- Sealing off the still when not in use – if you are leaving for a few days put plywood over the glass and pinch off the silicone inlet and outlet tubes so the still can be contained and not run dry.
-
- Not letting the still cure before using it (it takes about 8 weeks to let the silicone cure completely, or you can reduce the time by letting it run dry with plastic over the top (or use the glass, but it will have to be cleaned as per the instructions above after curing)
- Not sealing the glass well or not sealing the solar distiller well with silicone.
- Using standard 100% silicone instead of the DOW-999A FOOD-GRADE silicone (special order). Regular silicone is NOT meant to be used as a food contact surface!

- Not flushing the still daily. – twice as much water should be put into the still as you get out daily, typically in the early morning just as the sun is rising, or in the evening at or after dusk. Flushing removes salts and mineral buildup from occurring within the still. This keeps maintaining and general operation of the still go very smoothly and as it will require less cleaning.

Now, to move on to the different ways to construct a still...

THE CHEAP SOLAR STILL

The least expensive ways to build stills are by using materials you already have on hand. If you like to collect (or have a friend who collects and is willing to share) what other people consider as “junk” then you may already have a supply of materials which can be quite handy in constructing your still.

Also, the type of still can greatly increase or decrease the cost of constructing it. Usually, however, the cheapest stills are the ones that can be built or made in just a few minutes. These are typically not permanent stills, but are meant for short-term use, such as survival stills or ones made for school projects or science fairs, or even roadside breakdowns. They are NOT meant to be used long-term, and may not be healthy, as I stated previously.

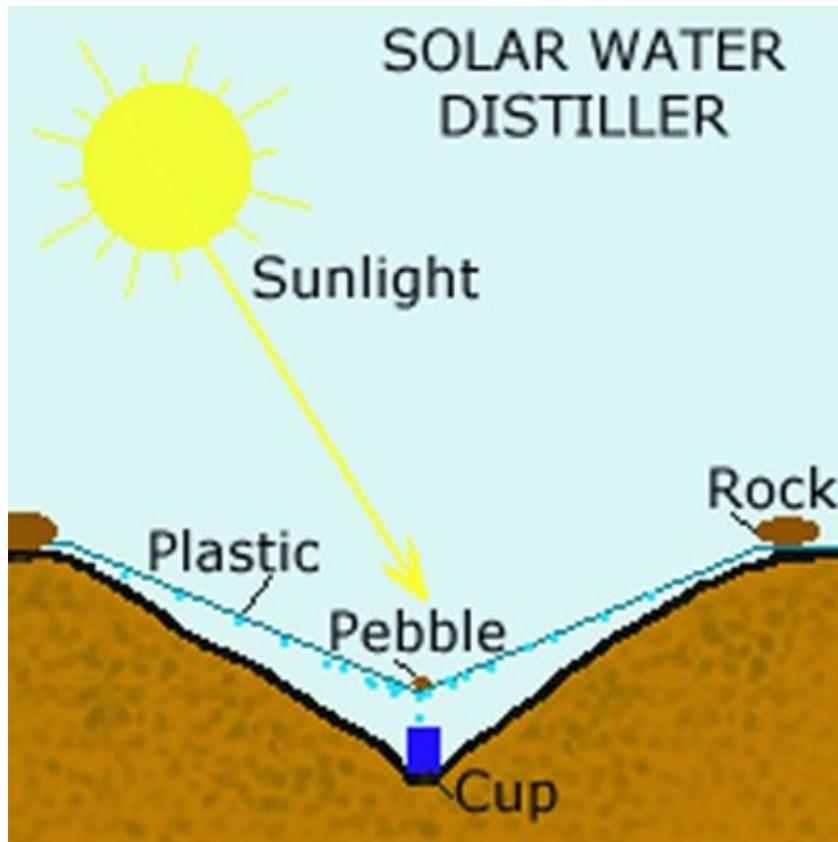
Emergency Solar Still

You can make a FREE or nearly-free solar still anytime or anywhere, even if you are stuck out in the hot, dry desert, as long as you have a clean (preferably a 5'X5' or comparable sized) piece of clear plastic with you. If you have some clear plastic on hand, especially food-grade plastic (an extra-large oven cooking bag may do) you are half way there. If not food-grade plastic, then this would be used as an emergency still only, otherwise it could be used longer.

STEP 1: Dig a conical hole in the ground and put a cup/glass/bowl/container in the middle of the hole.

STEP 2: Open up the plastic and stretch it out over the hole so that it covers the hole all the way (HINT: make sure your hole is not bigger than your plastic). You can put sand or rocks over the edges of the plastic to hold it down so it doesn't blow away.

STEP 3: Put a pebble in the center of the plastic to make the plastic dip down in the center, right over the cup that is underneath. Then sit back and watch your still work!



FREE solar water distiller out of a piece of plastic. Moisture from the ground collects and drips down into a cup or other collection vessel

The sun will come through the plastic, heat up the inside of the still (between the plastic and the ground) and cause the moisture that is in the earth to *evaporate*. Next the moisture will *condense* on the plastic, which will then run down towards the pebble and drop into the cup.

More water can also be made if vegetation or pieces of cactus or other plant material, or anything moist, are cut up and thrown into the hole before the plastic is put on. This gives extra moisture inside the hole so it can be distilled at a greater rate.

In emergency situations, and during war, people have also urinated into the hole to add extra moisture. Remember that only pure H₂O evaporates and condenses so there is no worry for contamination (as long as you remove the cup so you don't "splash" into it, and don't splash or contaminate the plastic either). In just a few hours you'll have some hot water to make tea or soup, or let it cool

down to drink it as pure water. Be careful not to burn yourself when you try this as it can get quite hot!

Condensation Trap Solar Still

STEP 1: Another survival option is to get a large piece of plastic or clear plastic bag (or buy a transpiration bag), which you may keep stored in your car trunk or glove box or backpack.

STEP 2: Place the transpiration bag over a small non-poisonous tree or bush that sits in the sun, especially if it is near the bend of a dried up creek bed or wash/draw/arroyo.

STEP 3: After you have placed the plastic over the tree/bush then cup it at the bottom so that when the sun shines through the plastic it will heat up the air underneath, causing the tree to get hot and “sweat”. The tree, in trying to stay cool will give off water vapor and it will collect onto the plastic and run down into the cupped area of the plastic below.

STEP 4: After some water has collected you can retrieve it. Be careful not to let it run out onto the ground or you will lose the condensate! Also, don't leave this type of still running too long or you'll dry out the tree and kill the poor thing. Generally the water needs to be collected every two hours or the tree will stop transpiring.

NOTE: Be careful of what type(s) of bush(es) and/or tree(s) you use as some give off odors and gases that can make the water taste bad, or even be bad for you or make you sick. Soft (pulpy) roots may also be good sources of moisture, as are plants with soft leaves; avoid hard, woody parts or too many dry stems.

THE BETTER SOLAR STILL

One of the first things I did before I built a still was by first reading everything I could get my hands on concerning this subject (I highly recommend doing that). Here is some of what I learned...

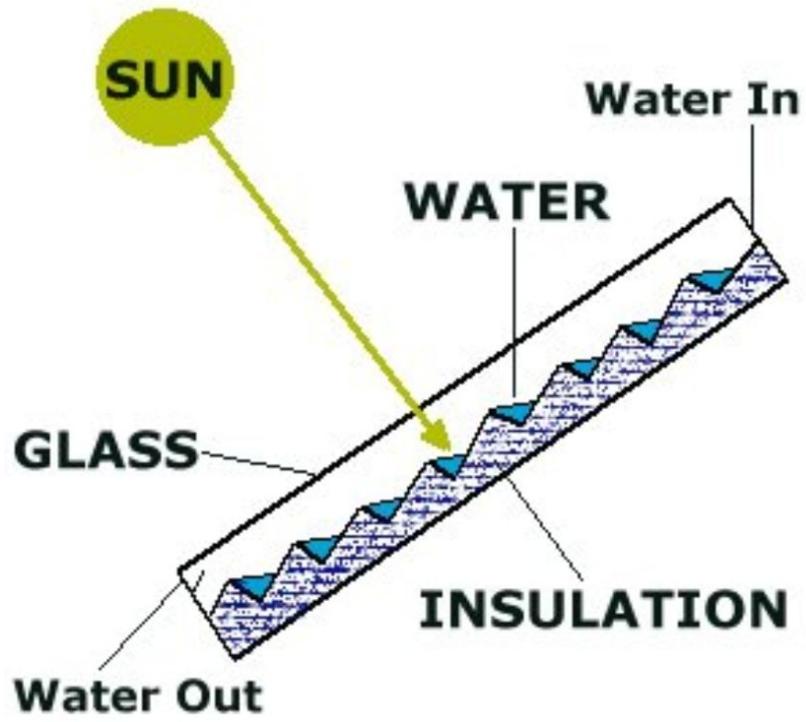
The Multi-Level/Troughed Still

Another type of distiller is a multi-level or trough type still. This is where, instead of one single basin, you have multiple smaller basins underneath a single piece of glass. Typically these stills are slanted at a diagonal angle rather than laid flat. The smaller amounts of water in these long but thin basins/troughs allow for rapid heating and evaporation of the water, but water must be added more often or the still will dry out too quickly. This can be done by a gravity feed tube or by automation and a drip-system.

I personally have found these systems to require more maintenance and attention (I like things that almost run by themselves) and so I tend to stay away from them; however, some people love their quick evaporation and condensation rates for a higher volume of distilled water in the same amount of time (as compared to a single-basin still).

I used to imagine spraying that Teflon coating onto the surface (since the product water will never touch it, it can withstand high temperatures, and will shed the mineral buildup easier than other surfaces) but I did not find out whether Teflon gasses off or could have any other potentially harmful effects or not, so never used this method. I recommend finding out if it gasses off or has any harmful issues associated with it first before you attempt to try it.

MULTI-TROUGH STILL



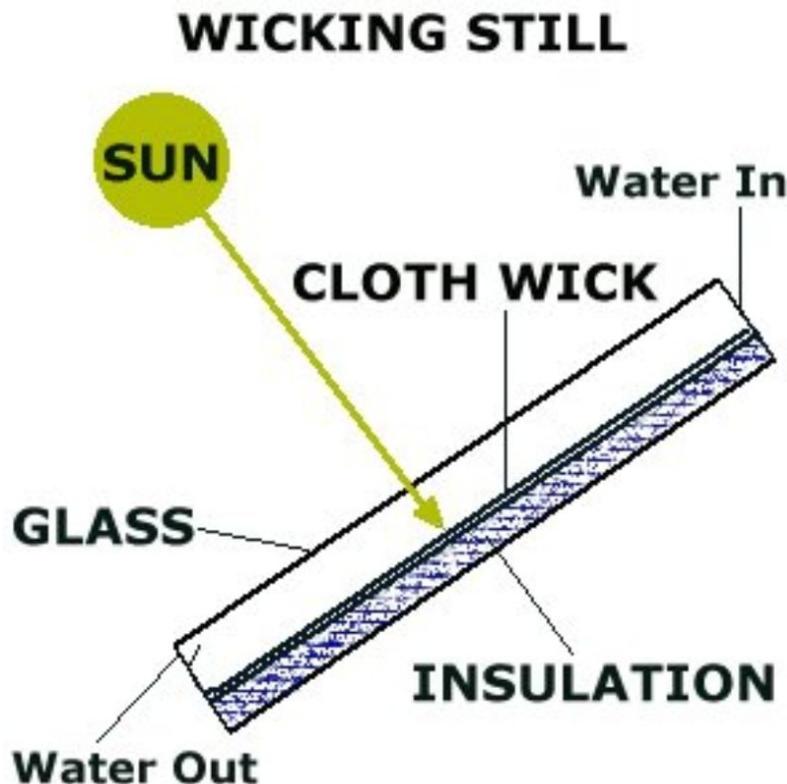
The Wicking Still

The wicking still is very similar to the multi-trough still in that it is a tilted still and evaporates smaller amounts of water at a time.

However, instead of troughs to hold the water there is a single piece of black cloth (natural fibers like jute or industrial hemp are best, definitely nothing synthetic as they can melt and/or gas off and even poison the food) for wicking the water through the length of the still.

Water is dripped into the top via a tube with tiny holes along its length. By the time the water reaches the bottom of the cloth most of the water should have evaporated leaving a salty white brine full of hard minerals, which drains out the bottom (you will want to keep this area clean so it does not clog or cause hard mineral build up).

The condensed distillate (or condensate) is caught above—via a collection trough—is so it can stay separate from the wastewater brine. Wastewater is one of the negatives about this type of still also, whereas a single basin still does not have this (although the basin will still need to be cleaned from time to time).



Like the multi-level still the wicking still needs more upkeep and maintenance, especially because the cloth gets clogged quickly with salts and build-up (calcium carbonate) and turns a bright WHITE, therefore the heat-absorbing qualities of the black cloth is quickly negated and one must open the still often to replace this cloth. In some ways this is easier than cleaning the still because it becomes disposable.

However, not all is wasted if you let it dry and run it through a shredder and throw it into the compost pile to be recycled, adding calcium and other minerals back into the earth. There is no reason to live as a throw-away society when something can be recycled in this way (provided it does not have arsenic or mercury or other chemicals in it that you would not want in your garden compost).

Finding proper cloth such as burlap (fair to poor material) or something that “wicks” evenly is also a hindrance, although there are some natural or man-made shammies (i.e. chamois, or chammy) on the market that people use to wipe down their cars that wick up water very efficiently; however, they may not be cheap and I have only heard that people have used them, but I have not heard whether they work well or not. Check with the manufacturer to find out whether their product gasses off or has any potential for poisoning the water (I cannot repeat this enough for ANY product you ever use to make a solar distiller, especially for anything in the interior.

THE BEST SOLAR STILL

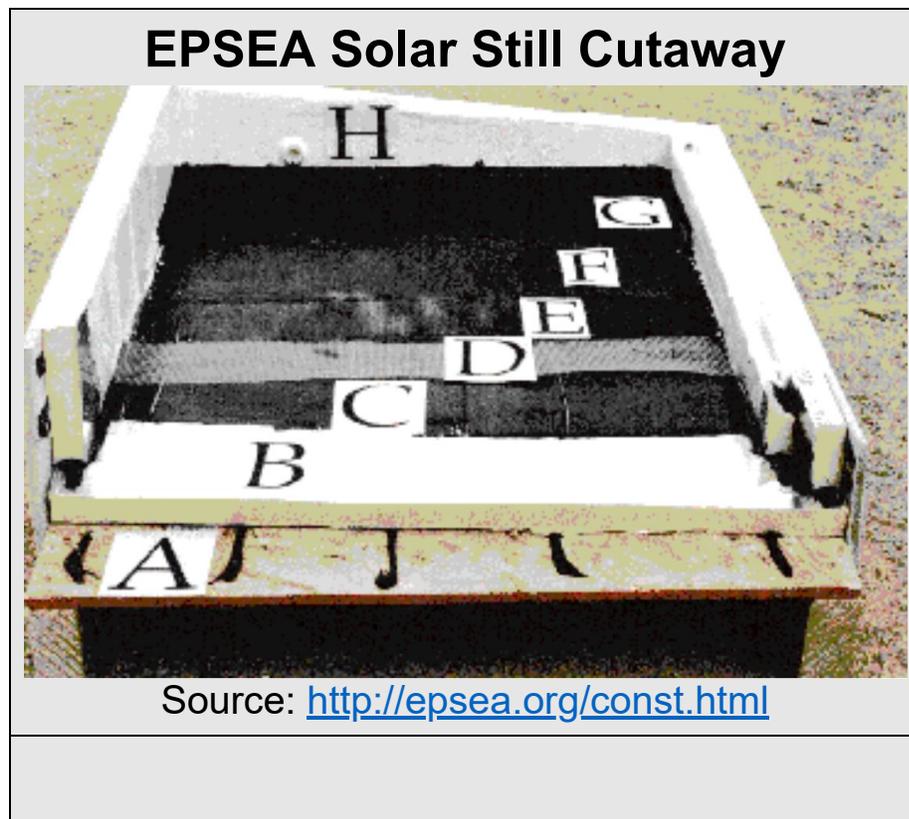
It is said by many in the solar field that the single-basin still is the easiest and quickest method to build a still. The water sits in the basin and evaporates as the sun heats it up—simple! This is why I consider it one of the best stills to make... easy, relatively inexpensive, very few problems, and does not matter if the water freezes in winter (it will simply thaw the next morning and start producing again).

Yes, there are other designs that might be more efficient (certain commercial varieties, or hybrid systems, for instance), but what is your criteria? What is “best” for you and your circumstances may be entirely relative. Build to suit your needs!

Single Basin Still

Horace McCracken was one of the first people in the country to really seriously work with the design of solar water distillers. He originally used concrete in his still design, but it was found to be heavy and slow in producing water due to the great mass of the concrete. He found that putting the sun's energy into heating the WATER rather than the concrete is the best way to go concerning efficiency. Just to note, however, that once the mass of concrete is heated up you will get a little longer time in nocturnal water production, so there is that slight advantage to concrete stills. Also, once the glass cools down from the night air, water tends to condense at a faster rate.

Horace McCracken worked closely with the El Paso Solar Energy Association in helping to design the best stills possible for one of EPSEA's solar still grant projects. Horace wound up taking some of EPSEA's ideas also, and started producing more lightweight and portable stills after that. A cutaway of this still is shown here:



**A- Base is 2X4 and plywood/osb
B- Insulate 4 sides and bottom
w/polyisocyanurate
C- Waterproof membrane - 1st coat silicone
D- Fiberglass screen
E- Imbed screen into silicone
F- 2nd coat of silicone
G- 3rd coat of silicone
H- Side walls and trough (right) same steps
w/white silicone and install fill/overflow and
outlet tubing.**

You can use the image above to build your own still, using the proper silicone (bought through SolAqua or straight from the company that manufactures it). Just make the box and work your way in, using the cutaway photo above. This “EPSEA Still” is no doubt one of the best and time-proven ways to construct a still, however there are some things you should know before tackling this endeavor.



Single basin still – note the gravity-feed trough

attached to the back (made of house gutters)

Important Rules for Making a Still

- The water needs to be very shallow, perhaps $\frac{1}{4}$ " to no more than 2" deep.
- It is best if the basin is black as dark colors absorb more light and heat up faster. Light colors—especially white or reflective metallic surfaces—reflect the light and heat back *out* of the still. If the still is made out of concrete (thinner is best as it takes some time for the sun to heat a lot of mass (as in thermal mass)) and you can spread black cement coloring powder in the surface concrete itself, or paint it black with a safe, non-toxic, waterproof type paint; however, know some paints may peel within a short time, especially when they are constantly wet and the temperature is 150 degrees F (65 ° C) or better inside the still. Be careful not to drink the water from the still until the paint has dried/cured/gassed off all the way.
- The main frame of the basin itself can also be made of wood with a waterproof food-grade liner of some sort. Some people also use glass to line the basin (with black underneath it) but be sure to seal the edges with *food-grade* silicone. This is a good idea but makes the still heavy and the glass may break easily if moved or something hits it. Glass may work better for permanently placed stills instead of portable ones, but it is an excellent way to get away from having to spend for special silicone, especially if you have access to cheap or free glass (HINT: Safety glass is best).
- It is best if the glass that covers the basin is no more than 4"-6" above the surface of the water as too much air space can cause convection within the still, therefore making heat-loss a problem
- Some people have put in a float valve like they use in toilets to regulate the water level. The pros of this are that it will fill a little at a time automatically (if a hose is attached) as the water level drops throughout the day). The cons are 1) the device could break and you could lose a lot of water or productivity, and 2) cooler water constantly being added to the still may drop the temperature enough to

consequently drop still production, in some cases significantly. One fix is to preheat the water with a small homemade water heater, or use an existing household solar water heater and tap it off of that.

- Make sure that the glass above the water is tilted at about a 10-degree angle. Any more and convection occurs in the still; any less and the water will not slide nicely down the glass into the collection trough, but will drop back into the basin where it will become recontaminated.

- Vinegar is an excellent way to clean both the interior and exterior sides of the glass and the still basin if/when needed. Rinse well before using.

- Add a closeable drain so the still is easy to flush. Some people have put this in the bottom, but most put it on the side near the bottom interior surface of the still.

- Insulate the (exterior) bottom and sides of the box with any water-resistant (non-paper) insulation such as aluminum-backed rigid foam insulation. As long as the basin is sealed from the outside insulation then gassing off (by the foam) should not be a problem. Remember that nothing can contaminate distilled water except what this ultra-pure water comes in contact with, OR toxic gases that are in the air and can permeate the water vapor itself. If you have volatiles such as gasoline, kerosene, or pesticides in the basin water then it CAN or WILL come through to the other side since volatiles have a faster evaporation rate than even water does. If there is any worry of the possibility of a small amount of volatiles in the water, then a simple carbon filter can be placed in the water tube/line between the exit trough and your collection vessel.

- Make SURE to use a food-grade surface material such as stainless steel or food-grade silicone, CPVC, or even glass as the *collection trough* and for the *collection vessel*. The collection jug can be polybicarbonate such as those 5 gal plastic jugs but be aware that 140-180 degree Fahrenheit (60-82 °C) water is dripping out of the still at a constant rate all day long (especially in summer) and that it can absorb the taste (or toxins from the plastic) of the vessel it is

contained within. Polybarbonate jugs also degrade in the sun over time so make sure to shade it with a box or piece of wood or heavy towel or other opaque material. This will also help cool the water faster as it will now be shaded. Some people have their stills placed lower to the ground (like on cement blocks or a wooden frame/legs) and then dig a hole to hold the jar/jug since the earth helps cool the water and shade the sides; however, the top will still need to be shaded or protected from sunlight. I personally do not ever recommend any kind of plastic for water storage, especially for hot water (and believe me the distillate exiting the still is HOT and can burn you!). I know that 5-gallon carboys (jugs) made of glass are hard to find, but keep looking, and stock up. Otherwise, use stainless steel or smaller 1-gallon glass tea jugs (some come with a spout) and change them out more often, or set up an overflow system to fill more than one at a time.

□ Always use food-grade silicone tubing for the inlet and outlets so that the tubes don't crack and break in the sun. Don't ever use regular garden hoses for the tubing as it has rubber inside and will make the water smell and taste terrible, and will poison the water.



EPSEA solar water distiller

The “EPSEA” still utilizes food-grade silicone (DOW 999-A) which is a *special order product only*. Cost is about \$10+ /tube and it takes about 24 tubes to make just the silicone “liner” of the still, considering it takes 3 layers of silicone for completion. Then the silicone needs to cure by outgassing (best if put out in the sun for a few weeks/months); the time can be reduced by setting it in the sun with the glass on (without water in it).



Mike Cormier (on left at corner of still) teaching a solar distiller construction workshop at a solar energy fair. They are installing the mesh over the layer of silicone.



Spreading the white silicone on sidewalls



Sealing corners with DOW-999A food-grade silicone



**Last layer of silicone for liner
(white for sidewalls, black for basin bottom)**



**Mike Cormier showing how to attach silicone tubes
and bucket (optional) for feeding water into inlet hole to
fill still with water once it is cured**



Distiller with glass attached. Robert Foster (Renewable Energy Engineer and lifetime member at EPSEA) on left, with Gerald Martin (volunteer) at end, both speaking with interested gentleman (right) about stills.

When you pre-cure the silicone and if the still is run “empty” of water then the silicone can outgas causing an invisible film on the underside of the glass and the purified water production will go down to almost zero until it is properly cleaned off (glass cut off and flipped over, or else cleaned with Liquid Plumber (or similar brand) and a soft scouring pad – use HEAVY RUBBER GLOVES and do NOT touch this stuff as it will burn your skin!) until the film is removed. RINSE glass thoroughly and let the still “run” with water it in afterwards for at least a full day before drinking any of the distillate. The last thing you need is poisoned product water.

If you do not use food-grade products such as the DOW 999-A silicone then make SURE that what you do use is safe and doesn't

leak. Some prefer to use stainless steel, however this can be quite expensive also and you must be sure to use high quality stainless steel (316 or better), because low quality stainless can pit and corrode over time.

Another item that is hard to get is the silicone tubing for the inlet and outlet tubes, as well as the overflow tubes on the still. The tubing itself is readily available; in fact, most companies that sell it do so in entire ROLLS rather than just a few feet (which is all you would need). Why buy a \$50 roll of tubing if you only need 3-5 feet of it?

A solar still Rainkit™ 990 (for the hard-to-find items) to make the EPSEA still can be bought from SolAqua for around \$245 <http://SolAqua.com/SolAquakit2.html> (KIT comes with the EPSEA still construction plans).

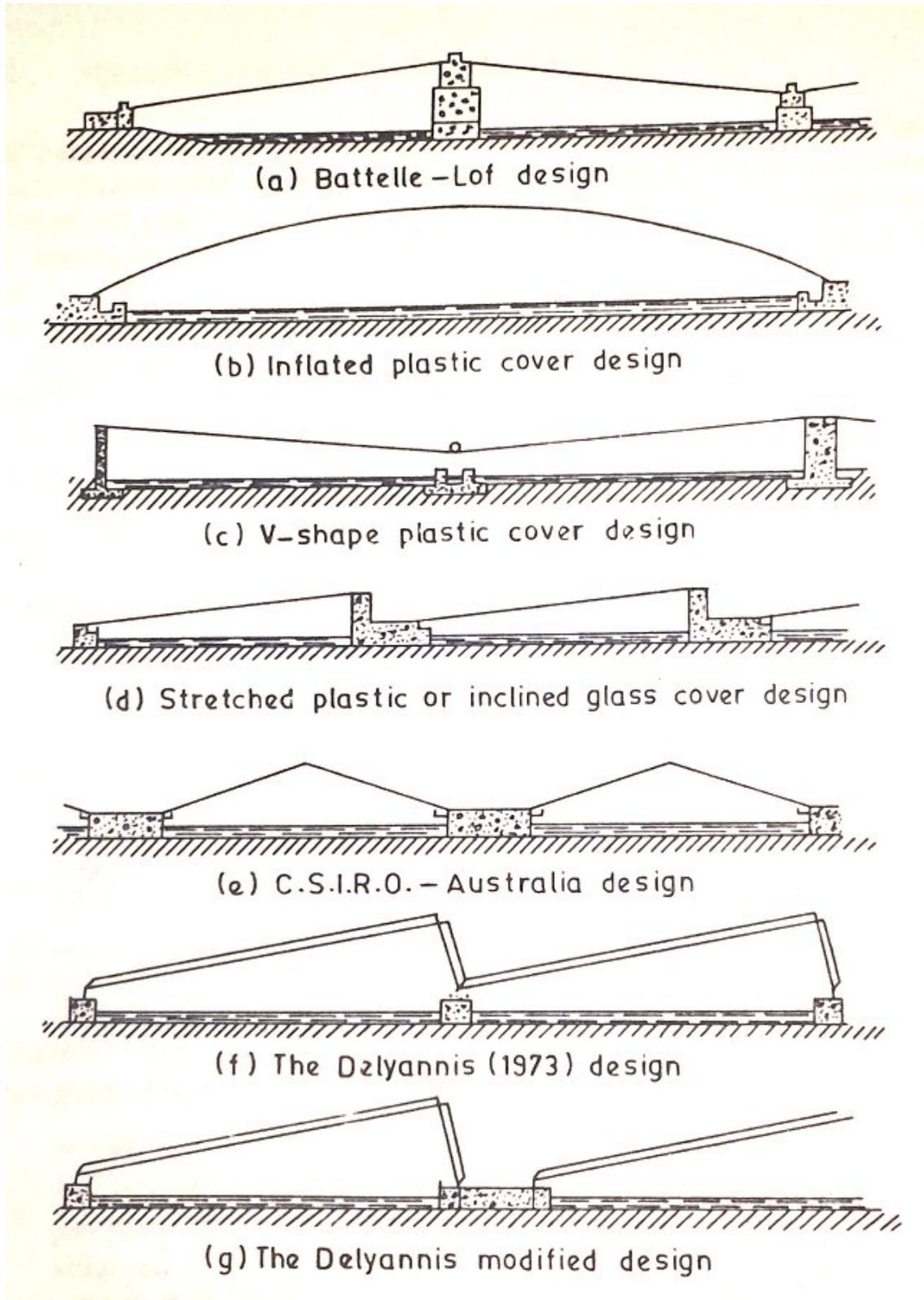
COMMERCIAL STILLS

There were many fly-by-night solar companies and new products that presented themselves during the 1970's due to the solar credits, which were paid by the government for solar contraptions of many kinds—this being from solar distillers to solar water heating to solar heating of homes, and other interesting inventions. Many of them did not work well because they were not fully researched and developed or tested long enough in the field before they were made and sold, and many of these companies could not guarantee their work with a warranty.

Many of these companies went under and closed down due to their products being inferior. Still yet, there were some gems, and the information gleaned about what *not* to do concerning solar projects and programs, became evident to the masses over time, so ultimately I am personally glad for that “learning experience” time in America's solar energy history. Some of the solar distillers that did not work, and some that did, were carried forward and eventually tweaked and updated again and again, until either the most complicated and expensive, or the most simple and inexpensive designs were in place. Only the ones that worked best tended to stick around.

Multi-Trough or Array Style Stills

Today we have some excellent choices and knowledge about the engineering and efficiencies of solar water distillers. Some of the methods that are tried and true today were only slightly adjusted because at one time they were not the standard (nothing was, really).



Picture source: *Solar Distillation: A Practical Study of a Wide Range of Stills and Their Optimum Design, Construction and Performance* (Malik, Tiwari, et al., 1982)

The picture above of some of the styles of glass, for instance, were used on commercial stills for many years, even into the 1990's, and some of them are still used today. However, we know now that glass that is set perpendicular to the sun's rays has a much better chance at going through and heating the water than glass that is set at an oblique angle to the sun, which impedes sunlight and slows down the process of heating, and therefore distillation.

Plastics, especially back in the early days, were probably not as food-safe when heated as some food-grade and microwave/dishwasher-safe plastics today, and glass was typically used anyway.

The famous "tent", or double-slope still design (where there are two pieces of glass on top that form a double angle with a peak in the middle, like a tent shape—see Battelle-lof and Australia styles in picture above) can work great for one side as it allows the sunlight through, depending on where the sun at any given time of the day, but may be working fairly inefficiently on the other side if the angle of the sun is wrong. This is also known as the "classic" style solar still.

These style stills were often made in long troughs that ran north and south (so the sun would hit them fairly evenly as it traveled from east to west), and these long troughs were placed side by side, like rows in a vegetable garden. The glass "tent" peak would run down the middle above each trough, and the sides (lowest point of the glass) would have a small channel or collection trough just for the distillate/condensate. These troughs would run down the length and collect in pipes and eventually cisterns or tanks or some other holding container for later use of the product water.

The multi-trough stills, all set up in an array of sorts, have been made out of different materials (usually concrete) and can produce many, many litres/gallons of water in a day's time. The good thing about these is that they are passive in nature, although fans have been attached to the end to allow air to run through the middle (some heat loss may occur). These stills are often found in developing countries to aid bringing pure water to villages that suffer from a lack of potable water. Saline or salt water from the ocean is what is usually placed in distillers like this.

I also spoke with an inventor once who had designed a bubble style still once that had a round tube-like shape to it that the sun could shine through, which would heat the water inside and cause it to condense and drain out the far end of the tube (I have seen other similar designs). Because of proprietary information that was told to me, which I cannot repeat here, I cannot give any more details about this still, but I can say that it worked well and produced more product water than a typical passive solar still would. However, this prototype never made it to the market, nor was a company formed to produce it for the masses.

Things have come a long way in the last several decades. I have watched most still companies (charging \$800+ per still) come and go over the years. I have no indication as to whether the ones here today will still be here tomorrow so I'm going to tell you that in order to find them just do a search on the Internet.

That said, there is one company that I will mention here that we used for our solar distiller grant projects that continues all of these years later to make distillers and even has a one-year warranty on them.

Single Basin Passive Solar Stills

The **RAINMAKER™ 550** is made by SolAqua. This is the same company who sells the KITS I just mentioned. We installed Rainmaker solar stills in the EPSEA solar still grant projects as well as the EPSEA homemade stills.



Photo of a SolAqua distiller I installed in El Paso, TX

SolAqua took the EPSEA solar still and improved upon it greatly, adding in awesome features such as a second overflow trough, a special one-piece silicone liner which has outgassing reduced from 60 days down to a mere 2 days! Now, if the still accidentally runs dry any film that may be there will just simply wear away and vanish.

Another feature I really like is the removable trim that holds the glass in place, because it makes it tremendously easy to clean the still. In homemade versions the glass is silicone on, so it has to be cut off, cleaned, re-siliconed on, and then run for a couple days before it can be used again.



Notice the 1-gallon glass jug from supermarket used to collect the product water via the silicone tube exiting the still. This is a 2'x4' still.



**Two stills juxtaposed reminds me of the quote:
“...*why build one when you can have two
at twice the price?*”—S.R. Hadden
Played by actor John Hurt (movie: *Contact*, 1997)**

These stills are lightweight and easy to handle. Stills can also be automated using sprinkler systems and connections available at your local hardware store. Once a unit is bought it can be set up in a matter of minutes. These stills produce about 1 ½ - 2 gallons per day during summer, and half that in winter in most climates that have 5-6 of solar peak hours per day.



RAINMAKER™ 550 Solar Still

For any further information or to purchase one of these stills please see www.SolAqua.com.

If you choose to build your own still, then I wish you the best and please have fun; the reward is clean tasting ultra-pure water for years to come.

Hybrid Family or Industrial-Sized Solar Distillers

Earlier in this book I mentioned that my friend and colleague, Hill Kemp (engineer), had installed a prototype of his new still design at my house in El Paso, Texas. I have an acre of land, so there was plenty of room for him to dig a large hole and install his new creation. I understood the concept of a hybrid still, and expected it to work well, which it did!

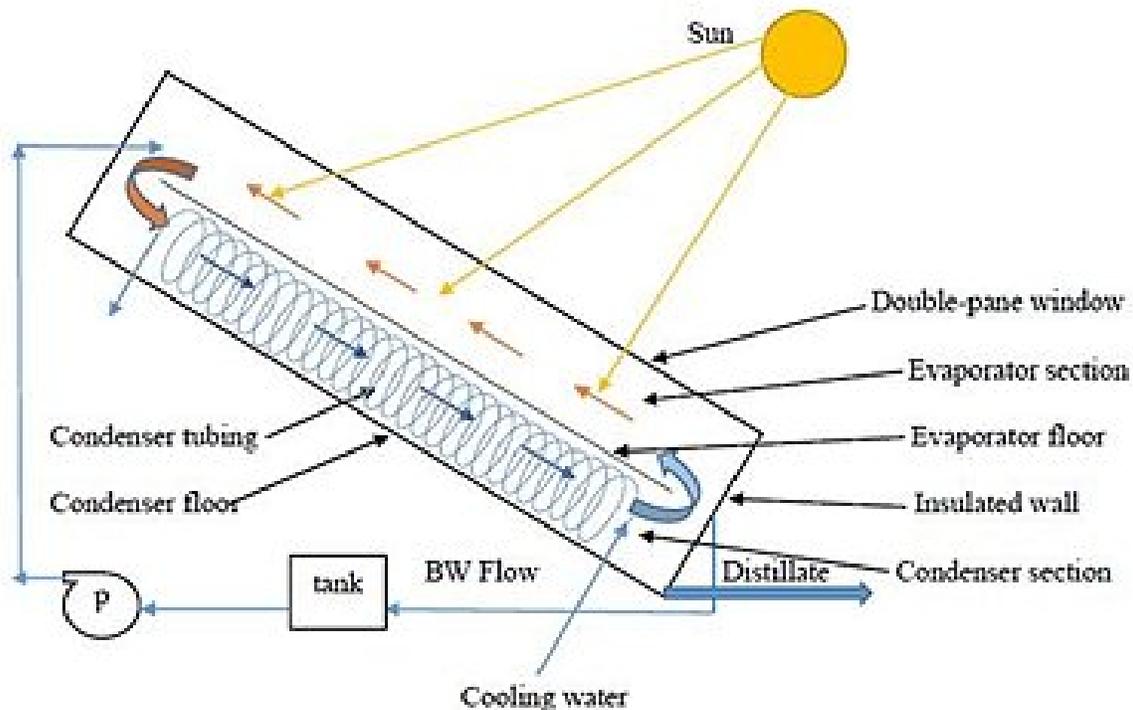
After about a year and a lot of testing, data collection, and going through the numbers, he removed the still as promised, filled the hole back in, and left my yard as if it had never been there. I am pleased that he was able to do this on my property, and consider him an excellent designer of commercial stills.

You see, I know something that most people do not know, and that is the concept of wind making things cooler (in nature)—like the cool glass inside a still—and its effect on the condensation part of the distillation process... but it has to be engineered just right for it to work correctly. I learned it by making many phone calls and talking to just the right people at the right time, so when he told me about his still design, I knew already what he was doing, and grasped the project without ever having to see it in person.

The concept and design was excellent, and still is. He has tweaked it even more since then, so I am happy to present it to you, with thanks to Hill Kemp for the use of his pictures and information for:

The Suns-River Solar Distiller

(see picture next page)



Suns-River industrial-sized commercial still

I am very excited to show you this design because it is made specifically for families or even large-scale projects such as factories or military facilities or larger businesses—even cities!. The larger the product water needs, the larger the array of stills needed to produce the water. The Suns-River stills are perfectly scalable.

The difference between Suns-River stills and a passive single basin type of still is the fact that it is a hybrid (combination between passive and active solar—active means there are moving parts or mechanical pieces). The still itself is passive because the interior of the box has no moving parts, but externally is a small pump that uses solar PV (photovoltaic) panel(s) to produce the electricity for the pump.



Suns-River hybrid solar water distiller

This still, when comparing its square feet of sunshine to the same square feet of sunshine in a passive solar still, will produce several times the amount of product water, just because it is designed so efficiently, and yes, it is a patented design.

One particular feature is impressive, because although this is a hybrid still, it technically is, according to the Suns-River website: “... *the only desalination technology with no internal electrical or mechanical parts and 100% solar powered*” and produces about 1 litre per hour.

Hill Kemp told me this:

“Our single-wide 2.75 m² unit actually produces about 25 liters/day, enough for cooking and drinking for a family of four. We hope to get the refined price well below \$999. So it's not confined to industrial.”

With multiple units ganged together we serve industrial and larger uses .”

Now, you are in for a special treat. About a month or so after the publication of this book Hill Kemp was interviewed, and the link to the long audio file was placed on the suns-river.com website. I listened to it all very carefully and took notes! I am including those notes below.

I have not seen a more efficient solar still on the market to date, which is completely off-grid and overcomes many of the old inefficiencies associated with the old fashioned classic “greenhouse” solar still. Enjoy!

Hill Kemp Solar Still Interview Notes

From Sept 2015 radio show interview linked from suns-river.com

Deserts have millions of gallons of salt water underground, but it is too salty to drink. Stills excel best in deserts. Stills can also easily be used to desalinate ocean water, of which there is an unlimited quantity and availability on earth.

Aristotle documented around 350BC that when a cover is placed over a dish or pool of salt water, the condensation on the inside of that cover is pure, salt-free water. The salt stays with the pool. He also said it was a lousy way to make fresh water because productivity was so poor.

The classic solar still (greenhouse style—tent-like shaped glass cover) over a pool of salt water performs okay but people give up on them after a while. Survival kits for boats—these are about the only viable application around for a solar still in that circumstance. The salt in sea water, if drunk, demands more and more moisture out of you, so is basically poisonous. That survival kit will produce a small amount of water to keep someone alive temporarily.

Hill Kemp took technology, broke it down into six steps, then micro-engineered to make these steps more efficient in his solar still to produce more water than the classic solar still. Every square meter of glass surface in a classic still can produce 3-4 quarts or liters per day.

Three of the six steps were severely restricted, so he changed equipment to eliminate the bottlenecks. So now the Suns River still productivity is 11-12 liters per square meters of glass surface!

The classic still is a greenhouse over a pool of water and the six steps are:

- 1) sun shines through the clear roof,
- 2) Solar energy heats the bottom of the pool and warms the water at the bottom ,
- 3)warmer water drifts to the top of the pool,
- 4) evaporates across the air space inside the greenhouse and
- 5) condenses on the inside of the greenhouse glass, and
- 6)a gutter at the base of the tilted glass collects the pure distilled water.

Greenhouse roof has two purposes: let sunlight through and condense humidity on the inner surface of the glass. Why is that inefficient? Because droplets on the inner surface diffuse the sunlight and take away productivity. Suns River changed this so there is no condensation on interior of the glass in this design. We tried coatings but double glass is what we went with. Control temperature so the interior glass is too hot to condense water. We have a sloped "falling film" of water rather than a pool. The film is 4/10ths of a millimeter thick, cascading thin film, so when solar energy hits the floor the water evaporates quickly (4x as efficient). Further, we use tubing coiled in a flat configuration under the evaporation floor and run cooling water through the tubes. With an air space at top and bottom of the sloped floor, humidity created inside the still goes up (chimney principles, convection) on top of the floor then down-flows on the back by the cooling tubes, so there is natural internal circulation inside the still. Hot air up, and cooler dryer air goes up the floor (closed circulation).

We start out using salt water as the cooling water (tank full of cold water in the morning), which is all that is needed to condense the water for the whole day. During the day cooling water heated by condensation in the solar still is stored in a classic style still—a salt

water pool with a greenhouse cover. That equipment does its usual lousy job during the day, but at night temps drop 25-30 degrees F (day to night) and overnight that hot water is only insulated from the cold night desert air by the greenhouse roof, so it pulls energy out and condenses like crazy (second effect). Cools the pool off so by dawn the tank water is cool, it is transferred back to the cold water tank and starts cycle again the next day.

RECAP: At dawn begin with tank-ocean water/saline water—coolant, recirculate water through the still for condensation then into second tank for “second effect” tank with transparent roof – 40% of distillate is from the second effect. That solar heated water is like a charged battery. The second effect does two things: produces more water, and cools off the pool for use next day.

Thin film of salt water on floor that receives solar energy throughout day, flows down black sloped roof. There is a closed salt water circulation and goes around and around. In the late afternoon stop adding make-up to that concentration (3000 parts TDS (total dissolved solids)) and concentrate it up to around 100-150,000 parts. That concentrate is put into a thin pan in 1/2" layer of water in thin pool, and in 2 days evaporates and is dry salt. Sulfates and salts (not sodium chloride) mix from ocean water.

That pan of salt condensate... the idea is to build it up over time to a 3" thick layer, then perforate on 3"x8" matrix, then break up into bricks. Build a building, stucco, and you've sequestered the salt. Like a salt brick "adobe" structure. Depending on what your feed stock the salt could be used as road salt. But 2/3rds of groundwater in New Mexico has more arsenic in it than what you can drink safely. What is left behind in pan... If composition of salt is okay then use for road salts, some like it for its mineral content. Potential building material.

A Las Cruces, NM artist suggested a round pan to begin with, build up as it goes with different form shapes and make a sculpture. Can't go very high with mold at a time, and the salt is built layer by layer.

The product (of the solar still) is pure distilled water. Free of minerals and bacteria. You have to add minerals back to distillate to make it taste right because it's devoid of all minerals. 93% of feed water winds up as distilled water from the still and second effect. You can increase productivity by using feed water to add minerals. But that depends on the quality of the water coming in. If there are poisons in the feed salt water you don't want to make the saline content of the product too high.

Small remote areas that do not have standard access to clean water. How do you scale this up to something like southern California on a massive scale? Scale and application—4' wide X 10' long X 1' thick box will supply water for family of four. Decentralized on-site system for drinking and cooking purposes. Modular designed equipment in standard units.

Add modules together: 3 modules x 8 modules put together, raises productivity tremendously. Multiple-effect distillation, multi-stage flash, membrane distillation, all need a source of hot water. Still creates this source to run multiple processes. Adding modules is what it would take to produce water for a small city. Need land available can put 24 modules together and feed into multi-stage flash or multiple-effect distillation... 20-50,000 gallon range or higher. This is completely scalable, based on amount of square meters of glass made available to the sun. Tiny model portable unit which fits in a briefcase still works (1 quart per day).

Use a pump for pumping water up the slope—1/50th of a horsepower swamp cooler pump. Also cooling water through tubes needs pumped, all can be done by PV cells. New Mexico unit for contest was completely off-grid and ran strictly on solar energy. Pumping occurs during day, so only works while the sun is shining, then the second effect takes over, then in the morning you pump the second effect water back into the tank and start over.

People are concerned about the thin film of salt water and a crusting effect, but we have commodity amounts of distilled water, so once per week or month we start off with distilled water in the system (hot

water) and it dissolves the salt that might be in the system and keeps it from building up.

No internal or moving parts, just an external pump. We can automate it—we ran non-stop 13 days with only simple timers. We had to stop for 4th of July holiday. When you use hot water for multi-stage flash, then that is more complicated. Our process can create a geothermal-like energy source anywhere. The hot water that is produced is like a source of that coming from nature but it is solar heated.

We have not explored making electricity production regarding the still, and focus on solar water distillation only. Electricity usually requires steam power and our still is designed for optimum distillation output of water, not making steam.

You can grow plants in the desert utilizing our stills too. Deserts are short of water, and shade, so desert application: 3 high modules, 1/2 meter space between rows. You can create a large space underneath the still that gets partial sun, which allows you to grow all kinds of plants that would normally not grow in the hot desert full-on sun. So you now have partial shade and a water source.

People are worried about economic collapse or the apocalypse, or just being self-sufficient. At the family level, the still can be used for as long as you need it. Life-cycle can run 12-15 years. The floor material that maintains the film might need some work or maintenance during that time, or the pump. Everything else—the box, the cooling tubes, etc., will all last over 15 years.

Hill Kemp is a chemical engineer, and started out on this project because of global warming. People have been trying to slow down or halt or reverse global warming. Because of this process and its peculiarities, it can be done on a very large scale. Cold ocean current offshore of Morocco (Canary Islands current) actually creates the Sahara desert, condenses all the moisture of the incoming weather, so it cannot rain past this area (called the rainshadow effect). High mountain ranges also create a rainshadow. My process needs cold water and good sunlight, and this is what these areas have.

Can grow renewable forests in 90% of that area using sea water as the source water and cleaning it via distillation. I have a voraciously growing tree species chosen that has a 75% growth time of a southern pine, which will grow well in these areas. Trees can replace what we have lost in tropical rainforests. CO₂ is converted to sugar and releases oxygen. They can store 24,000 tons of CO₂ per acre. [Trees are the lungs of the planet. The desert has been there a long time, and it can be turned into an oasis.] You can create an economy where there was no economy, especially when millions of acres of idle desert are available. If you get a drip in a water line 1-2 trees spring up naturally.

Could create a one-acre scale in NM but the sad part of the story is... I was in a contest and they got 69 entries in 29 countries around the world, and my still was in the top 6, but I was not able to raise enough money to build the unit to compete.

Been building these one at a time but they are designed for assembly line production. They should price out between \$600-900. A still for a household may be a little over \$2,000.

Contact Hill Kemp at www.suns-river.com [I recommend investors contact Hill personally]

Am working with UTEP (University of Texas at El Paso) to license the technology, contact Melissa Silverstein: msilverstein@utep.edu

Biggest road block now (have had grants from the government (put up 40% cost, he put up 60%), working with UTEP) is raising capital. Need the capital to begin the project at a larger scale. Our technology is so far outside the box and does not have a lot of gadgetry to it. Simple and off-grid. People want complexity in technology, but this is simple stuff. The National Renewable Energy lab and people think it's too simple and cannot get over it.

People could collaborate or team up to help with capital. Can build the unit and have it in operation in California and around El Paso, Texas for \$40-50K. The full-fledged business probably around \$2M.

Another application: a lot of people in the desert country learned they can grow pecan trees from irrigation water (has salt in it), about year 8-10 yrs the salts kill the trees. I have been working with folks to once or twice a month to water with distilled water because it dissolves the salts around the roots and rejuvenates the trees. So an occasional regimen of a distilled water flush can lengthen the life of the trees.

500p tds is what people expected for drinking water. If feed water is safe then this is doable. Distilled water is mineral free and virus free. You can drink it right off the still. No concerns for E-coli or other pathogens.

www.suns-river.com

Capital raising is going in with bartered rates right now.

I own three US patents and share two more with UTEP, and also is patented in Australia and India. I own this technology, so any partners stand to benefit from my intellectual property for a promising venture. Have spent six figures on patent lawyers with my social security checks to get this far.

BEYOND DISTILLATION

I personally did not feel that this topic about solar water distillation—making your own rain—would be complete without touching on a few more methods regarding the process of evaporation, condensation, and collection. Namely because technologies exist that many people worldwide are taking advantage of to purify water or produce it from thin air.

Yes, you read that right... you can produce water from the air, sometimes passively, without any electricity whatsoever. Dew and fog collectors fall into this category. So does collecting the water from earthtubes (I cover this in a separate book), which is a design I have played with for years, but not yet had a chance to utilize. Rainwater harvesting is yet another method I will talk about briefly, but first, fog collectors.

Fog Collection

There is a non-profit organization in Toronto, Ontario, Canada called FogQuest (fogquest.org) that utilizes sustainable methods for condensing and collecting water from fog. They report on projects occurring all around the world, from Guatemala to Yemen to Los Angeles, California.

FogQuest has also reported on how places like Japan have researched issues like fog chemistry, specifically in regards to acid fog and forest decline, or how fog drip is important to the ecosystem in humid climates. In places like Costa Rica or Puerto Rico they have fog/cloud forests, and experiments have been forthcoming for large fog collectors that can even withstand high wind speeds in Africa.

Places, people, and events that have shown interested and research or promote fog collection have included students doing their undergraduate or graduate thesis at Oxford University, international conferences on rainwater catchment systems in Mexico City, people doing fog deposition studies at the Free University in the Netherlands as well as the University of Bern in Switzerland.

World Water Day or Fog Conferences are events where you may find fog collection efforts being displayed, and people who utilize dew collecting methods also include groups involved in community services, social development, universities, churches and non-profit organizations (like FogQuest) or other NGO's (non-governmental organizations), Social Justice groups, governmental entities titled as the Department or Ministry of Agriculture, or other environmental, food, or water related groups or individuals.

Interestingly, fog is not only studied or harnessed in the cooler or wetter climates, the Desert Research Institute in Namibia and other desert climates (especially near the ocean, like in Chile where fog collection is popular) are able to harness water vapor for collection and use it as a water source, sometimes for entire villages.



“Fog Catchers”

Picture source: <http://inhabitat.com/possible-solutions-to-tackle-the-california-drought/>

Often these fog collectors look like a large square or oblong-shaped screen material stretched out onto a frame, with a collection trough underneath to collect the condensate. They typically work best at night when it is cool, just like how dew forms on the blades of grass and on plants in the cool of the evening. That is why these devices are referred to as both dew collectors and fog collectors.

Geographical Considerations for Fog Collectors

Like the air that cools and condenses water vapor into droplets within a solar distiller, air movement and wind are what carries clouds and fog through fog collector screens, along with topographical features (both large and small) are crucial features in having a fog collector (also called a fog fence) that works successfully.

Here are some of the features and circumstances you will need, based on experiences of those with fog collectors from the 25+ countries that use these methods that collect water for drinking, cooking, bathing, and irrigation purposes:

- Global wind patterns, trade winds, or persistent winds
- Mountain range that intercepts clouds, or isolated hill
- Altitude—typical altitude is at two-thirds of the thickness of the clouds for optimum moisture levels, usually ranging between 400-1000 meters above sea level.
- Orientation—it is best when the longitudinal axis of the mountain range is perpendicular to the wind direction. Clouds flow over ridges, through passes, and dissipate on the downwind side.
- Be as close to the coast as possible... 3-15 miles (5-25km) is the typical drop off rate, although these furthest distances work well as long as fog and upwind clouds pass or form there.
- Flat-topped mountains, ridges, and upwind edges are best locations to install fog collectors. Several meters of space (at least) should separate individual collectors in the array.
- No obstacles within a few miles of the array, upwind of the site, should be present. Winds will divert around ridgelines and other obstacles, reducing collection potential. A local basin may heat up during the day, creating a low pressure area, which can improve sea breeze speeds and help move clouds flow over the terrain.
- Prevailing winds force winds up valleys and cause wind direction changes. If the inversion base is below a ridgeline

then passes may serve as a good site.

- Studies show that site locations along ridges or crestlines, or just barely above the crestline, are optimum. Avoid a downslope wind flow.
- According to Natural Resources Forum (1994, vol 18, no 2), where this information is gleaned, “Gently rising slopes upwind of the collection sites are ideal.” Steep slopes make collection difficult. Also, where small valleys, large boulders, or lots of small hills are present the collectors may not function properly.

Mimicking Nature for Fog Collectors and Distillers

As you may have noticed, there are definitely some features within fog collection, where physics in nature is involved, that mimic the best possible situation for solar water distillation as well, at least as it concerns evaporation, condensation, and collection (at least in how my mind works and makes connections and sees patterns). Some examples...

A single basin distiller holds a small body of water, similar to the large body of water that is the ocean near fog collectors. In effect, by making a solar water distiller, one is copying what nature already knows how to do by recreating a miniature landscape with just the right elements, and harnessing its power to reclaim that moisture for practical use, just on a much smaller scale. The same goes for fog collection, except the ecology and geology and geographical features are already there and one simply recognizes it and places the fog collectors at the best possible collection sites, then causing condensate to form so it can be collected in a trough for storage.

In the case of distillation, moisture is created by heating the water with the sun and causing evaporation, which condenses on the cooler glass above the water. For fog, the sun heats the ocean and causes evaporation, which cools by winds and topography, forming clouds/fog that condense on the mesh or parallel wires of the fog collector.

I personally find it interesting that, like solar water distillers, where a slight incline in the glass (about 10 degrees) is present, fog collectors also work best when the land is at a slight incline. Both have to do with circumstances for optimum condensation rates. A still with glass too steep causes convection, and therefore circulation patterns within the still that disrupt the gentle condensation process. A hill with too steep a slope or rough topography similarly cause disruption in the wind patterns and reduces collection rates. A still with glass laid too flat will cause the condensate to fall back into the basin rather than roll down into the trough, and a flat landscape with not enough wind will not cause enough cooling for condensate to form on the fog collectors so it can drip down into the trough.

Both distillers and fog collectors work on similar principles but stills are a bit more versatile. Fog collectors tend to be limited by and are dependent upon location, terrain, wind patterns, moisture levels, orientation, and temperatures. A solar still can be placed just about anywhere, as long as there is sunshine. A limitation to a solar distiller would be having enough water to place in the distiller to begin with, whereas a fog collector, if in the right area, can produce water from the air itself.

Dew Collection

Although fog collectors are a type of dew collector, not all dew collectors collect condensate from fog. Nighttime dew that forms on plants, without the presence of fog, is an example.

A *dew pond*, like fog collectors, is usually in a depression on top of a hill, and is artificially made. Originally intended for watering livestock, dew ponds are utilized when natural sources of surface water are limited or nil. Dew ponds are also called *mist ponds* or *cloud ponds*, although they are actually not filled by mist or fog as much as they are by rain (that is important to know).



**Dew pond near Chanctonbury Ring,
West Sussex, England**
Photo source: Wikipedia

The saucer-shaped dew ponds are typically made out of natural materials, being lined with chalk or marl, puddled clay, or chalk/lime that is insulated on top with a layer of straw; however, some dew ponds are made out of cement or concrete.

The layering is not only used to collect the water, so that it does not pass through the ground and get lost, but also to deter burrowing animal, including earthworms. Clay is a commonly used near-waterproof barrier if it is done right. Sometimes soot is also used with lime and mixed with the clay. After the straw is laid down to protect the lining from sunlight, which could cause cracks, a chalk rubble is placed on top of that to prevent livestock hoof prints from damaging it further.

The concept is fairly easy, the pond is used to trap water and retain it, and cool air captured in the low setting also helps prevent evaporation. Letting grass grow long or placing it in a hollow also helps restrict evaporation. Dew ponds have a long history and go back before antiquity.

One could imagine how using a depression in the earth's surface that collects water could work in tandem with a solar water distiller that uses rainwater or similarly collected water to purify it further for human consumption.

ABOUT SOLAR WATER DISTILLER CONSTRUCTION PLANS

I have shared pretty much all of the information that I know and have practiced with the years I have had as the Project Manager for EPSEA in the grant projects for the solar still projects, as well as personal experience in designing, building, and using solar water distillers (I do not ever plan build a concrete still again—boy is that work!), as well as in training others and helping with solar still construction workshops. I have cleaned umpteen stills in the field, and installed well over 100 of them personally.

By now you should have a good idea about how solar stills work, and with the cutaway view, and pictures, and examples I have given you could probably build a solar distiller using just the information in this book. However, if you still feel the need to buy an actual set of construction plans in order to construct one on your own, then I would recommend splurging to buy the SolAqua solar still construction plans. There may be other companies that have some too, but I am unaware of them, plus am familiar with the SolAqua plans because they were based on the EPSEA still that we used in the field.

For years EPSEA had these available for sale to the public. There are three options for getting the original EPSEA (although no longer available through EPSEA because that organization is now basically gone) distiller construction plans, depending on your choice of media.

SolAqua spiral-bound printed copy
available for through
www.SolAqua.com

Last I checked the solar still construction plans were available at the bottom of the solar still “kit” page for \$27 (as of this writing). I hope

you have found this book useful and that your solar still construction goes well.

Remember that you can also use the *cutaway image* on page 69 to build a still now that you know which materials you can use that are safe, and where to buy hard-to-get materials such as the silicone.

A supplemental chapter follows about problems in colonias for those with further interest in the subject of social justice and clean water in poor or rural areas. The struggles of communities continue... I offer ways in which you can help, no matter how small the gesture, even if it is only by giving someone a copy of this book.

PROBLEMS IN TEXAS COLONIAS

I do not have a problem with rules and laws that are meant to help people and for the betterment of society as a whole, in fact, I was the former Social Justice Committee Chair at my previous UU church until 2010, and also helped with community water projects in west Texas/southern New Mexico colonias when I was the Organizing Assistant for Border Interfaith; we worked within the rules, and met with people in power (at the city, county, and state levels) to gain city water lines into some of these areas. However, when the laws meant to protect people wind up victimizing them instead, then I feel it is my duty to stand up and give voice to those who may not know how or have the means to do so themselves. I am not an activist, and am not an advocate, but I am a writer and so this is my contribution.

It is my love for ALL the people of this beautiful earth, and the part I have played in this story (whether installing solar distillers, or living in these areas with deficient water and impossible rules, etc.) that brings me to my knees in sorrow and regret that human rights and basic needs for quality of life are not met.

Water is life, and should be a right, not a privilege, because without it people die. When it is available but is polluted or deficient, then people get ill or die. It is not just water that is important... electrification, in particular, holds significant value in freeing up people from the conditions of poverty. Areas that are developed find growth, and improvements, and all neighborhoods in the entirety of America—from coast to coast, and border to border—have, at one time, begun as a rural single dwelling that someone called home. Whether that was a tipi (teepee), wigwam, or longhouse by Native American Indians, or by a settler that crossed the prairies by wagon and built a sod house, or whether it was a log cabin at the Rocky mountains, or a wooden shack built in the desert by a railroad track, these areas are

now called “cities” such as Sioux Falls, South Dakota (or other major city in another state where Indian tribes lived), or Omaha, Nebraska, or Denver, Colorado, or Phoenix, Arizona, respectively.

It is no mystery that times were hard in the past, but for some people today, it is just as rough. The homes that were built in the past always had to start with one, and then more were added, and in time villages turned into towns, and towns into cities, and modernization ensued, until today we have people who hang out in Starbucks and play games on their cell phones using the Internet. So much is taken for granted that to not have these luxuries must be a crime! No? Perhaps in some peoples’ eyes. They are labeled and turned into “the other”... as if sub-human. Verbal lines are drawn in the sand, and delineations of quality and worth are struck by the gavel or written in by the pen.

People in political power and common citizens alike must realize that some people *choose* to live rurally, and off-grid (the electric grid), and that their choices need to be respected, and their lives not quashed. In some cases it is all they can afford, or want to afford. In other cases—like for children—there is no choice. As a thinking, feeling, conscious society we have a responsibility to each other, to help when possible, and lift each other up. It is important to believe that tender circumstances today could improve and be strengthened tomorrow. It is important to know that most all American cities started out rural and poor and few in number for population. Rural communities today need to be given a chance to succeed as well. They need tools for survival, and education to build capacity so they can prosper.

Despite the fact that I am not blind to the problems in colonias, I find issue not with how people are living, but that they have trouble finding the resources they need to improve their lives. There are numerous reasons for this. My experiences and discussions with colonia families are more geared to helping people, and seeing them as trying to eke out a living like anyone else, just with far less money, plus due to colonia laws that often seem to do them more harm than good. This is particularly true in Texas where I am from.

I have to say that as a cultural anthropologist I have a bad taste in my mouth regarding the stereotypes about colonias that abound, especially among lawmakers and the media—most of who do not even live there—who portray them as filthy and vile, when rich people (ranchers and farmers and business owners that are well to do, for instance) live there too. There are a good many people who have clean drinking water (even if they buy it or purify it), flush their toilet like any other person in a developed nation, use their dishwasher, turn their thermostat up in winter, turn on the A/C in summer, charge their cell phones, play video games and watch TV, have a full working kitchen and appliances, and bathe or shower regularly like anyone else.



House near El Paso, TX. Notice the 2,500 gallon poly-water tank (uses water well pump for water pressure).

A household filter and distiller are not acceptable or “approved” forms of water purification for Texas border colonias...Why not? They need to be

NSF-certified systems. Any company/organization with an electric-free system like solar stills that are approved by the NSF may have a promising future in providing systems to colonia residents all along the Texas-Mexico border.

The word “colonia” has become a bad word, and so people who choose to live rurally, and live in a simpler lifestyle, are often grouped among the poorest of the poor, even if they are wealthy. The same Texas (in particular) laws apply to them, including the ones that forbid these homeowners to access electricity (even if it is available—causing their living conditions and quality of life to worsen to disparaging levels) unless they have a water well or get water from an “approved” centralized water supply.

Impoverished border town grows from shacks into community

By **Emanuella Grinberg**, CNN
July 9, 2011 3:57 p.m. EDT

www.cnn.com/2011/US/07/05/texas.colonias/index.html



What started out as a hodgepodge of trailers, shacks and homes in various stages of construction are giving way to homes typical of a middle-class American suburb as Las Lomas slowly prospers.

Screenshot from CNN shows a nice home in a Texas border colonia area—one of many thousands subject to the same colonia laws

Colonias, like every other community on the planet, may start out small as I mentioned before, but eventually grow and transform; despite counties that parallel the border (including inland within the continental United States) or that are away from the Mexico border, at the “magical” 151st mile mark and beyond. I am speaking of areas where actual colonia-like homes (such as deep in the Appalachian mountains or other rural areas) abound, yet have no state colonia laws such as these that forbid the sale of their homes or access to electrification unless they have an “approved” water source.

If the problem is *truly* about clean drinking water then a distiller or household filtration system would suffice because it solves the problem for clean drinking water. It is not just immigrants that live in colonias; US citizens live there too. To reiterate, if it were *truly* about clean water and healthy living conditions then permanent programs should be in place by now to help provide purification systems or other ways to improve quality of life for ALL of those in need.

I have heard it said many times, including by an elected ex-House of Representatives, Hydrologists/Engineers, Community Leaders, and so on that what is happening in Texas colonias is unconstitutional. Mark my word that some attorney(s) in the near future will be filthy rich on a contingency fee when they hire someone who is Spanish-speaking (I am not that person) to help organize the people for a class action lawsuit due to Texas legislators that have made laws that are not only illegal, but that seriously damage peoples’ property values, plus forbid them access to electricity that they need for quality of life (based solely on having “city water” (they know is not available) or a “well” (that is also not feasible in many desert areas because they can cost \$10,000 to drill deep enough, and many come up dry or have horribly saline unpotable water)).

The consequence to these laws is that people have had electricity and could not get it turned back on once turned off, so they were

forced to abandon their homes or live in true third-world conditions. Is this not a crime?

Others have bought land, spent thousands developing it and getting septic tanks and house foundations put in, only to find out they could not get electric service even if they paid for it entirely out of pocket.

Yet other families have built their homes and lived comfortably for decades but have a change in employment so needed to sell their house to move, only to find out that the new owner of the home cannot legally get electric service, and only the original owner can get a waiver to get it back on (in their name, ONLY if they live there themselves, but by then it is too late—these waivers were non-existent until well after the first colonia laws were instituted).

Who is going to pay for all of these losses that Texas has caused? I have heard so many horror stories over the years. This does not include the special favors that have been given to ‘pay off’ legal suits that were basically won behind closed doors—by those with money—against the state (yes, I heard about this firsthand from someone who ran a business in far east El Paso, but do not ask me... do your research!). However, many if not most colonia residents are not aware of the laws, let alone their rights, nor do they always have the money to fight in a court of law to regain their financial and other losses. They give up, or they live without any amenities whatsoever, in far worse conditions, because they have nowhere else to go or cannot afford to lose what they have already invested in their home. It sickens me to think about it.

The losses have occurred to so very many families across the entire Texas border, whether Mexican (realize the majority of people living in US-Mexico border colonias are Hispanic), Caucasian, or other ethnic background, or whether they are rich or poor or in between.

The laws discriminate against their location and whether there is city water, yet the state is not paying to bring them that city water either. Their goal is to “eliminate colonias” so they do not have to pay—to force them to move and reduce population in these areas (many of which include immigrants, whether legal or not, including legal

citizens), and so without dense population numbers in these rural pockets the officials are now especially disinclined to ever substantiate the cost of bringing city water to these areas. Problem solved, right? It is like big brother being a bully and abusing rather than helping his little brothers and sisters.

Colonia dwellers are doomed no matter what, unless they stay put forever (with or without electricity), waiting another 20-30 or more years before city water might finally arrive. Colonia laws are causing extreme hardships in numerous irreparable ways. Yes, irreparable because it is not reversible. The damage has already been done. They live without clean water, and in some cases without electric service, and not by their own choice, but by force.

Yet solar distillers can help people now, even if only in some small way. Small blessings can be a Godsend, however. They work whether or not there is electricity or city water pressure available. It is a solution to the health problem the colonia laws have caused/worsened.

Almost ANY water source, including pilas or water storage tanks, could otherwise be purified a good number of ways, from a whole-house filtration system, to RO systems, to solar water pasteurization methods, solar water distillers, etc., so realize that the laws are not actually promoting health via water sanitation, but rather causing unnecessary hardships on families by worsening their living conditions.



My son Tyler and “Donald” (still recipient) near Hueco Tanks Historical State Park east of El Paso, TX. Note the two 5-gallon jugs sitting on the still, which Donald said were BOTH filled to the brim daily via this solar distiller (due to the hot desert days).

The Texas colonia laws are found in Subchapters B, C, and E of Chapter 232 of the Local Government Code. These laws were designed to eliminate colonias in similar ways that laws in the past were designed to disenfranchise or eliminate “races” of people, and have made the residents’ homes practically unlivable (without access to electricity, although since then there is one law—HB 2096—that they passed that grandfathered in the original homeowner—since then other Senate Bills or House Bills may have been passed as well, but as of this writing the colonia laws still stand, much to Texas’ own detriment in the end, I predict). The laws have devalued the homeowners’ land substantially (making it worthless and unsellable). It is illegal for the homeowners/property owners to sell their own property, and all of this done without the reason of “imminent domain” by the state of Texas. *Houston, we have a problem* (or should I say Austin?).

Aside from a collective lawsuit, the only way around these laws for individual land owners is to make them not applicable to one's life... by living sustainably on their own property without the need for their centralized utilities and the bills that go with them. At least there is hope for a return to quality of life in this way for those who feel stuck. It should not be illegal to *choose* to live off the grid any more than it is legal to be *forced* to live off-grid.

Perhaps for some there is no need for a *non-transferrable Certificate of Compliance* to receive electric service like anyone else in the city has the right/privilege to (colonia dwellers are not afforded the same rights/privileges, and in fact, have no rights as legal land owners now, so there is definite discrimination here).

Texas colonia laws? *We don't need no stinking Texas colonia laws!*

No electricity? Sure, because some people have solar panels and/or wind turbines, passive solar homes, and natural cooling systems like earthtubes.

No city water? No problem, because some people have rainwater harvesting, water storage tanks/cisterns, graywater recycling systems, NSF-approved composting toilets, and solar water distillers.

Yes, there are always ways to survive, and thrive, and live a healthy lifestyle, but who of the poorest of the poor in colonias can afford these things? It is a catch-22 and the state knows that, yet forces its heavy hand anyway.

The colonias are a worse mess than if the government had done something to help instead of hurt (hurt, in the name of "help") these families; but I digress... this is supposed to be about water and why solar stills are so crucial to humanity worldwide, not just in states or countries that do not take care of their people.



Solar still on top of a pila in west Texas colonia

This is exactly why solar water distillation is so important, because it is a method that is both inexpensive and reliable for bringing absolutely pure water to colonia dwellers, or anyone else for that matter. Solar distilled water is far cleaner than the chlorine- and/or-fluoride laden 'approved' city water that the rest of society drinks, which is full of a lot of other nasty smells and tastes and whatever else is in there and defined as 'drinkable.'

I would probably apologize for the length of this particular portion of this chapter because it is a side-step to the actual construction of a solar distiller... but is it? Methinks that it is crucial for people to know, and for others to realize that people in the know, like me, need to be a call for help for the many silenced voices that have not been heard.

Here is an opportunity for you to help in colonias... where is the need? Fill it. Who has the deficiency? Aid them. Where is the money to do it? Go get it. Who can put a stop to this madness? Change it. Speak Spanish? Motivate the people, sign a petition, hire an attorney, do whatever it takes.



Still facing solar south with white shed wall behind it to reflect extra sunlight into the still to boost production

One last diatribe... I am not a conspiracy theorist, but realize that these laws were originally intended to go after shady land sales companies that promised water that would never come, yet somehow turned against the customers who bought the land in hopes of the so-called "American dream." Wake up America! I think it would be a good service to humanity to actually have laws that serve the people, rather than victimize the victims. Okay, I will get off my pedestal now about the laws that punish rather than advance individuals and families, including children and the elderly... that is all I have to say about that.

That said, it is no doubt true that in a number of the more poor areas in colonias some of the houses do not have adequate septic systems (if at all) and/or no running water. However, as we know, *not having city water does not equal not having potable water* and anyone telling you otherwise is ignorant of the truth. Solar water distillers are about as perfect of a solution as you can get for areas with full sun and a lack of utility services. The water is cleaner than mere "city water"... not just pure, but ULTRA-PURE by laboratory standards and testing. Distilled water is the purest water on the planet, period.



Grunge in the bottom of a 55 gallon drum (a water storage container found in some border colonias).

Whether people drink water out of a drum like the one shown above or not, it is simple solar water distillation technology will remove ALL non-volatile contaminants from non-potable water stored in containers such as particulates (salt, sand, sediments, rust, etc.) heavy metals, and other contaminants, and a small carbon filter will solve any problems with possible volatiles.

To recap, the solar stills are appropriate technology for colonias, rural, and other areas because they are site-specific, use no electricity to run, have a quick payback period, require no running water to work, get rid of all microbial contaminants (including giardia and coliform bacteria, which are commonly found in colonias and other areas), have a life expectancy of 20+ years, and are easy to use and maintain. They are especially great for people with health problems, the youth or elderly, or pregnant women.



**SolAqua style stills installed
for a family in Anapra, Mexico**

Now, with the tools I provide in this book, solar distillers can be made by colonia dwellers, and grants can be gotten by Universities, NGOs, non-profit organizations, church, and the like, to provide solar still materials/kits or manufactured distillers to these communities in need.

If nothing else, perhaps you can build a still yourself and teach someone else how to build one. Or perhaps you can buy them a copy of this book so they can build it themselves. Or if you are so inclined, you could give them the copy you hold in your hands or share it with someone else who can make a difference. How can you make a difference for someone today, or next month, or before the year is out? Writing this book, and providing version-1 of this book free to the public, is my personal contribution. I pray for a better society where people take care of each other, and where government does the same.

***Enjoy building and using your
solar water distiller!***

HOW TO DESIGN A PASSIVE SOLAR HOUSE

DEDICATION

Dedicated to all the solar energy enthusiasts who support renewable energy and energy efficient housing, who taught me and many others, and who still inspire the world in this field today and beyond. Yes, Chuck Reel, Mike Cormier, Steve Cook, Hector Gasquet, and Robert Foster, in particular... this means you... thank you.

INTRODUCTION

This book is for beginners and people who would like to know how to think about passive solar home design and learn about design features that go into eco-friendly and energy efficient homes. This book is also for the owner builder (someone who would like to build their own house), whether they prefer standard construction or alternative construction techniques (such as straw bale home construction). Passive solar principles can be applied to most any house floor plan.

Many people hear me mention a “passive solar house” and automatically picture a regular house with solar photovoltaic (PV) panels on them, which produce electricity for the house. In fact, that’s the first thing they generally start talking about. However, a passive solar house is NOT necessarily about solar electrification. Interestingly, while a solar house CAN be electrified using solar panels, this does not necessarily have to be the case; it is more about the design and functioning of the house itself. So then it begs the question for those who want to know... just what *is* a passive solar house?

In short, a passive solar house is where the home itself becomes the solar collector; not for producing electricity, but for gaining thermal comfort—heating the home *passively* without any moving parts or electricity needed. The house is designed to allow the sun in during the winter for added warmth, and yet keeps the sunlight out during the summer so that the house stays cool. To the novice, this seems like it requires some kind of magical formula, high-tech equipment, with an expensive price tag attached, but nothing could be further from the truth... at least not historically or prehistorically, nor does it have to be in our modern era. To be honest, where a passive solar house *could* utilize technical or mathematical formulas, and expensive equipment, and have high costs, it simply does not have to. People have built passive solar homes for pennies on the dollar, or even free (if they are resourceful enough).



A passive solar house is where the home itself becomes the solar collector

In this book I will show you how to design a simple low-tech passive solar home yourself, which can have high-tech add-ons if you choose. Ideally, a passive solar house is just that... passive. That means it has no fancy gadgets or electronics or machinery or moving parts at all. Where some parts may be moveable (such as insulated shutters that can be manually or automatically open and shut), these things are optional and are addressed through personal choice and budget allowances. However, the bones of the house (the basic structure) should be able to nearly hold its own without much or any aid at all for heating or cooling, when it is designed right. This is the whole point—to live in your home without spending excess money for construction, heating, or cooling, in order to be physically comfortable. This saves energy and money in the planning, the process of constructing the building, and continues for the lifetime of the house in greatly reduced (and in some cases eliminated) utility bills. It is all in the design.

You will hear me repeat, numerous times, the main principles of passive solar design so that by the time you finish this book you will have a handle on it; the knowledge will 'stick to your bones' so that you are convinced of how it all works. It is relatively simple.

This book also will show a little information about how my family and I built a passive solar straw bale house when we lived in Nebraska in the 1990's. We had the completed shell of a 1,500 square foot house (for \$20,000) when we move inside to finish it. Although we lived in a no-codes county, most places have building codes and require building permits in order to construct a home, regardless of whether it is standard construction or alternative construction. I will provide examples of what you can do to design a safe and adequate passive solar home, plus will provide tips to get house plans drawn up to have it approved for construction through your local planning or zoning department for building permits.

Passive solar design of buildings is not new, but a very ancient practice. People have been doing this for literally thousands of years. They had no special modern equipment, but they did understand how to track the movement of the sun, and in some cases also understood astronomy at a deep level. Although you do not need the latter to design a passive solar home, you do need to understand a little about the sun and how a passive solar home works, because although it has no moving parts, it still functions. Like the bones in your body support your weight so you can do what you need to do, the passive solar design aspect to your home is the support that ensures your home functions smoothly and is balanced between heating and cooling. This means you will need to understand basic principles of solar insolation, the "true south" direction (solar south), glass-to-mass ratio, and insulating materials vs thermal conductors (thermal mass), how to calculate overhangs, among other things. I will cover all of these and more in this book.

When you design and build a passive solar home it should be able to provide 20%-60%—and in some cases even 80-90%—of the home's heating without additional aid, and all for an additional cost of about \$1-3 USD per square foot. This means a great reduction in heating as well as cooling bills. Most conventional homes are too poorly designed (so builders can build them cheaply) to utilize this natural resource. I will show you how to think about solar design. You will be provided many simple concepts in this book so you can understand the basics and physics of why and how solar energy works, and—as they say in permaculture—how to *sink it* (solar orientation), *slow it* (thermal mass storage), and *spread it* (insulation makes it go farther / last longer). Mostly, I want you to learn *how to think* about solar energy so you can apply what you learn to designing and building your own home.

In the meantime, here are some basic ideas of what some of the peoples from past cultures and even during modern times have done with passive solar, and how dwellings and other constructed objects or buildings were designed to be aligned to the sun. Where some of these were for ceremonial purposes, the principles of solar movement

and tracking and aligning as it relates to manmade structures are the basically same. Anywhere the sun shines can utilize passive solar design. The great thing about the sun is its warming rays are free to all.

The Sun in Past and Present Cultures

Aeschylus was an ancient Greek playwright and philosopher who lived around 525 / 524 BC – 456 / 455 BC said rather bluntly (much to the chagrin of many of today's modern home building contractors and architects):

"Only primitives & barbarians lack knowledge of houses turned to face the Winter sun."

Socrates, who lived from 469 BC – 399 BC, on a more practical note said:

"Now, supposing a house to have a southern aspect, sunshine during winter will steal in under the verandah, but in summer, when the sun traverses a path right over our heads, the roof will afford an agreeable shade, will it not?"

The ancient Greeks and places like Priene in Asia Minor provided a way for every home in their cities to have access to solar energy during the winters. Their streets ran north-south and east-west so all homes could face "solar south" and warm their dwellings.

Ancient Rome had south-facing rooms called a *heliocaminus*, which means "sun furnace." They trapped the heat from sunlight in these rooms by putting in windows of mica (muscovite is also a form of mica). Mica has basal cleavage, which means it is a mineral that grows in long thin sheets, one on top of another, and can be peeled into thin flexible sheets for use. This is why chunks of mica are called "books of mica." The heat held in the room, because of this window barrier, made the *heliocaminus* a very warm place to stay or sleep in.

The Greeks did not utilize these windows of mica in their southern-facing homes, so consequently they were colder (but not nearly as cold as homes that did not face the sun!). This goes to show that solar energy can be as efficient or as inefficient as one prefers, depending on the amount of knowledge and materials at hand. Small choices can sometimes make a big difference... it can make a home that is 20% more efficient, on up to 60% or more.

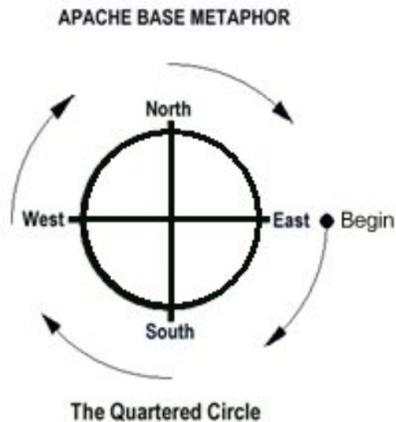
The bathhouses in Rome had large windows that faced south; nevertheless, many areas in Europe stopped utilizing solar design after the Fall of Rome. However, where one culture loses its traditions in architecture and culture, others survive and thrive. Commonly, knowledge like this spreads between cultures through cultural sharing. It can also be discovered and developed independently. It does not take a genius to understand the simple concept that the sun warms things up, or how to pay attention and figure out how to capture that energy so it can be used later. Modern day home builders and designers have ignored or never learned these principles, which is both stupid and sad, respectively, in my opinion. It is unnecessarily costing homeowners hundreds of dollars extra annually to heat and cool their homes, which multiplied by millions of homes across the nation(s) is contributing to the environmental disaster we are presently witnessing in the world. I shake my head in despair, and write books like this to help remedy the problem, one house at a time, and hope it will spread like wildfire. All homes and buildings should be passive solar, period. This is ancient 'technology' still applicable to today.

Some countries have a long history of tapping into the sun's warm rays. China's traditions and practices, which were guided by the cosmos, continued on (for millennia) the knowledge and practice of associating the southerly direction with not only summer, but with good health and warmth. The Forbidden City in Beijing was aligned in 5 directions – east, south, west, north, and center (the "center" was where the Emperor was). Both astronomy and Feng Shui are associated with ancient solar and cosmological influences. Some practices should not be forgotten.

Native American Indians have utilized the sun for thousands of years, and kept within their traditions sacred ceremonies that pay homage to the natural order of earth, sky, water, and the great fire in the sky... the sun. There are other items of importance, depending on the tribe, but the Lakota Sioux realize that there are not just 4 directions, but 6 of them (east, south, west, north, up, and down).

To the Apache people the number 4 is in accordance with the four directions. They begin their ceremonies from the east, and then

dance “sun-wise” (clockwise), toward the south, then the west, and finally the north, before closing the circle in the east where it all began. The reason this is called “sunwise” is because this is the path the sun travels in the sky (at least in the northern hemisphere)... sunrise in the east, the solar body travels across the southern sky during the daytime, and then sets in the west). For the Apache, the early morning sun shines into the east-facing opening of the ceremonial tee pee signaling for the teenage girls (in their “Coming of Age Ceremony”) who run out with their baskets to begin the rituals they have prepared for as they enter into young womanhood. After four days (for the 4 directions, 4 divisions of the day, 4 seasons, etc.) of the ceremony and feast the girls end the official public part of the ceremony the same way, running into the eastern sunrise with their



baskets, before giving away gifts to the crowd. Always (with few exceptions) their dances begin in the east and go sun-wise, as a symbol of how the sun tracks through the sky. This is following the natural order of things. It is called paying attention.

The sun is, in many cultures, associated with the endless cycles of life. It is the giver of light, and of life. The Maya in Central America were cosmological and mathematical geniuses when it came to celestial observations and how they derived their three calendars into one. They understood about the solar equinoxes, solar and lunar eclipses, and planetary alignments, and they paid special attention to the moon and Venus as well. Their large-scale architecture, like towers and temples, included construction where the sides faced the four cardinal directions. In the classification of what are called E-

group structures, the stepped pyramid would always be positioned on the western side of quadrilateral platforms / plazas. North and south structures accompany the plaza on the eastern side, and an east-side stairway allows one to climb to the summit of what archaeologists now think were observatories. From the summit the sun can be seen very accurately through smaller temples during the equinoxes and winter and summer solstices. Another Mesoamerican city called Teotihuacan has a structure called the Pyramid of the Sun.

The SUN is the SOURCE of what directs human observation (not forgetting the moon and the rest of the cosmos) in and of nature to dedicate the “sunrise” to the east, and the hottest part of the day to the south, and “sunset” to the west. When the sun is not visible at night, it is on the “north” (other side of the earth) until seen again in the next sunrise. Ancient societies understood that the sun was not “gone”, but just remained hidden before it again appeared where expected the following morning.

Many cultures, specifically Native American Indians, have associated the east with birth and youth, the south with adulthood, the west with old age (and/or death and dying), and the north with the underworld or the unseen spirit world (understanding and having that faith that although it is not seen with the eyes, it still exists). Renewal comes with the next morning’s sunrise. It is no surprise that the sun, namely solar energy from the sun, is called “renewable energy”, even though it really means that it can be renewed, since it is an unlimited source that returns and returns, in what seems an endless cycle.

Many cultures throughout history and prehistory worship(ed) the sun, and it has been tied into many of their religious beliefs, whether they used it in their architectural designs or not. In Egypt there was Ra / Re, the sun god. Also, the 5th Dynasty Pharaohs built Sun Temples. The Sun Temple at Niuserre was excavated by Borchardt between 1898 and 1902. The Sun Temple had an obelisk symbolizing the benben (the rock, when during the creation of the world, had the sun’s first rays shine on it).

The Great Pyramid at Giza (built around 4,500 years ago) is probably the most well-known of all of the ancient structures in Egypt. Each of the four sides face closely to the four compass directions of

east, south, west, and north. For a moment, we will focus on the north side (realizing it includes, not excludes, the three remaining sides, due to its equal 4-sided shape). The reason it does not point directly to magnetic north is because it is off by a little bit, which makes it face directly to what is called “truth north.” You will be learning later about what true north, and especially TRUE SOUTH, both mean, and how this relates to the passive solar design of homes and other sun-oriented buildings.

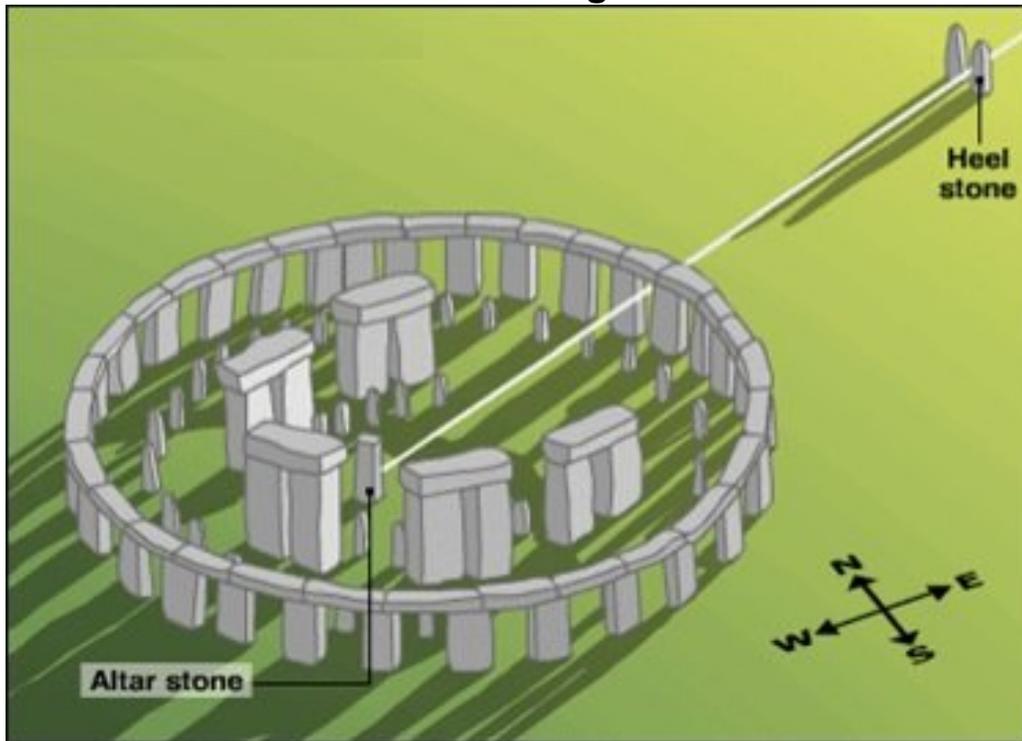


Aside from the pyramids, there are also places of interest, which are also wildly popular among tourists and people who enjoy topics of archaeoastronomy or ancient construction techniques, such as

Source: easyweb.easynet.co.uk Stonehenge, Wood-henge, and more. One item of interest is a 4,000 year old circle made of **Seahenge** timbers called Seahenge, since it was found just off the Norfolk coast.

Another well-known ancient structure, made up of many vertical and horizontal megalithic stones arranged in a circular pattern, was known to be used in accordance with the cosmos. This would be Stonehenge, located in Britain. This is still a place today that is considered sacred by those who attend the first morning light of the summer solstice (the longest day of the year) event, as well sunset at the winter solstice (the shortest day of the year – with the equinoxes being exactly the same day-length during spring and fall).

Stonehenge



Source: news.bbc.co.uk

Two miles northeast from Stonehenge is a place called Woodhenge, where 6 concentric rings made up of postholes form its shape.

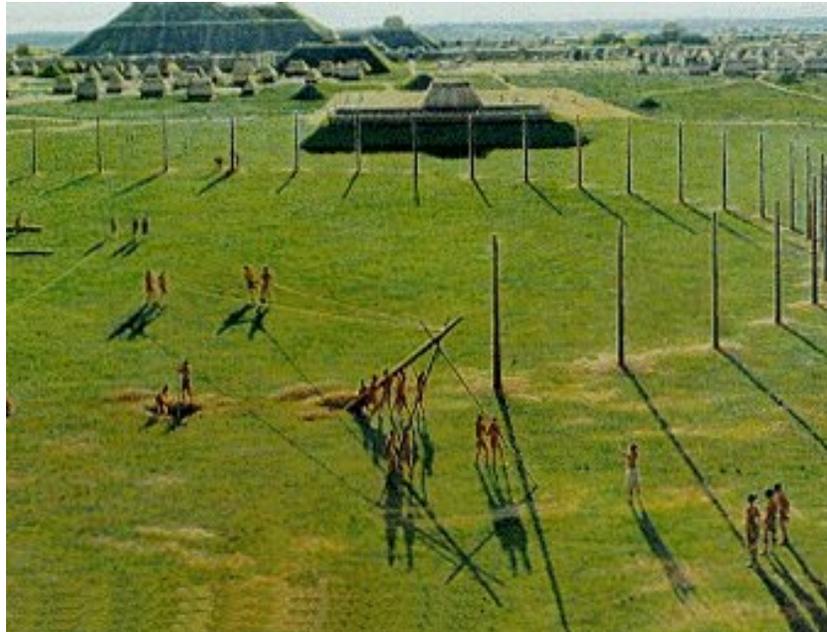
Woodhenge



Source: catkinlodge.fsnet.co.uk

There is also a North American Indian based “Woodhenge” at the “Cahokia” site (600 AD – 1400 AD) near Collinsville, IL, that is part of the diverse Moundbuilders cultures (3000 BC – 1500 AD, including sites all over the eastern US. The site(s) is/are also based on the 4 directions and that also mark the equinoxes, solstices, and other cycles in astronomy.

Moundbuilders



Source: www.utexas.edu

A passage tomb called Newgrange, dated around 3,300 – 2,900 BC, and located in the Republic of Ireland has a strange hollow box-shaped passageway above the door. This passageway is aligned perfectly with the winter solstice sun to light up the interior of the tomb on that single day out of the year.

Newgrange in Ireland



Source: knoweth.com

These ancient civilizations and peoples and cultures exemplified above make but a collective dent into the vast list of places around the world where the sun, and other astronomical bodies and cycles, were important, and continue to be important today. The study of the importance of these alignments falls under anthropology, ethnoastronomy, archaeoastronomy, as well as other cultural studies and archaeology.

As we have seen, the sun (among other things in the celestial sphere) has been very important to human beings for millennia. The sun is still important to people in our present day. Solar energy and wind energy (wind being a result of solar infrared heat causing convection currents) companies abound and are flourishing as a renewable energy source, especially as pollution and climate change concerns continue to escalate. Technological knowledge is increasing daily, and the price of oil / gasoline is pushing the solar energy arena to a more equally competitive basis, at least when it comes to certain applications. Renewable energy sources of all kinds are crucial to our future, and whether we use solar energy for electricity, or for hybrid or passive solar designs, including our homes, we can be rest assured that the sun is not going to disappear... it will always rise again in the morning.

Today, in our modern world, we emulate the light from the sun with mini-electric “suns” (light bulbs) that can be turned on by the flip of a switch, and we take much for granted in doing so – that is, until a storm or other event knocks out the electricity as a reminder that we are quite dependent upon this technology. Passive solar homes should use less electrical lighting during the day because sunlight floods in through the south-facing windows, so they are naturally very bright and cheery, which saves on your electric bill. In the winter the sunlight enters directly into the house, and in the summer it is indirect lighting that brightens the room.

Be sure to tailor your home to your latitude (I will teach you this later), environment, climate, and pay attention to what indigenous peoples have done historically IN YOUR REGION. Several solar energy resources are below.

U.S. Department of Energy, Energy Efficiency and Renewable Energy:

<http://energy.gov/eere/solarpoweringamerica/solar-powering-america>

Look up your state and regional chapters of ASES (American Solar Energy Society):

<http://www.ases.org>

Natural Resources Canada – Renewable Energy:

<https://www.nrcan.gc.ca/energy/renewable-electricity/7295>

Solar & Sustainable Energy Society of Canada Inc. (SESCI):

<http://sesci.org/>

PASSIVE SOLAR BASICS

Designing and building a passive solar house is easier than people realize. I was 19 when I learned about solar energy for homes, and by my mid-20's had designed and was building a passive solar straw bale house in rural Nebraska, about 40 minutes' drive northwest of Lincoln. We built the house ourselves with new, used, and free materials. The 1,500 square feet shell of the house (that we moved into in order to work on the inside) was finished in 1998 and had taken us a few summers and fall seasons (with a little done in the springtime, and never the winter). All of the labor was done by (my then-husband) Gerald Martin and myself, friends, neighbors, volunteers, plus our children helped in any way (however small) they could as well. At one point we co-hosted a straw bale construction workshop so had a dozen or so adult students from that class help us build the walls. Later, we hired a few young men to help put up the roof trusses and install the metal roofing. After the roof was on, winter was almost upon us so we had to hire the only professionally-contracted out work that was done on the house, which was to plaster the house. The last of the fiber-reinforced plaster was troweled on just as the snow arrived. Our total investment for the completed shell was \$20,000.

**Straw bale house we built, as it
looks 20 years later**



If you want to design your own passive solar house (whether standard construction (wood frame, metal frame, post and beam, etc.), or using alternative materials (straw bales, cob, rammed earth, adobe, etc.) and build it yourself, then you may have questions such as:

- What exactly is a passive solar house?
- What does active solar mean?
- Is a house “solar” without PV electric panels?
- What does it cost to build a passive solar home?
- How energy efficient will my home be?
- Can I really design and build it myself?
- What are the differences between a passive solar home and one built by standard construction?

I will attempt to answer all of these questions and more in this book. If you do not think you can build it, then think again. Learn more, do more. Build your knowledge base, your capacity, and your efficacy. Help a friend, and ask for people to help you. Never stop learning, and trying new things. If you really want to build a house, you can, although there are easy and hard ways to go about this. First

of all, it should be done correctly (with building permits where required, and professional help where it is mandatory). Second of all, whatever you build should be done well. Built it above code, not just “to code”. If you plan to stay in it a while, or longer, then you will definitely reap the rewards of a home built well. Do not get me wrong... you will make mistakes, just as I did. There are some things I learned that I would not do again. It will likely be the same for you. Try to learn from others’ mistakes by not repeating them.

My goal is to give you a solid understanding as to what goes into the simple design of a passive solar home. Once you understand the basics, then the rest comes easily enough. I cannot promise that you will learn everything there is to know about designing a passive solar home, but you will walk away with a solid grasp on what it means, how to design a passive solar home, what your next steps are, and you can follow the advice in this book to start a plan that is tailored to your needs. Lastly, you can mark off the checklist (last chapter in this book) for each item you have accomplished. Before long, you will have a floor plan, your land, a site analysis, will have drafted floor plans, obtained proper permits, and then you will break ground and begin the work on the infrastructure, foundation, walls, electrical and plumbing, insulation and roof, and whatever else is required in your plan. Having the ability to envision the final product in your mind, and then putting it on paper and constructing it one step at a time, will eventually pay off in dividends... a home of your own that will have greatly reduced utility bills that lasts for either your lifetime and/or the lifetime of the house.

What is a Passive Solar House?

Passive solar house? As I mentioned in the introduction, most people I have met who are not familiar with the ‘passive’ part of ‘solar house’ typically imagine a large array of solar photovoltaic (PV) collectors placed on the roof or in the yard by the house. However, solar panel collectors—also called PV panels—for producing electricity are not a ‘passive solar house’. They can be added to a passive solar house, but they also may be nonexistent on the home.

PV systems are usually considered a hybrid system between passive solar and active solar.

PASSIVE solar is a system using solar energy *without* moving parts in order for it to 'work'.

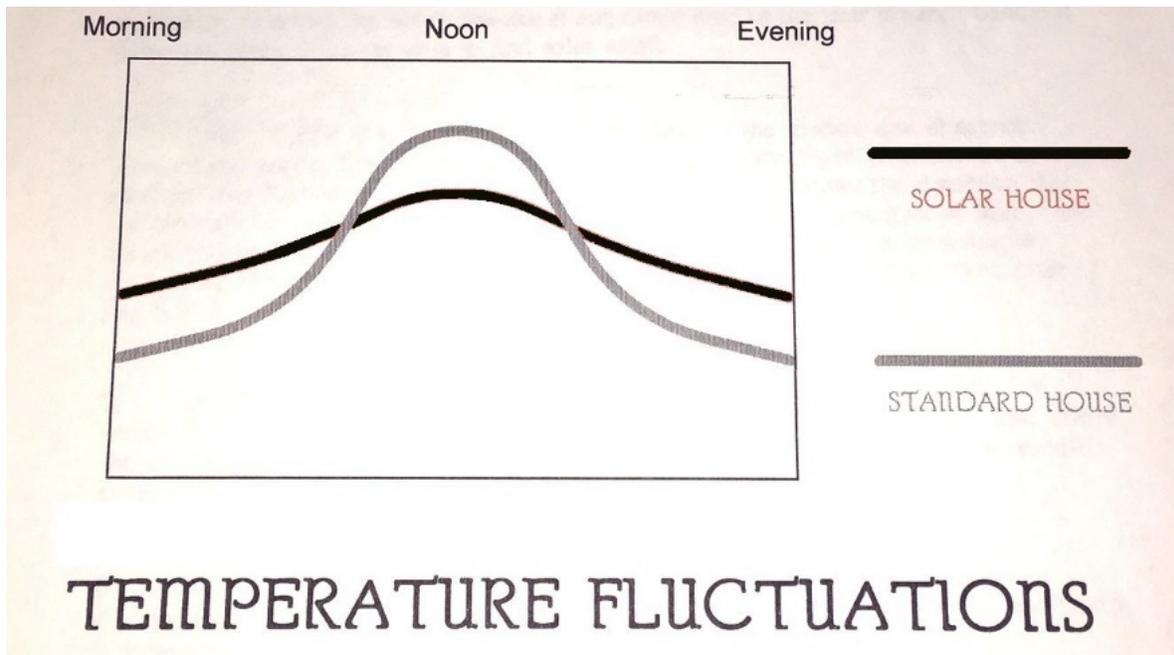
ACTIVE solar implies using solar energy in a system *with* moving parts... mechanical pumps and fans, etc.

PV panels, although considered passive in and of themselves, provide the electricity to run these contraptions; therefore, a PV system is typically considered a HYBRID solar system since the electricity is directly connected to the use of lights, plus electronic and mechanical devices (pumps, fans) and appliances. Some people just consider PV systems as 'active' systems for this reason.

The problem with mechanical machines is that they have moving parts that wear out, so in time they will inevitably break down. In contrast, unless you had a keen eye, many people likely would not notice that a passive solar house was even solar oriented unless they had a good idea of window placement and its relation to where 'solar south' is located, and specific knowledge about solar angles and overhang lengths, etc. A passive solar house can look like any other house on the block, except that they typically have many south-facing windows, but lack many windows on other sides of the house. Because a passive solar house is designed for energy efficiency, it may be superinsulated on the north and west sides (all sides where there is no glass / glazing), and especially in the roof as well as the foundation.

To further distinguish the difference between a standard house and a passive solar house, you need to know that technically, most EVERY HOUSE IS A SOLAR HOUSE. This statement is true as long as it has windows on at least one side and allows direct sunlight into the home. The difference comes in here: a properly designed passive solar house will be naturally—and many times significantly—warmer in the winter and cooler in the summer than those built by standard construction (the term 'standard construction' meaning up to 99% of

the homes built by residential building contractors) without the aid of additional heating or cooling such as with HVAC systems, wood stoves, pellet stoves, oil heaters, electric heat, air conditioning, etc. I am not saying a passive solar home would not need a heating source, especially in the north, but I am saying that the temperature inside a passive solar energy-efficient home is more stabilized and comfortable without a furnace if you compared it to a standard house without a furnace.



The next obvious question people ask is: how can this be? They guess: does it have to do with having more insulation? It could, but that is only part of the equation. Is it because of better, more efficient heaters and air conditioners? No. More cost into building the home than a standard house? No, not necessarily that either (although it can cost more, but on average only \$1-3/sq ft more). Is it because of all those windows that let the sun into the house? Well, yes, but that is only partially true. Then what, you say? The key is knowing not just how to let the sun IN to help warm the house in the wintertime, but it is also about knowing how to keep the sun OUT in the summer. Also, the energy from the sun must be stored somewhere, and this happens in thermal mass materials, which are strategically placed

inside the building envelope. I will explain more about thermal mass later.

Every house is solar house

So how is this little trick done? Is it just a matter of adding windows and insulation and more mass inside the home? Well, before I tell you, let me ask you something, because the point of all of these questions and answers is to help you think about solar design. I want you to understand the basics. I want you to be able to walk into *any* house, look around, and be able to pick it apart, so that you can tell right away whether it is a good design or a bad design (this is actually really good practice—go on a solar home tour, then go visit ‘open house’ homes for sale and notice the differences!). Whether it is energy efficient or has flaws. Believe me, after reading this book you will have a grasp on exactly that. It really boils down to simple physics. Do not worry, I said *simple!* For example, think about the home you live in now... do you have any windows that face west? If not, then think about a house you have been in that has west windows. Have you found that in the hot summer, after an already sweltering day, when the sun is lowest in the sky, that the blazing sun is shining straight through that west-facing window making it even HOTTERR in your house, and causing your air conditioner to work even harder? You can shut the shades or curtains, but it is too late—the sunlight has already entered the window, therefore making the house warmer than it should be. Folks, that is what solar experts call energy *inefficient!* If that is happening in your home I can almost bet that the home / building was built under "standard construction" methods or just poorly designed; however, it may not be the contractor’s fault... they just build according to the design (house plan) they were given. Architects are knowledgeable about passive solar—let them work for you in the best of designs... passive solar. The most vital part of an energy efficient house is all in the DESIGN (proper design). If you superinsulate and the windows are still in the wrong places you just blew it. The sweetness of passive solar design

is that it is intended to let the sun inside in the right way and times. This way the house itself becomes the solar collector *in an efficient way*. Efficient means keeping the sun out when you do not need it, and letting it in when you do. This is why you will hardly ever find western windows in a passive solar home, with few exceptions (such as legal or safety reasons, like fire escapes / building codes, or a view).

In the northern hemisphere, the majority of the sun's energy comes from the south (in the southern hemisphere passive solar homes are pointed north, so all concepts in this book would be reversed). For the purposes of this book, which is intended for countries in northern latitudes (like the United States and Canada), I will discuss solar under the assumption that solar gain will be coming from the south. Also, it should be assumed that any passive solar house design will also be *energy efficient*—far more than a standard house. Probably even better than a house build to LEED standards. This means it will be superinsulated, and that thermal bridges and air gaps will be greatly reduced or eliminated, and the right kind of windows will be in place, etc., but I will go into this more later. Just remember that this is all about *design*—it does not have to be super expensive. In fact, if done using the methods in this book, building a passive solar home can even be less expensive than what I call “everybody else’s house” (i.e., standard construction with non-passive solar design). Now, if I mention terms like *everybody else’s house*, or *anybody else’s house*, you will understand what I mean. YOUR house should be comfortable (not cold or drafty, or overly hot), ultra-energy efficient, passive solar, built as green (eco-friendly) as possible, and will help reduce greenhouse gas emissions (GHGs) because of having lower heating and cooling bills. Your house will NOT be *everyone else’s house*.

NOTE: A passive solar house should have about 1 square foot of window area for every 3-5 square feet of floor area. Otherwise, you will be looking at either a cold house or a very overheated one.

When thinking about passive solar design, realize that between 60 and 80 percent of direct sunlight is available to use as solar energy. This means that large double pane or triple pane windows facing solar south can provide up to 60 percent (on average, but sometimes 80-90% can be gained) of a building's heating needs when the windows are insulated during the night with tight-fitting shutters, insulated curtains, or especially some other *exterior* device that closes to trap the heat in (note that this is not the only variable). Clerestory (oblong, vertical but placed lengthwise left-to-right) windows in conjunction with a split-shed style roof can be used for additional light to upper levels within the structure or to back rooms that would not normally receive direct sunlight.

A single upfront investment of \$1-\$3 per square foot for passive solar design features will save you hundreds of dollars per year for the lifetime of your house! The total cost for all of the window orientation, overhang considerations, energy efficient additions, etc. are usually less than \$3,000.... that's a mere \$2-\$3/sq. ft. for the average 1,000-1,500 sq. ft. house and goes down considerably with homes with more floor area. Remember that it is not the money invested (which you now see is but a fraction of the cost of the house but makes a HUGE difference overall for the LIFETIME of the home) that makes such a difference, but it is the DESIGN of the home that does. Just moving things around and making simple changes such as altering window area and placement, and some of the flooring and colors, can turn what would have been a disaster into an efficient passive solar home. Much of passive solar design is merely a trade-off (substitution) from things like carpet to tile (at least in sunlit areas), more area of windows in one area than another, etc. You will learn *why* soon. Remember to add in these energy efficient aspects (INCLUDED in the \$1-\$3/sq. ft. cost estimate) to ensure that you do not have unnecessary heat loss (or heat gain) in your home. This will make your passive solar-designed house run efficiently!

Remember that passive solar design is not new. Modern technology has made it easier or more convenient, and more efficient (in some cases), but the principles have been used for millennia by different peoples all over the world. Cave dwellers throughout history

(and prehistory) understood the simple concept of passive solar (the southerly sun warms thermal mass materials)... if they could do it, so can you. This is not rocket science. You already know that 'every house is a solar house' because the buildings let light in; however, now you need to know the differences between a regular so-called "solar" (standard) house and a well-designed passive solar house. Here is what a standard constructed house and a passive solar designed house have IN COMMON:

<u>STANDARD HOUSE</u>	<u>PASSIVE SOLAR HOUSE</u>
Roof with overhangs Floors with flooring materials Insulated exterior walls Windows and doors	Roof with overhangs Floors with flooring materials Insulated exterior walls Windows and doors

All homes should have these (unless you live in a cave) features above. The difference between these is that a properly designed passive solar house will be warmer in the winter and cooler in the summer than those built by "standard construction" (this is where most house building contractors, architects, or home designers (and home buyers!) that choose inefficient home designs get it all wrong). So what are the DIFFERENCES that make this incredible energy efficiency happen?

<u>STANDARD HOUSE</u>	<u>PASSIVE SOLAR HOUSE</u>
1. Roof as improperly designed overhangs for the latitude where it is built.	1. Roof has properly designed overhangs that keep the sun OUT in summertime and let it IN during winter to warm the house.
2. Floors with flooring tend to be NON-thermal mass (i.e., insulating) materials such as	2. Floors / flooring materials use have darker colored thermal mass (i.e., conductive) qualities such as tile,

<p>carpet, wood, or linoleum.</p>	<p>stone, brick, concrete, etc., to store and release heat slowly into room for maximum comfort. Floors are the most direct / easy way to store the sun's energy when it enters the house through a window.</p>
<p><u>STANDARD HOUSE</u> 3. Insulated exterior walls and interior insulation between rooms.</p>	<p><u>PASSIVE SOLAR HOUSE</u> 3. Insulated exterior walls, but interior walls may / should have thermal mass qualities (plus may be insulated) to store additional heat (mass walls, brick / stone, adobe (like trombe walls), even water, or concrete (stamped or colored, which is all the rage now). Walls are 4x more efficient for storing and releasing thermal mass temps into rooms compared to floors.</p>
<p>4. Windows and doors improperly placed for maximum sunlight exposure.</p>	<p>4. Windows and doors are placed on the proper sides of the house to eliminate unwanted sunshine (e.g., west windows in summer) and allow it in during winter (such as larger south and east windows. Note: north windows do not gain</p>

	sunlight but do lose heat, so avoid except for code requirements; skylights also waste energy).
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Here is another difference, conceptually speaking, that explains why passive solar homes are more comfortable for those who live in them.

1. A passive solar house is designed to be in tune with nature (excellent design).
2. A standard constructed house (everyone else's house) is NOT necessarily in tune with nature (poor design).

Nature teaches us lessons in life... do not stay out too long in the sun (overheating / burning will occur). Cover yourself when it is cold (insulating will keep you warm). These are the simple physical principles behind passive solar design. In the next chapter I will take this further...

WHAT NATURE TEACHES US

We should pay attention to Mother Nature just as we pay attention to our parents when we are young. There are lessons to be learned, and with good reason. As a species, our survival depends upon paying attention to our environment, and also nurturing it so it will sustain us. Today there are a plethora of unsustainable practices that are part of our modern society, from widespread deforestation that lacks proper reforestation policies and practices, to acidification of the oceans due to industrial pollution and runoff from agricultural waste products (herbicides, pesticides, and other biocides). Even our roads are made with carcinogenic products such as asphalt emulsion, which place poisons into the water table.

Only 3% of the world's water is fresh, and 1% of that is undrinkable, with the other remaining 2% becoming polluted or being depleted. The entire region underneath and around Mexico City is sinking due to the deep aquifer's depletion, and they are rationing water constantly. One day the water will run dry because the water use is occurring faster than it is being recharged. This overuse (abuse) of natural resources is causing problems in other major cities around the globe, including the city of El Paso where I am originally from (their long-term plan is to pipe in sea water to desalinate it or else the city will run out). What good is it if we have a home in an area that is going to run out of water? Water security equals food security. Present agricultural practices (which consumes two-thirds of fresh water) not only need to change, they will be forced to transform in time anyway because the present food production system is unsustainable. Permaculture has the answers to save the world, but this will require a major overhaul in how things are being done. Big Ag's monocrops will need to be replaced with polycropping practices and smaller localized farms. Centralized mass production will need to be diversified and decentralized. Biocides will need to be replaced with more natural ways of reducing pests and problems. If we want to leave our children and grandchildren a legacy at all, it must be in our

use of sustainable living—from the home to the commercial and industrial levels.

Policies are where the changes start, but people can also make a huge impact by every single individual taking personal responsibility for the part they play in living sustainably. Anything unsustainable has built-in obsolescence... meaning it is just a matter of time before it dies. Overfishing the oceans is just one example of many. Scientists now say that we are at the beginning of a 6th mass extinction, which is not on our doorstep any longer, but has moved inside our homes, and is taking permanent residence in our lives and affecting our futures. Only those in denial or the uneducated do not believe it or see it. In order to quell this we need to build ecologically responsible homes, and do easy things such as grow gardens using water-saving permaculture and regenerative methods: to sink, store, and spread water and energy for life, and to build homes in an eco-green way.

Scientists and economists with clear vision for where things are heading have been saying for years that the next war will not be about oil, but will be over water. Since water is life, and we need it to drink, cook, bathe, wash our clothes and dishes, to grow plants for food, and keep our animals alive, we had better figure out how to place water security into our daily life, and to not rely on the government to do it for us. We must pay attention to what is happening in the world, and in our neighborhoods, and in the forests and lakes, rivers and mountains, to the animal populations and with pollution levels. We must notice the patterns, and that they have been changing... and fast.

There are consequences to using fossil fuels—finite natural resources will eventually run out, and in the meantime their use is polluting our planet. If every home in North America were designed with passive solar principles (not including businesses and malls, industrial buildings and government buildings, which are equally important) the reduction in electric generation and use would be substantially reduced. Building codes for new construction automatically incorporates the phasing out of old inefficient buildings, and dismantling them to reuse the valuable parts and pieces so they can be recycled or upcycled. The new codes are changing fast and

heading towards the “Passive House” standard as we see cities coming on board for the “2030 Challenge” for super energy efficient homes. This is already happening across Europe and many major cities in North America, as well as other parts of the world. The Passive House standard will eventually become the standard building code everywhere. We can build green homes, and can solarize our homes through passive solar home design, as well as by adding PV panels and wind systems, etc., to produce electricity for clean energy.

Just to recap a couple terms from the previous chapter, we can utilize both ‘active solar’ and ‘passive solar’ in our homes. This is an easy way to remember the difference between them...

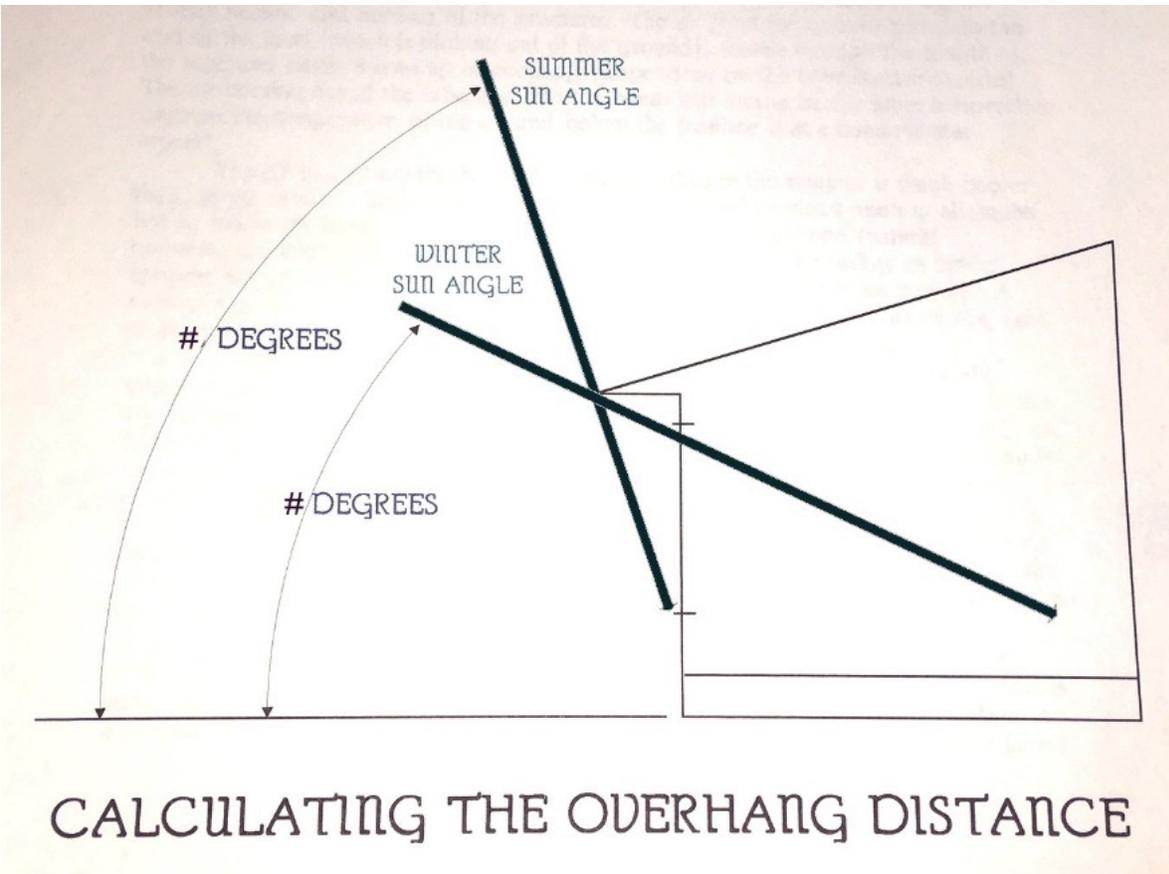
ACTIVE SOLAR = MOVEMENT

Uses mechanical pumps, fans, blades (e.g., wind generator, since wind power is a derivative of solar energy), or other devices that eventually wear out, break down, and need repair from use. These devices use the electric power generated from renewable energy sources such as solar power systems. Active systems typically cost more (than passive systems) to buy or make, as well as maintain or replace.

PASSIVE SOLAR = NO MOVEMENT

Runs silently with no moving parts (e.g., energy stored in batteries or light bulbs, etc.). Passive solar designed homes are also passive systems because the HOUSE ITSELF becomes the solar collector and requires the usual “walls, roof, floor, doors & windows” but no moving parts to make it work. It just sits there passively and ‘does its thing’ with little to no input from you.

A passive solar house is designed so that where you place the windows, and how much “glass to mass” (I will cover the glass-to-mass ratio later on) there is can make a huge difference in your energy use. Insulating the envelope and where you place your overhang (and calculating its depth) are also important keys to a well-designed passive solar home, all of which are based on patterns in nature, including the sun.



We can watch the sun and see that it shines from a higher place in the sky during summer (longest days of the year) than it does in winter (shortest days of the year). This means that a proper overhang will allow that low sun to shine into the house during and around the winter solstice (around December 21st) to warm it inside. However, about mid-way to the summer solstice (around June 21st) are the equinoxes (March 21st and Sept 21st), and the roof overhang needs to start shading the sun as summer approaches. By knowing the angles of the sun at its highest and lowest peaks (at the solstices), we can ensure that the sunlight enters the top of the window all the way to the bottom for full-stream solar gain into the home. We know these sun angles because we can observe them, record them, and calculate their angles to utilize them for our needs.

The point is that we can learn things by paying attention to nature. Once we start watching, and listening, we start noticing patterns. Pattern watching is exciting; once you start seeing patterns you can

figure out ways in which nature also changes them by altering some of the variables. This can go both ways—bad and good. These are the *principles of construction and destruction, also called the processes of creation and disintegration*. If you want to create a garden of weeds, then till / break open the ground or clear off the land. If you want to inhibit the growth of weeds and create deeper richer topsoil, then add mulch. Both of these processes are natural processes—nature uses them to her advantage every day, via the elements and flora and fauna. When the environment is right, then certain things flourish. When toxins are in the lakes and oceans then vast mats of algae grow, which choke out the life of fish and other water animals. Everything is a trade-off.

However, there are basic things we can learn about passive solar home design by watching nature... that of color and thermal mass qualities for energy storage.

Nature's Perfect Example of Passive Solar Energy

A horned lizard (a.k.a. "horny toad" is now an endangered species in the southwest United States) is not unlike a vast variety of other lizards or snakes in that they are cold-blooded. This cold-blooded nature is the exact reason why you will often find reptiles sitting on a rock in the sun in the early morning (this is a pattern you can observe). The sunlight warms the rock and provides heat to help warm up these creatures so they can scurry around doing whatever these little creatures need to do the rest of the day. The principles behind what this horned toad knows is simple.... he is naturally equipped with the knowledge of passive solar design even though he does not know that humans call it such! If a mere lizard, or snake, or horned toad knows that a rock stores heat from the sun, which he can use to warm his cold-blooded little body, then why do people not use this same technique for warming up on a cold day? In fact, they do! By utilizing rock (or concrete, slate, brick, etc.) adjacent to south-facing windows they are able to warm their house on a cold day via that same direct sunlight. Dark-colored stone or surface-finished colored concrete floors, cob, tile, brick, slate, or other rocks are all good thermal mass conductors, which store heat by letting the sun's heat rays sink in throughout the day so that it then slowly releases that heat energy back into the room at night. This is one of the major processes that happens inside a passive solar house. The horned toad has just taught you physics lesson #1—energy collection, storage, and transference.

Horned Toad



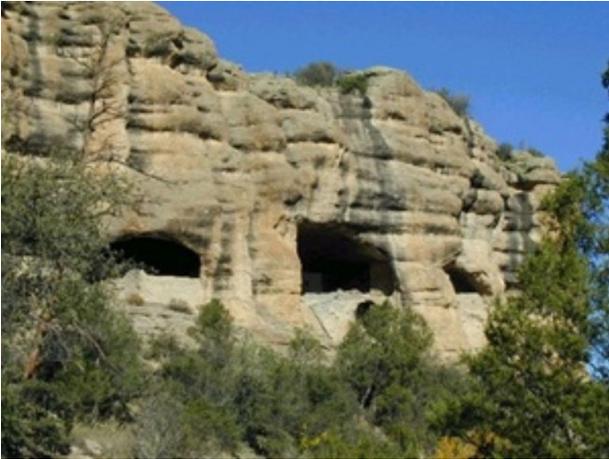
Source: animals.nationalgeographic.com

The technical term for the conductive / thermal storage properties of this rock (or other heat-storage material) is that it has THERMAL MASS. As you have just learned, thermal mass materials are able to soak up and store heat and then later release it. Rock, or bricks, concrete, tiles, the earth, metals, or even water are all examples of thermal mass materials that can be used to your advantage inside a house by storing the sunshine's warmth in the material so you can utilize it later, much like how the lizard uses the sun-heated rock to warm up. The difference is your design for your passive solar house will have an advantage... insulation, which helps to keep the thermal mass material warmer, longer.

What Indian Cave Dwellers Knew

The Indian cave dwellers across North America (and beyond) knew more about passive solar home design than many homebuilders do today! By harnessing the *simple* and *effective* aspects of sunlight (thermal mass and insulation) to create an energy efficient home, the owner-builder or even the building contractor can add thermal stability and quality to the home by providing up to 60-80+% of the home's heat in the winter *without a furnace*. In even better (but far more expensive and complex and active) designs, such as Net Zero or Net Positive, or Passive House buildings (which surpasses LEED and other energy efficiency standards), that percentage can go up to as high as nearly 90-100%, depending on the region in which you live and the amount of money you want to put into the house construction. Recall that this is not rocket science; it is my intention to keep it *simple* so you can do this in a far less expensive way than Net * homes, and far more efficient than the Native American Indians did with their cave dwellings. However, that said, the Natives knew a secret that has been lost to most of industrialized societies today.

Native American "Cliff Dwellers" preferred certain types of caves for their dwellings; specifically, caves that faced south. They understood simple principles of harnessing nature, which could help them stay warmer in winter and cooler in summer. They knew that the direction their caves had to face was south (in the northern hemisphere—in the southern hemisphere they must face north) to take advantage of the sunlight; consequently, they would often avoid caves that did not already have this orientation, except for very temporary shelter or to escape the elements (but not long term living). Sometimes this one important detail could mean the difference between surviving or freezing to death in winter.



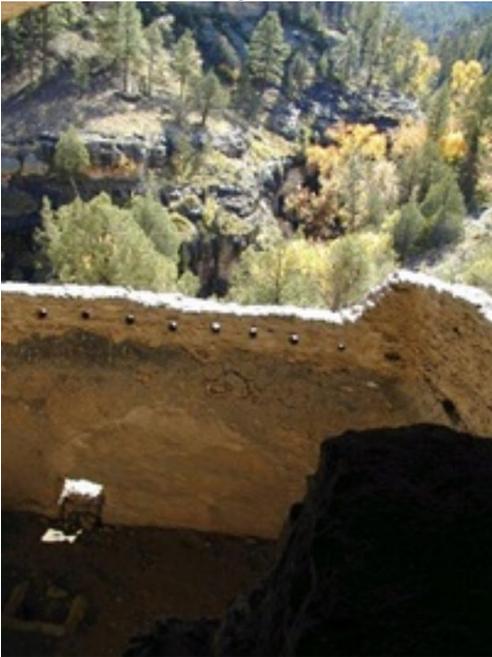
One of my favorite places to visit and go camping while growing up was the Gila Cliff Dwellings in New Mexico. I was always awed by these homes and wished I could live in one. There are cave houses around the world, but only the smartest peoples who observed nature and harnessed its natural abundant resources properly would take advantage of the sun in a passive solar manner.

We have es-tablished that in the winter the sun is lower in the **Gila Cliff Dwellings, NM** sky than in the summer. The same patterns existed when the cave dwellers lived at the Gila Cliff Dwellings. At that time, during the coldest months the Indians lived in the caves, the sunlight streamed into the wide cave opening, warming the thermal mass (rock) walls of the cave, plus additional rock walls they built within the cave, which provided passive heat for them. Even if there was snow outside in the winter, the sunshine stored in the thermal mass helped maintain enough warmth in the rock walls so that it was a far more comfortable living place than outside of the cave, especially when supplemented by heat from their fires, which were placed at the cave entrance to create a “heat wall” or “heat shield”—this acts as an invisible thermal barrier to hold in warmth (heat in the back of the cave could smoke you out plus overheat the rock in one spot above the fire so much that it could cause expansion, and thus, a rock fall).

Notice the opposite pattern in nature. During summer the sun is very high in the sky... pretty much directly overhead. The large overhang of the cave’s “roof” provided shelter and kept the sunlight OUT in summertime. Even today, the cool thermal mass of the cave's

interior feels like air conditioning during the hot summer because the cave's overhang keeps the sunlight out. And so it was when the Indian cliff dwellers lived there. They understood nature, and its patterns, and how to pay attention. People today have forgotten how to be aware of their surroundings in the country or the wilderness—we are insulated away from nature in manmade constructs called cities, and somehow think this is 'normal'. This is why it is important to pay attention and practice pattern-watching, and understand simple cause and effect.

Rock walls (whether a cave, or an interior constructed rock wall) are great "heat storage" for heat provided by sunlight. They stay warm in winter after the sun has warmed them, and release the heat at night. The rocks, alternatively, stay cool in summer since they are shaded, providing a cool-to-the-touch feeling in summer when it is scorching outside. During spring and fall / autumn *some* sunlight streams into the cave, which warms the rock during the day; this is also used for passive heating at night.



This simple predictable pattern in nature (physics) is one that most anyone can observe, experience, and mimic by constructing interior walls with rock, brick, or similar thermal mass materials. This is what a passive solar house is all about... doing what nature already does, but

Looking out from inside in a more efficient way.

Gila Cliff Dwellings

NOTE: Homes today that utilize interior thermal mass walls or floors that store heat from south-facing windows, particularly trombe wall systems, tend to overheat slightly in the spring and fall (equinoxes) since it is a transition period between the first day of both winter and spring (solstices). It happens because spring can fluctuate between extremes in temperature.

If solar gains outweigh the need for the sun, you can simply open a window, or shade the windows to reduce the amount of sunlight entering the home as weather warms up, although you may enjoy that little bit of extra heat on a sudden cold day as you head into fall.

SOLAR DESIGN DETAILS

It is important when you plan to have or use solar PV systems for electricity, or if you wish to reduce your electric bills, the most important rule is to always *improve energy efficiency* FIRST (meaning reduce your energy consumption), and THEN configure a system for producing the (lesser) amount of energy your home will require; otherwise, it will cost you a ton of money. Passive solar design and energy efficiency help you accomplish this.

**Always improve energy efficiency in
the home
before you design a solar electric
system so
your energy needs are reduced.**

I do not cover how to design a solar electric (PV) system for homes in this book. There are literally thousands of books and websites and companies available for designing electrification systems, and it is better left up to local and recently updated resources to support your endeavors because technology is changing so fast that as soon as something new comes along it becomes outdated within a short time. Whereas, with passive solar home design you can find new products to support your energy efficient home design, but the old rules (which are ancient, really) are basically the same—superinsulate the envelope, add thermal mass on the interior of the home, orient the home to ‘solar south’ for proper solar gain, configure your overhang for optimum seasonal exposure / protection, and apply any other sustainable and energy efficient features you can (such as eliminating thermal bridges, making the

home air tight, proper ventilation, etc.). What form of materials or products you use to build the home may change radically from one house to the next, just as the style of the home's exterior (Victorian, Modern, Pueblo style, or a plethora of other architectural styles) can vary from one house to the next—yet they all may be passive solar homes, and they may vary in their efficiency rates as well (depending on how well they are designed). That is what this book is about... designing your own energy efficient passive solar house.

You can make special accommodations to the design of your house if you are an owner-builder, which sometimes cannot be afforded to people who hire others (builders / contractors) to build it for them. Two-thirds the cost of building a house is labor—when you do your own labor, you can save two-thirds the cost of the house! This means a \$150,000 house can be built for \$50,000, or even less if you incorporate used and free materials into the construction. Most every young couple just starting out in life should be able to build their own starter house in this manner, especially if they begin with a “core house” (the “core”—living / kitchen area and bathroom) and add on bedrooms afterwards.

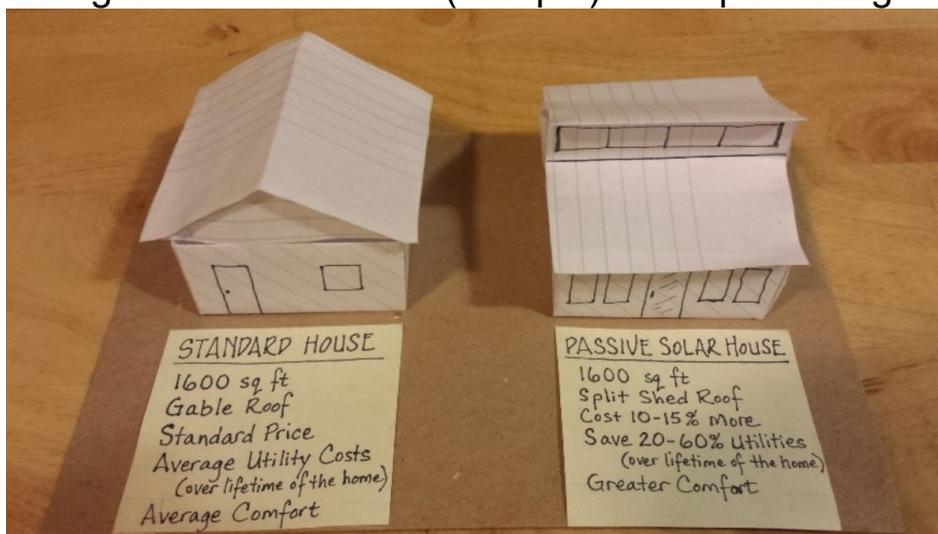
Anyone of any age can benefit from building a less expensive home. For one, you do not have to compromise and have a smaller house if you want a certain amount of square footage because by doing some or all of your own labor you can afford to build bigger (if that is your goal). I personally prefer a smaller carbon footprint in my home (also less space to have to clean), although some people in my family prefer larger spaces for entertaining, and more bedrooms for guests and storage. The benefit that I favor in this process for DIY (do-it-yourself) home building projects is that you can put better (green) materials and ensure a higher quality and build above the minimum code requirements by doing much of your own labor, which means your dollar is working smarter for you.

Regardless of who does the labor, you still need to design the home, which is what this book is really about. When you wish to design your own *passive solar* home, then you need to have some design tools in your house planning bucket. To start, you should look

closer and see how an average “stick and brick” (wood and brick) house that is built using standard construction methods compares to a passive solar (energy efficient) house, and understand how they are similar as well as how they differ.

THINK: Do you think the main differences between standard construction and passive solar homes are because a solar house has more insulation? It could, but not necessarily. Better, more efficient heaters and air conditioners? Not really. More cost into building the home than a standard house? By now you should know that the answer is no, not necessarily that either (although they can cost about 10-15% more, depending). Then what exactly are the differences?

Remember that ‘every house is a solar house’. If two homes—standard design and passive solar design—were built side by side and their energy bills compared, you will find some amazing differences, even if cost were the same to build them. For instance, if the homes were both rectangular with the same floorplan and square footage, both had the same wall thickness, the same amount of windows (but mostly on the ‘solar south’ side for the passive solar home) the same amount of insulation, the same kind of roof, and so on, the solar designed home would still perform 10-30% better in both overall comfort and by having lower utility bills, even without adding thermal mass or other features. However, you can make additional changes that can double (or triple) those percentages in efficiency.



I was folding some paper one day and decided to cut and tape some simple

shapes together to represent a model of what a passive solar home might look like, and to compare it to a conventional “standard construction” home. Here is what I came up with.

Conventional Home Passive Solar Home

The above design shows a gable roof for the conventional building, whereas high clerestory windows in the (split-shed roof style) passive solar home allow sunlight to the rear half of the building. This is only one simple design of many for a passive house with solar design.

Thermal mass should be placed on interior walls and floors, but can also be part of built-in furniture like benches / bancos, stone fireplaces, half walls, cabinets and counters, other permanent fixtures, or even a rocket mass heater. In case you do not know, a rocket mass heater is similar to a masonry stone fireplace, which uses thermal mass and a double burn chamber to heat the house with a single hot fire that burns 1-2 times per day, and heats the house for 24 hours. These produce far less pollution (only water vapor and CO₂) than regular fireplaces or woodstoves because of how they are designed. You cannot buy them, but you can build them. But I digress... I was discussing adding thermal mass to the interior of the home.

Floors should be darker colored if they receive direct gain from the sun. This helps them absorb (rather than reflect) the sun's rays. For areas without direct sunlight, interior walls are more effective than mass floors for absorbing and releasing heat. Cement slabs (thermal mass) become inefficient if too thick (over 4-6") so save your money and stick with a 4" slab if you do slab on grade. There are exceptions. One house I visited in the lower mainland BC, Canada, had a two-story house, which was entirely heated by a radiant floor heater in a 6" thick basement floor, which was insulated (underneath the basement floor as well as on the exterior sides of the basement walls). The house had about a 2 degree F (1 degree C) difference for each floor in temperature. People preferring cooler rooms to sleep in during the colder months slept upstairs, while the basement made an excellent den or place to hang out when you wanted warmth. The

main floor had the kitchen and living area, and so on. They designed it so heat would rise easily and naturally through the house through stairwells and vents between lower floors and upper floors.

Other *thermal mass* materials for INTERIOR walls and floors can include brick, adobe block, cement / concrete, cob, rock, tile, slate, cement block, plaster, stucco, or other materials that can absorb and release heat. I think you are getting the concept by now.

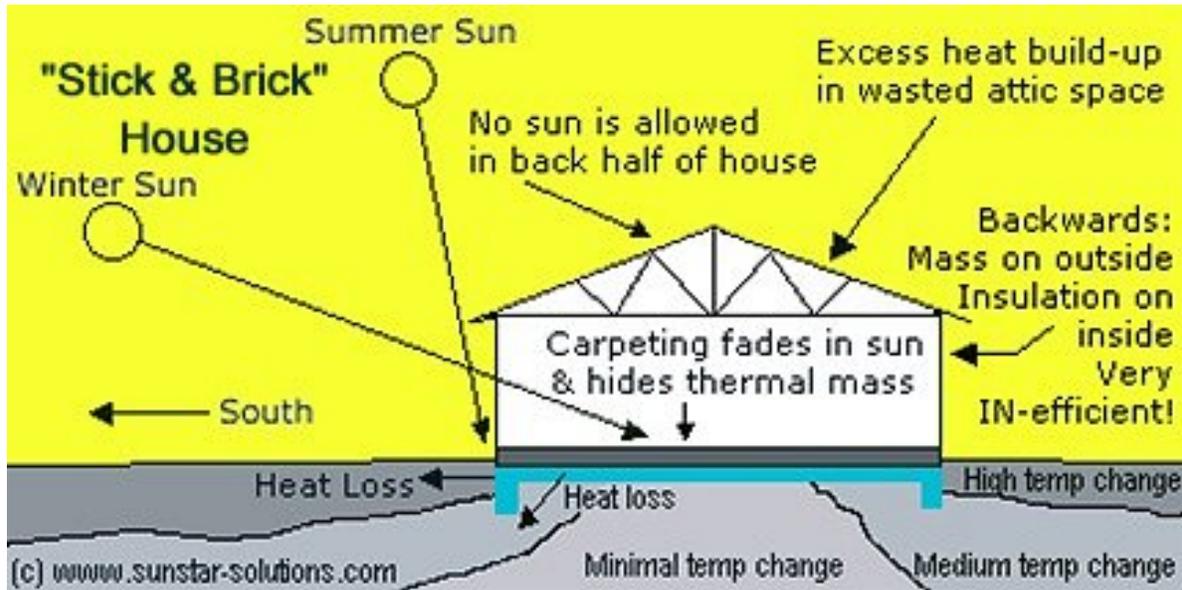
This is contrasted with *insulating* materials, which should be in your EXTERIOR walls to superinsulate the envelope—sandwiched between interior thermal mass walls is also good, but should otherwise be avoided on the interior, such as: standard insulated interior walls, wood products (siding, waferboard / OSB / plywood, wood flooring, 2x4s / 2x6s / etc.), gypsum board / drywall / gyprock / gypboard, and carpeting.

Having thermal mass inside the home, coupled with adequate solar gain, is the main difference between standard or conventional housing and passive solar design, and ultimately this makes a huge difference in helping to lower utility bills. Allowing sunshine in to heat the thermal mass, and the overhangs to keep sunlight out of the house during summer (keeping thermal mass cool), are together what stabilize the temperatures within the house. By insulating the envelope it ensures there is minimal heat loss or heat gain from or to the outside.

Passive solar design, then, is a system that works with nature and just sits there passively and does its work without any effort on your part outside of it being designed and built correctly. This can save you money for as long as the house exists because there are no moving parts to break down.

Next you will see a couple of pictures that exhibit the home designs (paper example) above, except with some information about design features.

Standard Construction

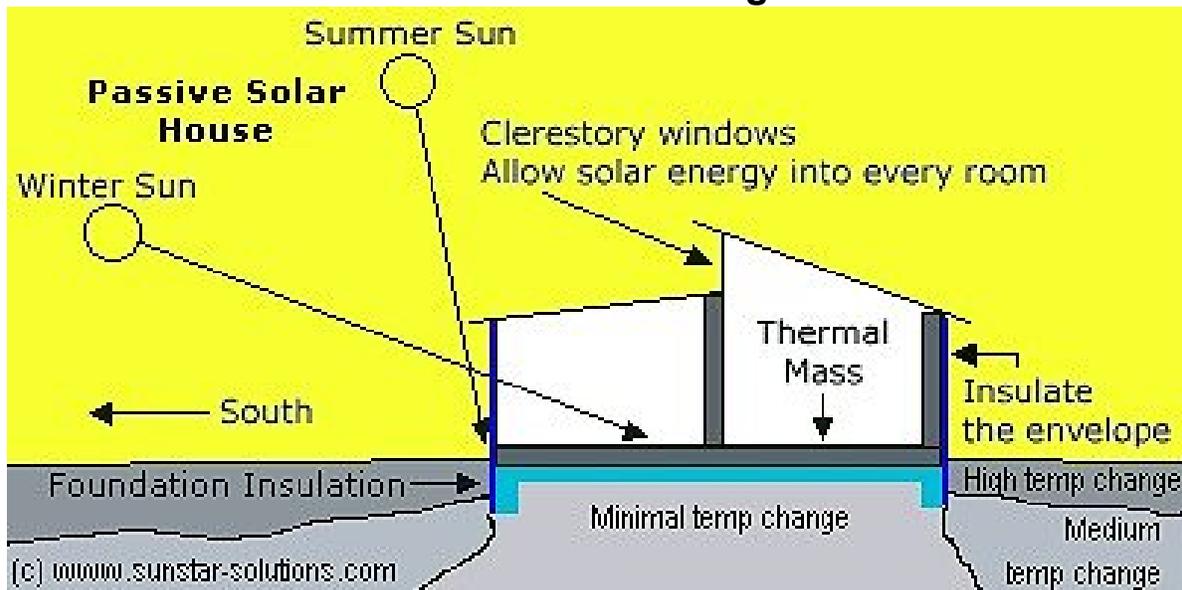


When you invest a little more (10-15% of the original cost of the house) then it can perform even better. The secret to this is because the designer of the home has paid attention to nature, and through mimicry and conservation of energy (sinking, storing, and spreading energy) understands why and how to make slight alterations that can, together, make a huge impact in how the home functions, energy-wise.

Your house IS the solar collector!

To recap what has been mentioned before (because repetition is important in learning), the key is knowing how to let the sun IN to help warm the house in the wintertime and keep the sun OUT in the summer, as well as storing that sunlight as energy / warmth inside the house to help heat it passively (without pumps / fans / moving parts).

Passive Solar Design



You are allowing the sun to enter inside a passive solar house so that **the house becomes the solar collector** in an efficient way.

You need about 1 sq ft of window area for every 3-5 sq ft of floor area

As nature (including our planetary position and its orbit around the sun) teaches us, in the northern hemisphere of the world, the majority of the sun's energy comes from the southerly direction. Because between 60 and 80 percent of direct sunlight is available to use as solar energy (the only way to access 100% is through solar tracking, as is done with large PV arrays that track the sun, but making an entire house track the sun is not entirely practical), large double pane or triple pane windows facing solar south can **provide up to 60-80+ percent in passive heating in the building when** the windows are insulated during the night with tight-fitting insulated shutters, insulated curtains, or some other *exterior* (preferably, although interior works as well) device that closes to trap the heat inside during the nighttime. These can be manual (simple = inexpensive), or automated (complex = more expensive). Some people like automated "exterior insulated roll-shutters" (search that term on Google to find some in your area)

that open and close using PV power, so they do not have to wake up at the crack of dawn to open them. Solar power does it for them with a light-sensitive eye to detect sunrise and sundown.

Notice in the picture above that clerestory windows can be used for additional light to upper levels or to rear (on the northern half of the house) rooms that would not normally receive direct sunlight from the south side. You do not have to add clerestory windows to your home, but it helps. Passive solar homes come in many, many architectural styles and shapes. Simple often works best.

Adding proper design features (natural heating and cooling) to a passive solar house costs can cost about \$5,000 - \$7,500 for each \$50,000 invested into the construction of a conventionally built home. However, this 10 - 15% investment will save 20 - 60% on average, or even up to 80+% of the heating and cooling costs monthly / annually, but again, it depends on how well you design and build it. Remember that this initial one-time investment lasts for the lifetime of the home so the payback period is typically relatively short and will produce dividends for you in savings. That means you will save money in utility bills immediately upon moving in, and it will continue for the next 10, 20, 30, 50, 100+ years (however long your house lasts). That is a good investment because your return is greater than your initial cost.

Design Features of Passive Solar:

The features that are included in passive solar home design typically include:

- 1) 7% of net glazing facing solar south (or if you live in the southern hemisphere, it faces “true north”)
- 2) The envelope is superinsulated
- 3) House has a proper glass-to-mass ratio, meaning that inside the house is adequate thermal mass to absorb and release heat to maintain a near-constant temperature
- 4) Roof overhang is designed based on latitude so it can keep sun out in summer and allow it into the windows during winter

It is important to remember that as long as *any* house has windows, it qualifies—at least in principle—as a ‘solar’ house, because sunlight can enter the home; however, to technically qualify as a ‘passive solar’ house it needs to follow those basic rules above (there are more guidelines, but you will learn about them later). Many solar homes are either designed by an architect and built by a building contractor, or they are designed and built by owner-builders; this book is intended to teach people how to design (in order to build) their own homes, but you can certainly obtain help in the designing, and hire someone else to do the construction, if that suits your circumstances.

NOTE: A passive solar house should have about 1 square foot of window area for every 3-5 square feet of floor area. Otherwise, you will be looking at either a cold house or a very overheated one.

Next are some sample homes that are passive solar, all of which were built by owner builders (including one by my family and me).

Modern and Straw Bale Passive Solar Homes

A modern passive solar home should look like any other house. In fact, unless you understand the pathway of the sun and the direction of solar south, and can recognize the orientation of the building—with the longer side facing the sun—and the angles of its south-side overhang, you might never realize that a random neighborhood house you are viewing from the street would even be passive solar in design. Again, a passive solar house does not require solar PV panels (for producing electricity), and many of them do not have them since that is a separate system completely. Some people who invest in their home may also invest in such systems, but it is not required since it has more to do with electric production and is used for net metering or off-grid homes, etc.

Our Passive Solar Straw Bale House

When we lived in rural Nebraska we purchased two acres of land that had a well and septic tank. Over about 2-3 years (minus winters) we built a passive solar straw bale house. In 1998 we completed the shell of the home, so we moved in to work on the inside.

Most things about the house was considered 'alternative construction' since everything from the foundation to the walls and other parts of the design were not found in a standard house. The foundation was a green treated posts / lumber and sand-and-gravel foundation, which included the stem wall.



Green-treated lumber and sand-and-gravel foundation. Fill was brought in later to level.

In the photo above you can see earth tubes (natural cooling method) sticking out at a diagonal angle by my legs. Once the foundation was done, we placed a vapor barrier down, and then installed the window boxes and door boxes (see image below). We aided Dave Carter (a building contractor and teacher at Southeast Community College) who taught a straw bale construction workshop through the University of Nebraska at Lincoln when it was time to build the walls. The attendees learned in the classroom at the university all morning one Saturday and then drove out to our house (40 minutes outside of town) so they could help us build the walls. They got the hands-on experience, and we got the free labor, so it was a good marriage of efforts for everyone that day.



The first courses of bales (half the wall) went up thanks to the straw bale workshop attendees

We placed a vapor barrier under the windows, built up the straw bale walls, placed more vapor barrier over the top of the wall, and then added a wooden roof plate (shaped like a straight ladder). The lumber for the house was purchased through a local mill as well as used lumber from an old barn that had been taken down (it was so well seasoned it bent many nails!). The walls, once finished, were cinched down to pre-compress the load-bearing walls using a compression-tension method of ½" steel all thread that ran through the walls from the foundation to the roof plate.



Adding vapor barrier and roof plate to walls



Roof joists and trusses were built with helpers and by renting scaffolding

The roof material we attached to the trusses was metal, and we installed a flue for the woodstove, which at the time of construction was the only source of heat outside of the passive solar design itself.

We intended to place thermal mass into the floor and inner walls of the building, but we did not get that far before we sold the home.



Roof trusses on with gable ends showing more straw as insulation and wall material

Weather turned just as the house got plastered so we were able to move in (unfinished inside)



We designed it to have a composting toilet and grey water system as well, which later were replaced by a septic tank and field by the new owner. For cooling purposes we built earth tubes, but years down the road he quit using them and put in a window air conditioner. We moved in to work on the house for one year on the inside before we sold it.



We sold the house to a friend, Wade Johnson, in late 1999 who finished it out inside and changed some

Passive solar straw bale house as it looks today

things (differently than we had planned it, including alterations to the floor plan to suit his needs). This image here shows the kitchen upgrades after the home was sold.

Green Building Energy Efficiency

By building using 'green' (eco-friendly) home materials you put less toxins into the environment, especially your indoor home environment. Indoor air quality can be improved in this way since many common house materials include toxins (carpeting has formaldehyde, for instance, and formed / pressed woods have glues or resins and can gas off, etc.). Passive solar and green home design can be whatever you want it to be, in pretty much any size or building type or design, as long as you focus on energy efficiency first, and passive solar design second—the rest is just choice of materials and style.

I cannot stress enough about the importance of energy efficiency in a home. If you want a passive solar home it has to be energy efficient FIRST. If it is not, then letting the sunlight into the windows is not going to help you much because without properly storing that energy in an efficient way, and insulating it so that the energy gained is not lost, then there will be nothing much efficient about it.

The building envelope (the outer wall system) needs to be insulated really well (above code requirements), plus windows and the southern side overhang need to be designed properly, and the interior should be able to store the energy gained from the sun. Lastly, all of this should work in harmony with the earth, the natural daily and annual solar cycles based on latitude, as well as keeping in mind your regional climate and local weather and your land / environment.

Green buildings are designed to reduce the energy that is consumed by the building in two ways—*embodied energy* (needed to extract and process, transport and install) for the building materials, and *operating energy* (needed to provide services like cooling, heating, or power) for the building.

Green buildings should be high-performance, which means they use less operating energy than their non-green neighbors. Also,

embodied energy becomes far more important here, taking up to one-third of the life cycle consumption of energy all in all. Buildings built out of mostly wood typically have a much lower embodied energy than buildings built out of concrete, steel, or brick, which all require a lot of embodied energy to produce them initially, even before construction starts, according to the US LCI Database Project. Bricks, in particular, are quite high because of the firing of the bricks; however, they also could potentially last much longer than wood in the life cycle of the house.

The key is to reduce operating energy when using the building. Designing a house in this way might include reducing air leakage through the envelope of the building, as well as adding insulation in the wall system, floors / foundation, ceilings, and adding high-performance windows, incorporating passive solar design, if you want it to be a low-energy-consuming building.

Good designers will place the majority of the windows on southern facing walls while orienting that longest wall along the east-west axis, so it is perpendicular to the direction of “solar south”. Overhangs, awnings, trees, bushes, porches, and other exterior devices or living plants / trees will be carefully placed to maximize **passive solar gain** (heat gain from sunshine radiating into the house) during the coldest months while allowing these things to shade the west side of the house and southern glazing during the hottest months.

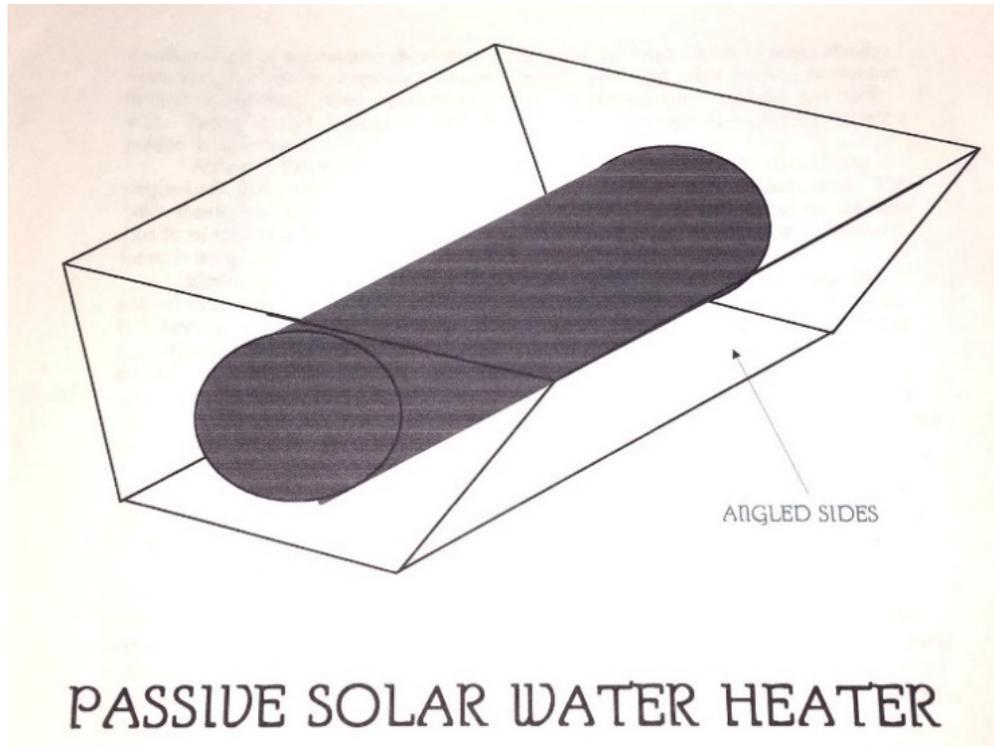


Natural daylighting - by Chuck Reel

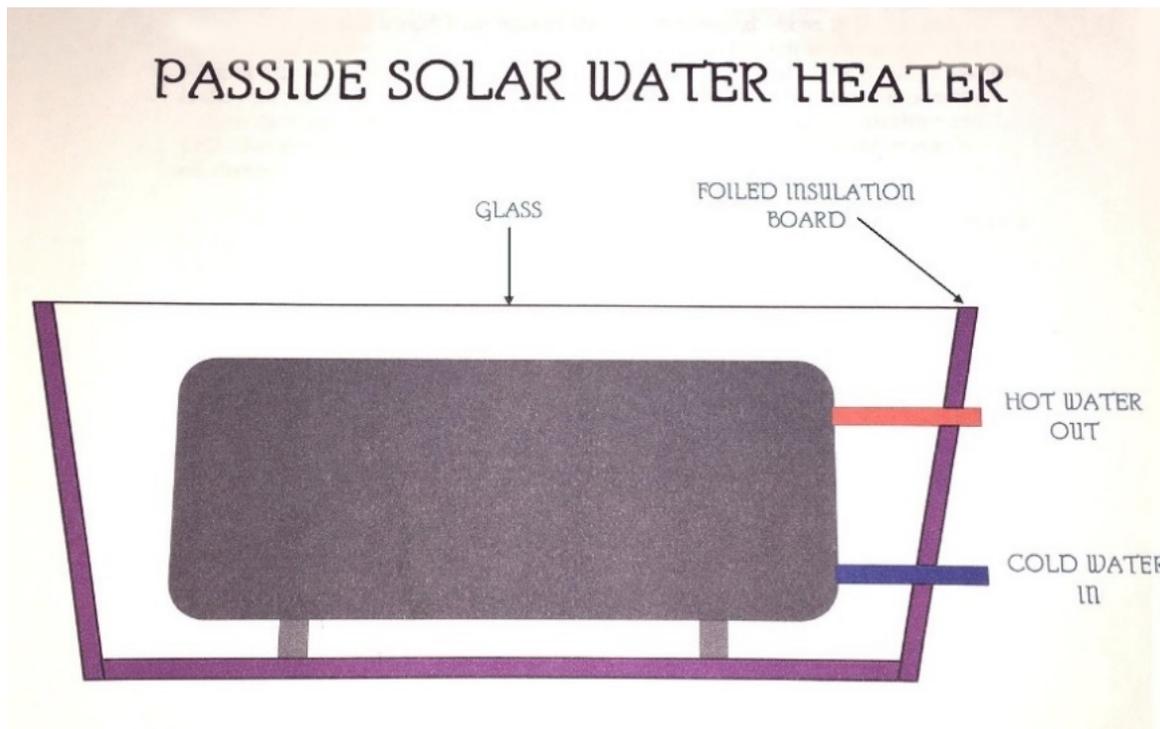
Daylighting is also a natural side effect that boosts the atmosphere in the house while reducing the need to turn on lights during daytime hours as well.

Passive Solar Hot Water Heating

Another way to reduce energy expenses is by utilizing a solar hot water heater, or a water heater that is incorporated into the woodstove or heating system to reduce loads. They can be made with a used hot water heater tank.



Be sure to research the (active solar) drain-back systems for batch style solar hot water heaters such as the one shown above so they do not have problems in freezing weather.





Systems in Canada—due to the colder climate—are typically required to use non-toxic food-grade glycol as an anti-freezing agent, but a solar hot water pre-heating system like this one that my friends Sandra Phinney and Barrie MacGregor use can serve up to 40 - 80% of the initial water heating, depending on the system and household usage habits.

On-demand water heaters also greatly reduce fuel use (30% or more). Anytime renewable energy sources are utilized (solar energy, passive or active, wind turbines, biomass, biogas, hydropower, etc.) it has the potential to vastly reduce the energy use loads as well as the environmental impact. Do note that the most expensive feature you can place into a green home will typically be when you generate power.

Passive House / Passivehaus

This chapter would not be complete without mentioning more about the Passive House design standard, which I have only touched

on thus far. Passivehaus (German), also known as “Passive House” in English, is basically the new industry standard for energy efficiency, and interestingly, is still a voluntary system and not yet adopted into policy for codes, but I expect that in the future it, or something similar to it, will be by cities, states and provinces, and countries worldwide. The standards for building codes are becoming stricter around the globe, and are especially needed in North America (due to high waste), as environmental concerns and energy consumption are still presently prolific. Passivehaus / Passive House standards help reduce that ecological footprint because their design requires very little energy input for heating and cooling the building space.

Recognize that Passivehaus / Passive House is the fastest growing standard on the globe with over 30,000 buildings (most of these occurring since the year 2000) recognized so far. Some of the strong points of the guidelines they introduce include design simplicity, significant thermal performance, and airtightness correlated with the use of a Mechanical Ventilation Heat Recovery (MVHR) unit. These homes can be built, they say, in any climate. You will presently find them across Europe, Canada and the United States, China, Japan, Australia, and South America. Research is also being done in Antarctica as of this writing, which is good since I have heard from the Canadian Passive House Institute (CanPHI) that adjustments to the design are needed for colder climates, such as in northern Canada. Their institute has a PHPP V9.3 software (as of this writing) for passive house design for those who would like to design but do not have the engineering background to do so. It costs between a couple and three hundred dollars (CAD), however, and expect for there to be a bit of a learning curve. If you are starting out learning with this book, then I would suggest that you have a handle on basic passive solar energy design (which you will by the time you finish this book) before moving into the Passive House standard, in case you do choose to raise the bar on building your home to include an MVHR unit and a few other changes. They also have classes available, for a price. I went to the Introductory course in Vancouver, BC in early 2017 and the vast majority of people attending were architects, so expect this to filter down to builders over time as they will have to know how to

implement these guidelines as architects continue to learn and design more homes with the Passive House standard.

To give you an example from the Passive House claims for energy efficiency and heating demand, Passivhaus buildings using “less than 15kWh per square metre per year means that annual fuel costs are reduced by a factor of 5-10. For example a household living in a 70m² Passivhaus with gas heating could spend as little as £25 on space heating each year.”

These numbers in the US / Canada equate to:

Buildings use less than 15kWh (kilowatt hours*) per 20 yd² (square yards) = 180 ft² (square feet).

So a household the size of 70m² = 83.7 yd² = 753.5 ft² will spend £25 = \$40.76 CAD = \$30.56 USD (Note: equivalent as of this writing, this will change as money values go up or down)

*A kilowatt hour (equal to 3.6 megajoules) is 1,000 watts energy units power consumption used in one hour.

As you can see, this is impressive, and should be indicative of what any well-designed and well-built green, energy efficient (especially passive solar) home can do to reduce your energy bills and increase comfort. While Passive House standard is based somewhat on passive solar design, it is not the same thing (the short explanation is that it lacks much thermal mass and adds insulation instead, but airtightness and heat recovery ventilation also come into play).

It is unfortunate that the Passive House (PH) standard is still voluntary only (with the ‘2030 Challenge’ we should be getting closer to it being adopted into standard building codes over time), but it is clear that it seriously outperforms LEED Gold certification requirements in regards to energy efficiency. Part of this is because it overbuilds and superinsulates the home in comparison to even LEED requirements, yet there is an important difference between a *Passive House* and a *passive solar house*. I will go into that soon, but for now I will show you a comparison between conventional construction and the result of the PH standard.

Passive House vs. Conventional Home

Similar to comparing a passive solar house to a conventional home, I will now compare a Passive House to a conventional home, especially regarding its design and floor plan.

<u>PASSIVE HOUSE</u>	<u>CONVENTIONAL HOUSE</u>
Solar gain is maximized by positioning the home on the land / plot so that the view through main windows face in a southerly direction.	The home and lot are positioned in any direction, which can cause solar gain overheating or under-heating due to misplaced window usage.
The home's longest wall faces as closely to 'solar south' as possible to allow for greater window area for solar gain.	Home may lack heat gain in winter, and may gain heat in summer due to improper orientation.
Modest square footage home (around 1000-1200 sq ft) has an open floor plan with living / dining / kitchen area for appropriate # of people.	Homes are oversized into "McMansions" with wasted space that has to be heated or cooled for the number of people living in them, causing energy waste.
Entry door on southern side should (preferably) be glazed for both the view and solar gain.	Southern facing entry door is typically solid, which disallows solar gain.
Master bedroom or other bedrooms may face the south and / or east and west if they wish to remain warmer.	Master bedroom or other bedrooms are placed haphazardly so no solar gain is considered for natural heating.
Local space heating / cooling is made more efficient by placing a	HVAC heating systems and ductwork run throughout the house and

<p>ductless mini-split heat pump above the bathroom door.</p>	<p>vent opening may be far away from heating source, creating heat and energy loss.</p>
<p><u>PASSIVE HOUSE</u> Space heating loss is reduced by placing frame-insulated triple-glazed windows on the south side of the home, with less on the east side, and little to none on the west or north sides.</p>	<p><u>CONVENTIONAL HOUSE</u> Window energy losses are due to less efficient windows, with the greatest losses from west, north, and east, and insufficient solar gain from the south.</p>
<p>Entry way or mud room should be on the north side of the house as a temperature buffer zone.</p>	<p>Entry way or mud room is placed without energy efficient design considerations.</p>
<p>Hot water heater located closest to bathroom and kitchen (reduces time for hot water to reach the sinks / shower) and eliminate waste of standing water in pipes. A solar direct hot water tank near the bathroom can reduce fuel use.</p>	<p>Hot water heaters / tanks may be misplaced and waste water and fuel while occupants wait for hot water to reach the destination sink / shower, causing standing water heat loss. Supplemental solar hot water heating is not typical.</p>
<p>Heating of the home is augmented by placement of ductless mini-split heat pump in the great room (central location). No furnace is required.</p>	<p>HVAC systems attempt to heat all rooms, while these same rooms have heat losses due to inefficient design rather than focusing on the main living space.</p>

As you can see, there are a few differences between a Passive House (PH) and a conventional house, but these differences are few when it comes to the floor plan of the design, with greatest differences being in the extreme air-tightness and superinsulation values achieved, and perhaps the style of the heater, which can easily be adopted by any passive solar home design, if desired, without having to have the PH certification.

Passive House Certification is something contractor builders would be more inclined to use (vs owner-builders) because they have to prove / market that they are building to a specific standard (to increase business and attain a decent reputation). Owner-builders typically have no need for getting their home certified if they plan on living and staying in the house long-term, although it is a consideration if it is to be resold later, plus certification may be preferred over saying it is 'passive solar' in design (even if the efficiency is similar). Like with LEED (also voluntary), it is really up to the homeowner and is personal preference.

Storing Energy vs Reducing Loss

There is one important distinction that arises when comparing a passive house to a passive *solar* house. A **Passive House is designed to greatly reduce energy loss**; whereas, a **passive solar house is designed to add and store energy**. This is actually quite a shift in thinking.

Passive House standards work excellently for people in more moderate climates, but they start to lose efficiency in extremely hot or very cold climates without adding cooling or heating units (meaning energy). This is where passive solar design swings in like a super hero and saves the day! The thermal mass that is added to a passive house (even admitted by Passivhaus on one of their many websites) will improve its efficiency in very cold (like northern Canada) or very hot (like the equator or desert) areas. This is because thermal mass *stores* energy, which stabilizes temperature swings—it helps keep warm houses warmer longer, and cool houses cooler longer. Insulation does not do this, it only helps prevent temperature loss (and temperature gain), like a blanket.

That a passive house does not retain its temperature as well in temperature extremes is not surprising (at least to me) since preventing energy loss is only as good as the medium in which the energy is stored—that being either solids, liquids, or gas (air), or objects in the home that have thermal mass, which are slower to gain heat but also slower to lose it.

Any mass (i.e., concrete slab) thicker than 4" (10 cm) is overkill for floors. For mass walls, 2"-18" (5-30 cm) thickness is acceptable.

Air does not hold its temperature levels very long at all compared to mass materials. Air, in fact, is the *least efficient* way to store energy (for temperature stability)—it heats up the quickest, but also loses heat quickest. This is why HVAC systems in conventional homes are always cutting on and off, continually—they keep trying to heat the air only, which is the #1 worst way to warm a house. You open the door on a cold day and everyone is shouting to close it fast because the temperature in the room drops quickly! The heater then has to cut on and warm it back up. In a passive solar house this is not the case; once the door is shut the temperature still feels warm because of the already-warm mass. While the superinsulation in a Passive House prevents that heat loss for a long time, it is trapping the heat rather than actually storing it in mass (since their design does not require thermal mass as part of their building or design criteria). Only thermal mass stores heat longer term. Using an insulated concrete slab-on-grade (or preferably a greener thermal mass equivalent) as your home's thermal mass source is a good idea if you build a Passive House (or even a passive solar house for that matter). Just do not rely on air as your medium for heat storage.

Water (liquid) is about four times as efficient than solid thermal mass materials for both gaining and releasing heat, but it is not a very good building material as it requires containers to keep it sealed away

from the living space, or grows algae or bacteria if exposed. People have tried solar pond roofs, storage barrels, water tubes, and the like, but so far one of the most practical uses has been by running water through PEX tubing in a thermal mass floor for radiant floor heating (not that they are not without their issues); however, the floor heating is more of a heat source than just a storage method according to some. Research this method well before using it.

Solids have thermal mass, and the reasons mentioned above are why mostly solid mass materials are used in passive solar home design, whether it is a 4" (10 cm) thick concrete slab on grade (**any mass thicker than 4" (10 cm) is overkill for floors, and 2"-18" (5-30 cm) for mass walls is acceptable**), or other mass materials for walls, built-in mass furniture, rock or water features, and so on. Interior mass walls are usually more efficient than non-sunlit floors, while sunlit floors are the most efficient for solar gain heat storage.

Think about simple physics... heat rises. In this case, where is the best place in the home to place your heater? Answer: on the bottom floor or basement (well insulated). That way heat rises from the bottom to the top of the house. For example, if you have a well-insulated basement (including the basement floor) with a radiant floor heating system, it will keep that room very warm, and if there is an open area for it to rise to the main floor it will keep that area warm, and if allowed to continue to rise to the second floor it will keep it mildly warm (on average about a 2 degree F (1 degree C) difference per floor if the house is well insulated). This is a fantastic way to use the superinsulation aspect learned from the Passive House standard combined with the thermal mass floor and design of a passive solar house, yet taken a step further with heated water in a radiant floor heating system (efficient heating for non-sunlight areas in particular) in the basement floor for the best efficiency. Heat rises... from the bottom floor to the top, naturally. Simple, yet effective. Insulate the envelope and get rid of any thermal bridges (places where cold or heat can transfer through from the outside to the inside—*conductive losses*) and air leaks (*convective losses*), ensure you have proper ventilation, and then you will have an excellently designed house system.

A well designed passive solar home will do these three things:

- 1) ENERGY INPUT: energy added through solar gain
- 2) ENERGY STORAGE: retain energy through thermal mass storage
- 3) ENERGY LOSS REDUCTION: reduce loss of energy through adequate insulation

Have you ever noticed that in a regular “stick and brick” (meaning wood frame with brick exterior) house the insulation is normally on the inside of the walls, with the brick on the outside? The exterior brick wall is great for resistance against weathering, and never needs paint, but this house is literally built backwards, and it is why standard homes are so inefficient when it comes to energy efficiency. The thermal mass (brick) should be on the inside, and the insulation layer (normally inside the framed wall cavity) should be on the outside to hold the internal temperatures stable. So you place your thermal mass inside, and then insulate the envelope. Of course, in a passive solar home you could do this AND put thin brick or other low-maintenance materials on the exterior wall as well (sandwiching the insulation) so you never have to pain the exterior again; just be sure that the main thermal mass is on the interior of the house, whether that be brick, tile, adobe, cob, concrete, stone / rock / slate, or other mass materials.

To recap, a passive solar house has thermal mass on the interior walls and floors, plus windows along the southern face (longest wall) of the house, including possible clerestory windows to allow extra sunlight into the back half of the house. Foundation insulation keeps heat loss from occurring through the floor and foundation as well, and is a minimal expense.

The 90% Efficient Passive Solar House

This next house is by far one of the best passive solar straw bale and adobe (combo) homes that I know of; not because it is fancy, but quite the opposite—because of its simplicity.

REMEMBER: Passive solar design simply means you let the sunshine in on the side of the house that gets the most solar gain (meaning the south wall with proper overhang length) and

store the heat in the floor and walls and other items with thermal mass, then insulate (air tight, but with proper ventilation) the envelope so you do not lose that heat to the outside. That is it. Simple.

When designed in this way, the house itself then becomes the solar collector, so to speak, and it sits there and “runs” without any moving parts whatsoever. Once you have moving parts, you have things that break down, and need fixed, and then things become more complicated and costly and troublesome. In short, it causes work... if not work to fix the potential problems, but work to make the money to pay someone else to fix the problems. Keeping a house simple is the key to maintaining an easy (or even minimalist) life. This non-movement or lack of mechanical parts is why it is called “passive” solar.

**"Simplicity is the ultimate
sophistication."
~ Leonardo Da Vinci**

In order to show that the information in this book can bring you bottom-line numbers for energy and money savings, you really need to know about a house (green (eco-friendly materials), energy efficient, and passive solar all in one) that was designed and built by my friend and colleague, Chuck Reel.

I met Chuck in 1989 when I joined the El Paso Solar Energy Association, which at the time (and for another decade and a half longer) was the longest running active solar association in the United States. He, and others at EPSEA (including Robert Foster, Mike Cormier, Hector Gasquet, and others, including Steve Cook at the Energy Center at UTEP (University of Texas at El Paso)) taught me much of what I know about passive solar design. Chuck also built two green buildings / passive solar homes in the San Luis Valley of Colorado, on La Veta Pass, which was made out of mostly adobe (mud brick) interior walls and straw bale (with true mortise and tenon

timber frame with arms and 1" oak pegs) exterior walls. This is an entirely “green home”, meaning that the owner, and Chuck (as the main builder), chose to avoid toxic materials in the home so there would be no concerns about outgassing or indoor air pollution compared to the toxins that fill a typical conventionally-built house.

What is significant about Chuck’s design is that it incorporates not only green building materials, but also alternative construction materials such as adobe *and* straw bales in the same house, with the former making up most interior walls and the latter making up all exterior walls. This places the thermal mass of the adobe blocks into the interior, which acts as a heat sink for the solar energy that enters through south-facing windows. Also, it strategically seats the straw bale walls on the exterior for superior insulation values of R-40-50 (standard walls are R-13-20) so the temperatures inside the house remain stable. This home exhibits 2,054 external dimension square feet—straw bales and adobe take up some of the space for walls, so internally it has 1,633 sq ft of living space. To build it cost \$250,000 using conventional contractors / sub-contractors (it was not owner-built).

Similar to the Passive House standard (I will discuss Passive House design later in this chapter), there is also no HVAC system, so no furnace is required. The only heating source in the house that Chuck built—besides the passive solar aspect of the house design itself—is a woodstove that utilizes at least 2 cords of wood through the winter (the home is at a 9,000’ altitude). With blown-in cellulose insulation inside the attic and a metal roof, this passive solar straw-bale and 2,000-adobe-blocks house remains a balmy and comfortable temperature inside even on -24 F (-31 C) winter nights with only a small woodstove (and a backup propane for cold snaps).



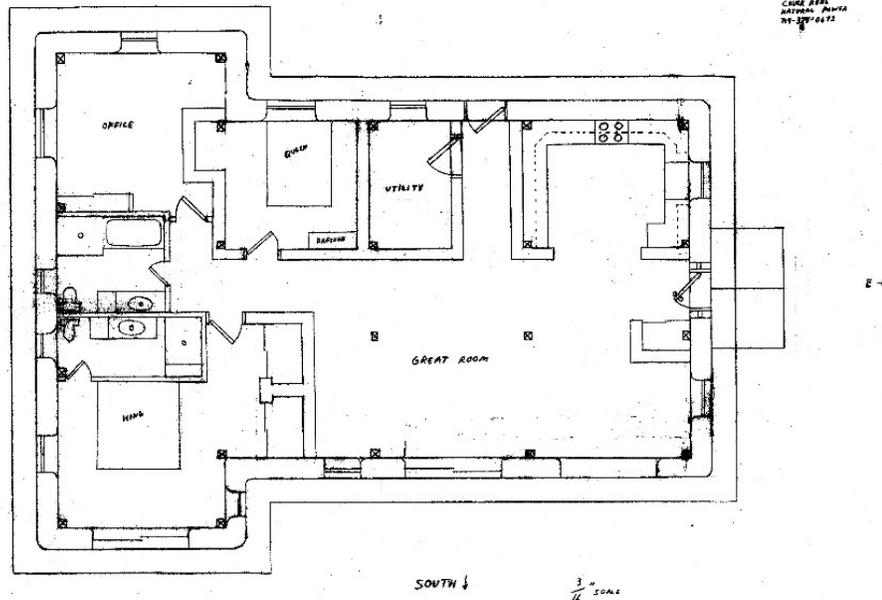
**Passive solar house built by
Chuck Reel in Crestone, CO**

So this goes to show that DESIGN is incredibly important in how efficient a building is for comfort, and does not have to be reliant on nonrenewable fossil-fuel burning sources of energy to heat and cool the space. Architects have the tools but typically do not push passive solar homes, and building contractors want to cut corners and save money wherever possible because new construction is expensive, and cheaper houses sell because people do not want to work the rest of their lives just to pay off a house. Unfortunately, those cheap designs and construction are passed on to the homeowner and cost them dearly in higher utility bills, and environmental degradation from extra GHGs (greenhouse gases) in our atmosphere from excess fuel used to heat and cool.

Certifications and standards are good to have and are required in some areas where codes and permits do not allow an owner-builder to construct the entire house without a GC (General Contractor) license. You can check into what an owner-builder can do before you ever build, and obtaining permits is not usually too difficult, but it does take some effort. The building code standards are neither necessary nor required in all areas of the globe in order to design a house and build a house, but they are definitely required and considered mandatory in most of the developed world, and with good reason (you

do not want the house to collapse from shoddy building practices). However, be sure that you choose the right area and know the code requirements before you build, and even before you purchase your land. Just by speaking with the local Planning office will help to answer most all of your questions.

Check into building codes no matter what—you will want your home to be built BETTER than code, never under code, and certainly not without using some standard as your rule for building (state or provincial codes typically trump local codes). The Passive House standard is a great one (the highest building standard in the world, presently, even above LEED certification), but is for a certain type of design that you may or may not choose to use, and is more expensive as well.



If you use the knowledge you gain from this book you can design a hybrid of the Passive House standard and passive solar home design, and build your own, costing less money. As far as the best locations for building are concerned, rural areas or outside city limits are generally easier to build in—for owner builders—than within city limits, and are usually less expensive for land costs and land taxes also. However, it is also farther from shopping and resources, and requires more transportation fuel and wear and tear on your vehicle, so keep that in

mind as you move forward in choosing your ideal spot to build your home.

The passive solar home that Chuck Reel designed and built is single level / ranch style and, he says, is about 80-90% energy efficient. Shown above is the floor plan of that house.

I show you this floor plan because although the Passive House Standard is the highest in the world, it still lacks the thermal mass that is the machine that “runs” the home by creating thermal stability, which reduces the heating and cooling loads through energy gain and storage. A Passive House merely gains heat through some passive solar house, but keeps it from escaping (through superinsulation), but lacks the thermal mass for long term storage. The Passive House experts claim you do not need mass because it takes too much energy to heat it up, but not requiring mass is only typically true for milder climates (and thermal mass can help in those areas too). Just because you have to heat up (or cool down) the mass *initially*, it then takes very little input to keep that mass temperature stable, especially if you superinsulate it anyway. This is common sense, at least to me, to have thermal mass in your house. It also is required in areas with temperature extremes because in very cold or very hot climates the efficiency is lost, and even the Passive House experts will admit to this fact.

The home plan above has up to R-50 (insulation value) straw bale exterior walls, and mass adobe walls used for all of the interior walls. It is built airtight, passive solar, with natural ventilation, and is energy efficient. This home stays warm in -24F (-31C) weather in Colorado with only the small woodstove for supplemental heat. It was not built by Passive House standards, but by using passive solar home design principles, and with green building (although it is not LEED certified) style materials. This was a “home grown” house built by my friend and colleague, Chuck Reel, for someone he knows; it is completely custom built, and purposefully simple and in tune with how nature works.

The reason that I use this house as my own type of “standard” for passive solar home design is because it meets the same basic 90%

or so efficiency level (in a colder zone 4b area in Colorado on the hardiness map) as a Passive House does, but without the R-120 ceiling or R-70 walls (typical Passive House insulation values for Ottawa, Ontario – warmer zone 5a on the hardiness map), because the interior thermal mass is doing its job. This is the same kind of house you or any other owner-builder can construct with the right plan, the right materials, and the right design.

Some changes made from the floor plan (shown above) that were made after the fact include:

1. The closet in the office was eliminated as drawn and instead placed inside the cavity in the NE corner of that room.
2. The guest bedroom has a closet in that NW U-shaped adobe section, the bed was never placed under that window as drawn and instead on the spot where it says dresser, and that dresser was moved to the west wall to the left near the door.
3. The door to the utility room was moved south on the same wall as far as it would go.
4. The kitchen had its stove top moved to the west wall and a window was added where the stove is drawn.
5. The drawn doors on the closet next to the front (East) door were eliminated.
6. The cast iron wood stove that was never drawn in was placed on the west wall of the Great Room.
7. The T-shaped adobe wall in the master bedroom closet was eliminated.
8. The Guest Bath had the bathtub and shower switch places.
9. A huge window assembly was added to the south wall in SW corner of the Great Room

One of the fantastic things about this house is that despite the deep frost line (5' in Colorado) he used Frank Lloyd Wright's (insulated footings design from the 1930's) alternative foundation technique called a Shallow Frost-Protected Foundation, which is used heavily in Scandinavia and parts of Europe, as well as some in the U.S. and Canada.

As far as this style of passive solar house in Colorado, you can watch a video on YouTube online by Chuck Reel for "**Green Home Design Course**" that shows a passive solar straw bale and adobe house at:

<https://www.youtube.com/watch?v=lyCLtyejBVQ>



Shallow Frost-Protected Foundation

Q&A – Test Yourself!

Question: Which rock will absorb heat from sunlight faster? A black rock or a white rock?

Answer: A black rock, because it is dark colored and absorbs more of the infrared (heat) from the sun.

Common sense fact: If you want to absorb more heat from the sun, use darker colors (this could be darker colors inside your house where the sunlight touches - such as your floor... use darker colored (thermal mass) tiles (brown or earth colored tiles are fine) or brick for your floor rather than white or light colored flooring materials... using dark colored carpet (an insulator) will NOT absorb the heat you are needing! Nor will wood floors (another insulating product).

~~~

**Question:** Which rock will reflect more heat from the sun? A black rock or a white rock?

**Answer:** A white rock of course! White reflects, as well as shiny metallic colors. This is why many solar collectors use metallic reflectors to gain more sunlight.

**Common sense fact:** Use light colors inside your house *where the sunlight does not touch*, to help reflect direct light, or diffuse indirect light around the room for a nice bright house instead of a dark dreary one.

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Question: Which rock will lose heat faster after it has warmed up? A black rock or a white rock?

Answer: A black rock will lose heat faster than a white rock. Just as black and dark colors GAIN heat quickly, they also LOSE heat faster than other lighter colors.

Common sense fact: Dark floors will lose the heat it had gained throughout the day by naturally releasing it up into the room (heat

tends to rise) at night. This is fine for *inside* the house. However, do note that a black roof will gain more heat in summer, and will lose more heat in the night during winter—stick with white or light colored roofs!

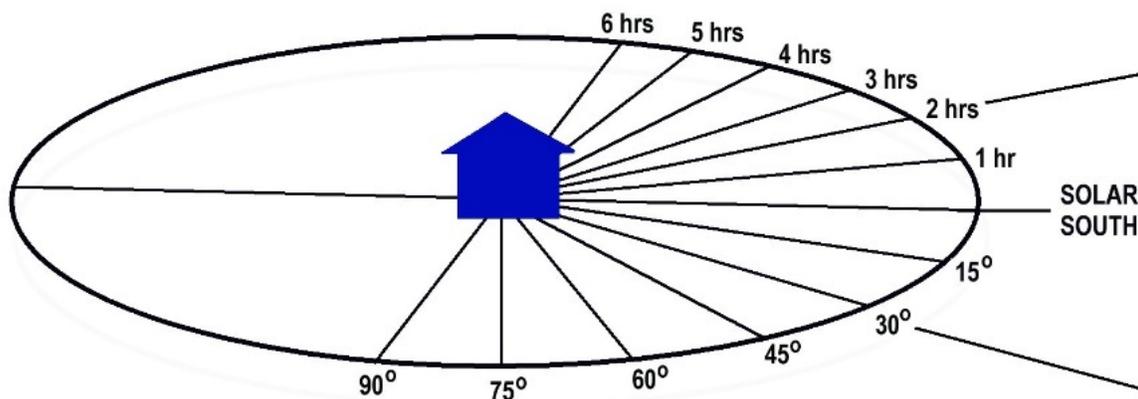
CALCULATE THE SUN

With some basic design principles under your belt, and perhaps having taken some time to observe where the sun rises and sets, it is time to understand what the difference is between “solar noon” and merely “noon”.

In this chapter I will also cover the difference between True South and Magnetic South, as well as their opposite directions (following the same idea) of True North and Magnetic North. Lastly, I will discuss what Solar South means, and how to find it so you can design the longest wall of your passive solar home to face that direction for proper solar gain.

OPTIMUM SOLAR GAIN

The sun travels 15 degrees every hour



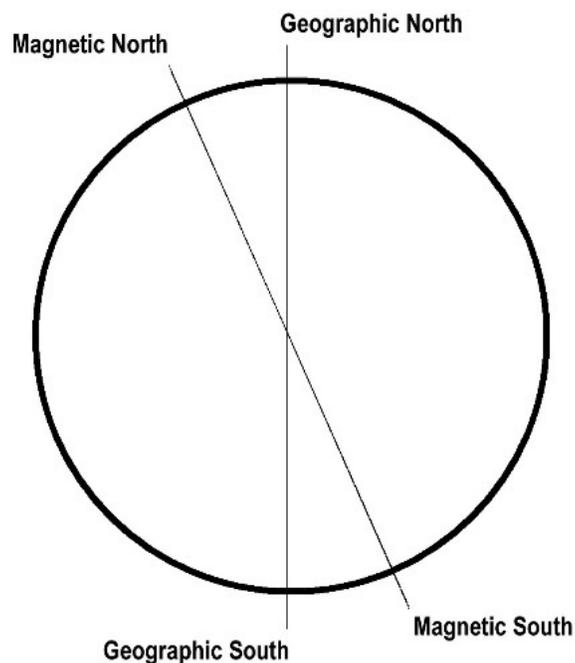
Ideal solar orientation (of your south-facing wall) is within 30 degrees of solar south, or else massive losses may occur in solar gain as windows will deflect light rather than let it penetrate

Remember the goal! Solar orientation of your home means it faces “solar south”. You will want to keep your home within 20 degrees (and absolutely no more than 30 degrees) of either side—east or west—of solar south.

In order to find solar south (true south), you will need to find true north first.

Magnetic North and True North

Notice that when you use any standard magnetic compass the little red indicator will point north—specifically, to magnetic north, at the north pole. Even a smartphone (touchscreen cell phone) has a magnetometer inside that allows it to show you the direction of magnetic north. The magnetic pole is not stationary... it wanders slightly near (not at) the Canadian arctic, but has been drifting (about 6.2 mi/yr on average, since the turn of the century) towards Siberia.



Magnetic North is not the same as *True North*. True north is not based on the earth's geomagnetic field, but instead on the location of the earth's geographic north pole (geodetic north), which is stationary and based on the earth's rotational axis. Technically, *astronomical true north* is slightly off (by a few arcseconds) from geodetic north since it marks the earth's celestial north pole (an imaginary spot in the sky just over the geodetic north pole). However, for the purposes of this book we are going to keep it easy and just call it "true north", to distinguish it from magnetic north.

The opposite direction of True North is True South, just as the opposite of magnetic north is magnetic south.

Now that you know the difference between these terms you will need to know about the difference between “solar position at 12pm” (noon, according to the clock) and “Solar Noon” (midday, according to the sun) because they are not the same thing.

Solar Noon

Many people are really thrown off by the use of the term “solar noon” because they think of the position of the sun at “noon”, but this is not the case. It’s better to think of two different ways of keeping time, solar time and clock time. Just as you can use a sundial to tell solar time, you use a mechanical or digital clock to tell clock time.

“Noon” refers to 12PM on the clock (no matter if it is daylight saving time or standard time)

“Solar noon” refers to the exact middle of the day between sunrise and sunset

Solar noon is where the sun is located in the sky at the exact moment between sunrise and sunset, which is located in the same basic direction all year long. Since sunrise and sunset times change daily (by a few minutes), the time for calculating “solar noon” changes with it, whereas “noon” is merely a time of day based on a variable clock (daylight savings time and time zones are variables, for instance).

I will give an example for where I currently own property near Yarmouth, Nova Scotia. During winter, the days are shorter, so on January 1, 2018 sunrise began at 7:59AM, and sunset occurred at 4:58PM. In this case, “solar noon” would have occurred between these two times, at 12:28PM (solar noon). As you know, even if it is only slightly moved in the sky (since the sun travels from east to west), the sun’s position at 12:28PM (“solar noon”) would be slightly more west than it was at 12PM (“noon”) on the clock.

You can calculate “solar noon” at:

<http://suncalc.net>

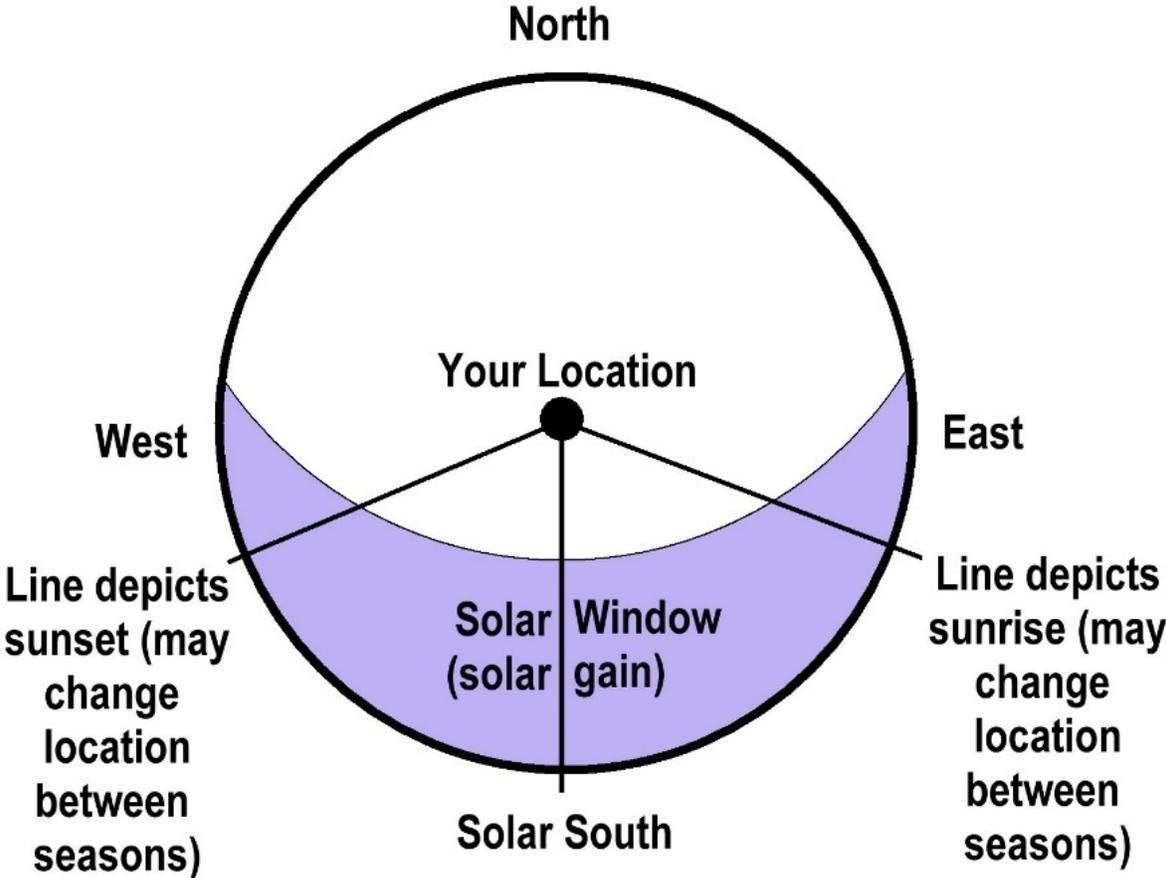
or click your location on the map here:

<https://suncalc.org>

I will include two sets of pictures below that were made at the SunCalc.net website, which allow you to see where the sun is at not only at “solar noon”, but you can also slide the clock time button to see how it differs at “noon” as well. This way you can examine the difference using this handy online tool.

In order to “read” the SunCalc.net images’ meaning I will explain it here. Once you go to the website and type in your location (wherever you intend to build your solar home) and other information it will create the image for you, which will show your location as it pertains to the sun’s path through the sky, particularly at sunrise, sunset, and in between these for solar noon.

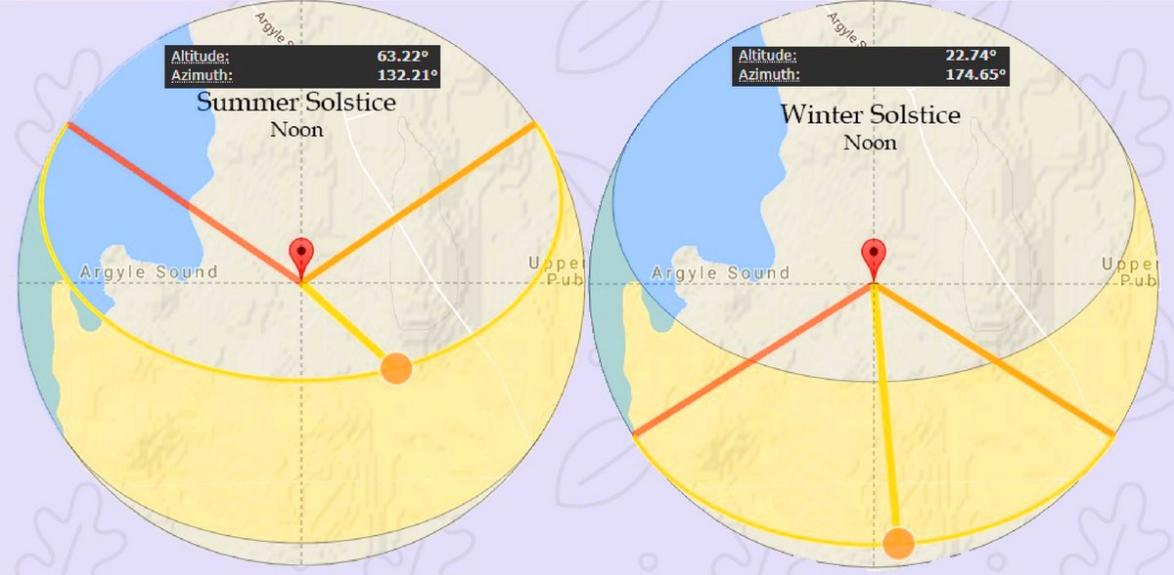
Example:



On maps, north is always up, and south is down. East is to the right, and west to the left. The arc of the path of the sun will always be

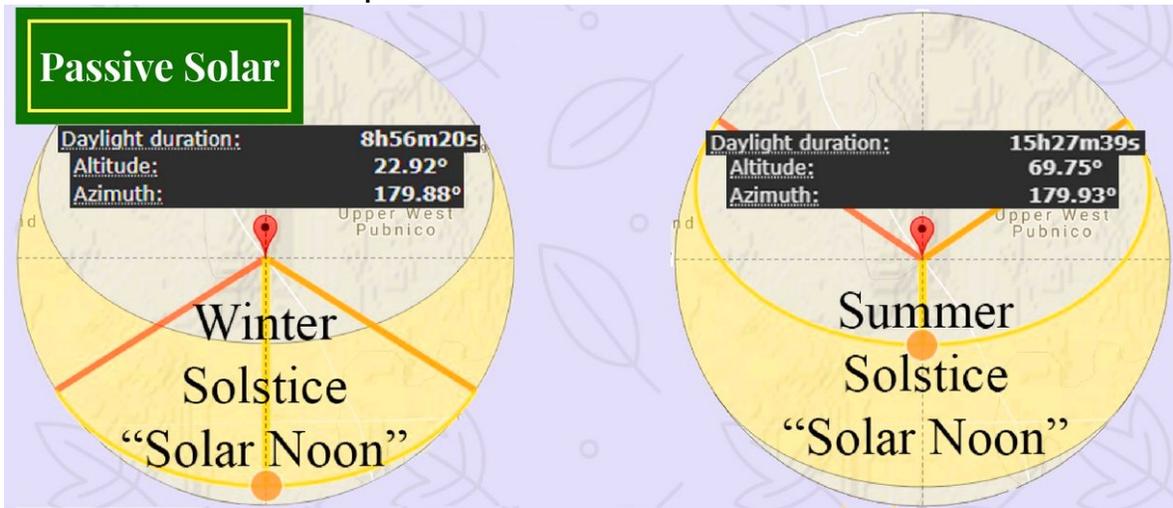
located in the southerly direction (in the northern hemisphere). The left and right arms / lines in the pictures determine sunrise and sunset directions. Also, in this first set of summer and winter solstice pictures (see below), the middle arm / line towards the bottom (south) shows the location of the sun at “noon” (clock time). As you can see, they vary between seasons because clock time does not match up with what the sun is actually doing. Clock time is not relevant, especially when you take daylight saving time into account.

The sun’s position at “noon” on the summer and winter solstices



Source: www.suncalc.net

The sun's position "solar noon" on the solstices



Source: www.suncalc.net

Notice that the second set of pictures show solar noon—with the sun in the same direction. The sun's position at solar noon is in the direction of "solar south". Solar south is the same basic direction year around even though the sun does move slightly (think about the sundial, which is 14-16 minutes ahead or behind a regular clock) because of a natural phenomenon known as analemma, which I will not go into here.

The solar noon position is the same year around; that is all you need to know for the purposes of understanding solar south. Where the sun rises and sets will change, but solar noon is a near-constant, at least for whatever location (latitude and longitude) you calculate for. Once you establish solar noon, you automatically know that the sun's location is in the "solar south" direction (or "solar north" if you are located in the southern hemisphere). Simple.

Shortly, I will show you how to find 'solar south' (based on solar noon) using three different methods, two of which are easy, and one that is more complicated but not too difficult.

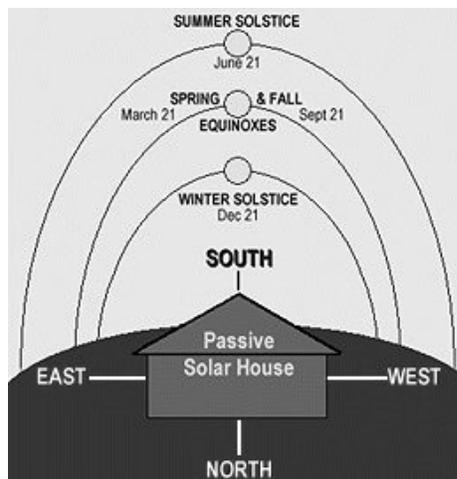
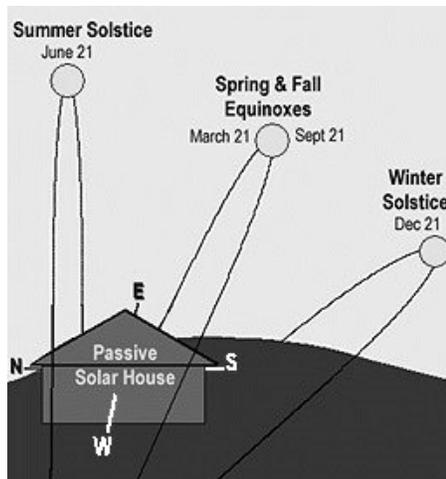
The only real difference in the terms "solar noon" and "solar south" is that *solar noon* is a TIME of day (between sunrise and sunset) and *solar south* is the DIRECTION of the sun at solar noon.

Solar South is also known as True South as it relates astronomically, rather than magnetic south (based on the compass).

So the system our modern society uses is TIME, which is based on clocks (is arbitrary and based on consensus); and the system used by the ancients was always based on the position of the sun (and moon) to manage time (sundials and archaeoastronomy).

The system modern society uses to measure DIRECTION is by the compass (magnetic north, therefore determining magnetically-based south, east, and west), which is dependent upon a more relative magnetic pole position (that moves slightly), whereas the ancients, again, used archaeoastronomy (the sun, in the daytime, and the stars—stars located far away—at night) to determine direction. Natives within many tribes in North America timed their ceremonies and dances with the stars at night. Many ancient societies determined time (sundials and star tracking) and direction (where and what orientation they placed their homes), which also guided how they moved from place to place. Even as a teenager I spent so much time in the woods—in nature—that I could look up at the sun at any given time and accurately guess (within 15 minutes) the approximate time of day it was (I would then verify it using my wristwatch).

Understand that solar noon is exactly in the middle of east's sunrise and west's sunset at any given time of year; however, the sun may be higher or lower in the sky depending on the season (higher in summer, lower in winter).



How to Find Solar South

Designing a passive solar house relies not just on knowing how to calculate solar noon, but also which way to face your home's windows; you must be able to find the direction of solar south, or "true south" (as opposed to magnetic south). Finding the sun in the sky at any given time of the year is easy.

Basically, there are three different ways to find solar south:

1 - The Stick Method

(easy)

2 – Shadow at "Solar Noon"

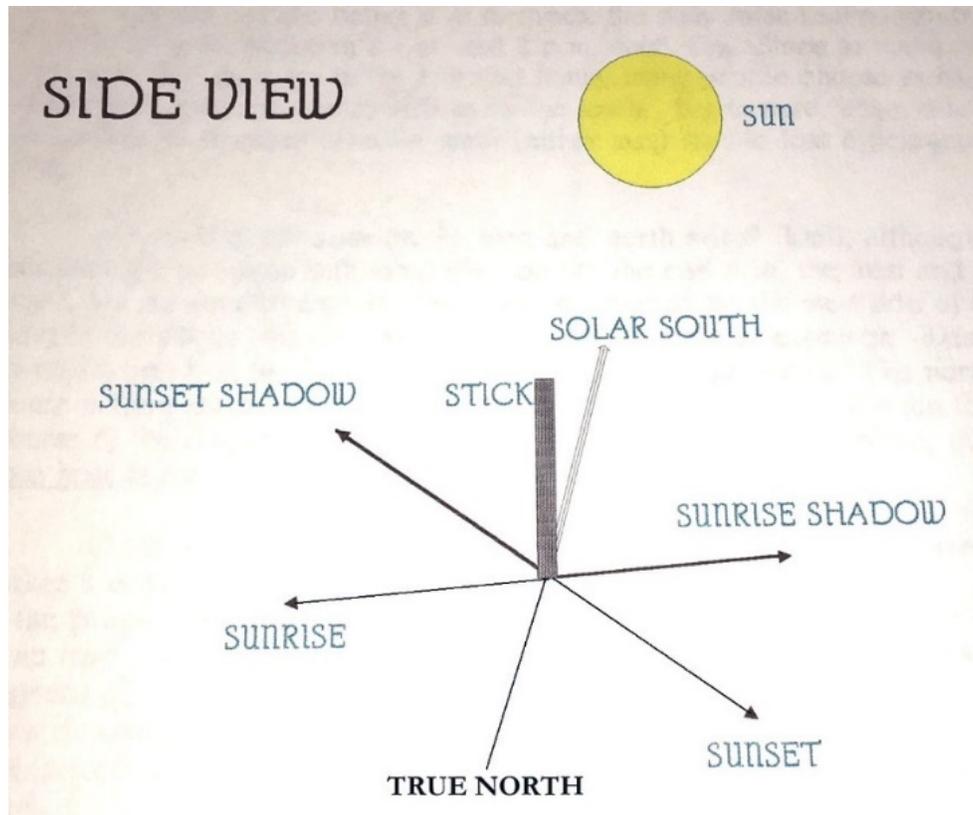
(easy)

3 – Compass Deviation / Declination

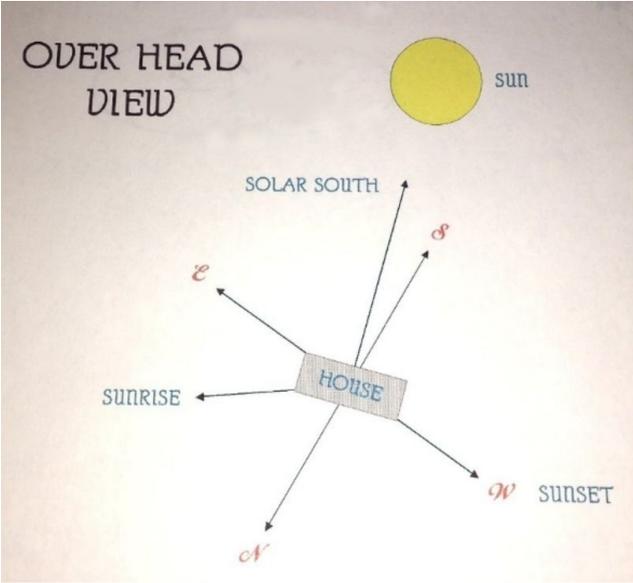
(less easy)

The Stick Method

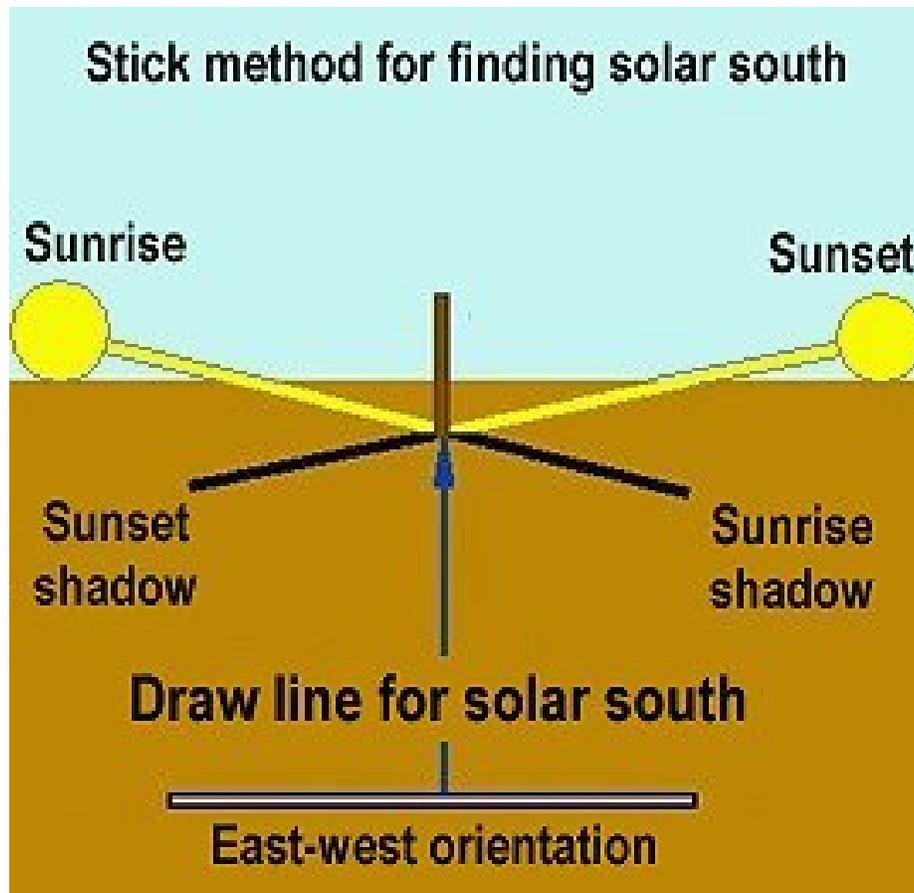
Probably the easiest way to find solar south is to use the stick method. It is free and only requires a few minutes of your time, notably, at sunrise and sunset. Here is how you do it.



1. At the exact moment of sunrise put a stick straight / perfectly upright into the ground (ensure no trees or other objects are in the way). Draw a line in the dirt where it casts a shadow and extend that line past the stick over towards the sun-side (make sure the drawn line is perfectly straight). This marks the direction of solar morning.
2. Then at sunset, using the same (unmoved) stick, draw a line where the shadow is cast, and extend it on towards the sun-side of the stick. This is solar sunset.
3. Next, draw a line exactly between these two marks (on the southerly side if you are in the northern hemisphere) and this marks 'solar noon'—noon referring to where the sun is in exactly the middle of the day (NOT the clock), between sunrise and sunset. This is also 'solar south'.



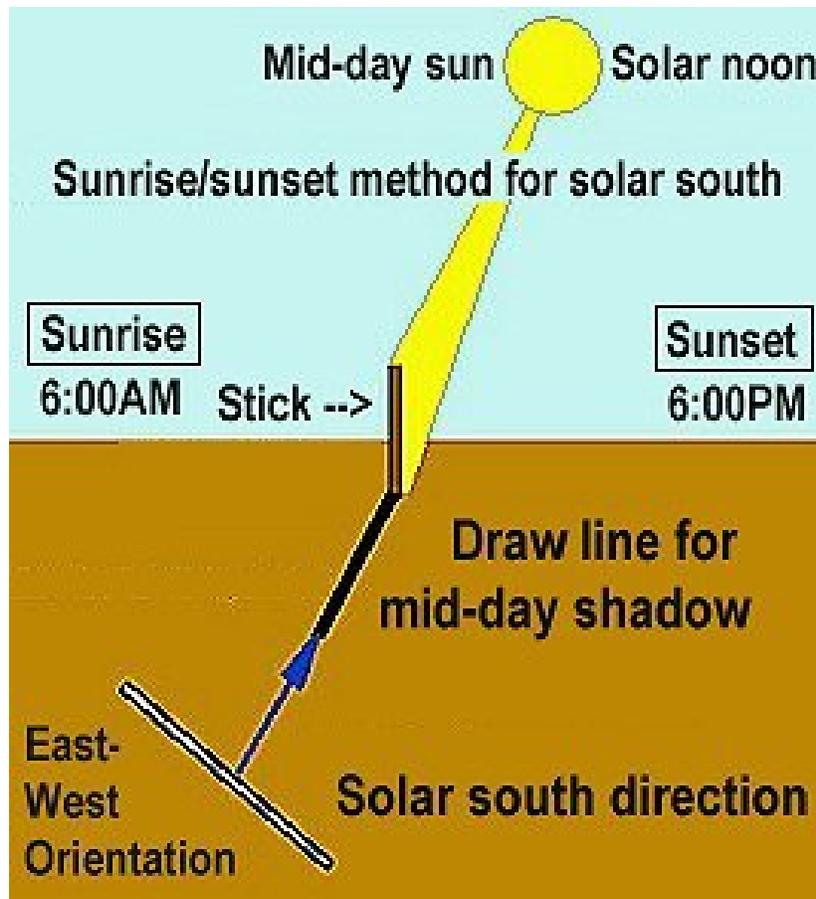
Solar south is the direction your home's (double-pane or triple-pane) windows should face to receive the most ample amount of sunlight for your structure. This should be south-southeast for many areas of the U.S. Here in Nova Scotia, it is just very slightly west of magnetic south.



Shadow at Solar Noon Method

This second method is equally easy, and perhaps even more so since you only have to go outside once, instead of twice. Here are the steps.

1. Watch the news on television, or check your Almanac, or use the calculator on SunCalc.net and note the times of sunrise and sunset for your location. At exactly in between these two times is called "solar noon"; write that time down.
2. Then at the time of solar noon place a stick in the ground and draw a line where the shadow is cast. NOTE: If you stand on the north side of the stick, facing towards south (where the sun is), that is where the shadow line should point. This is solar south.

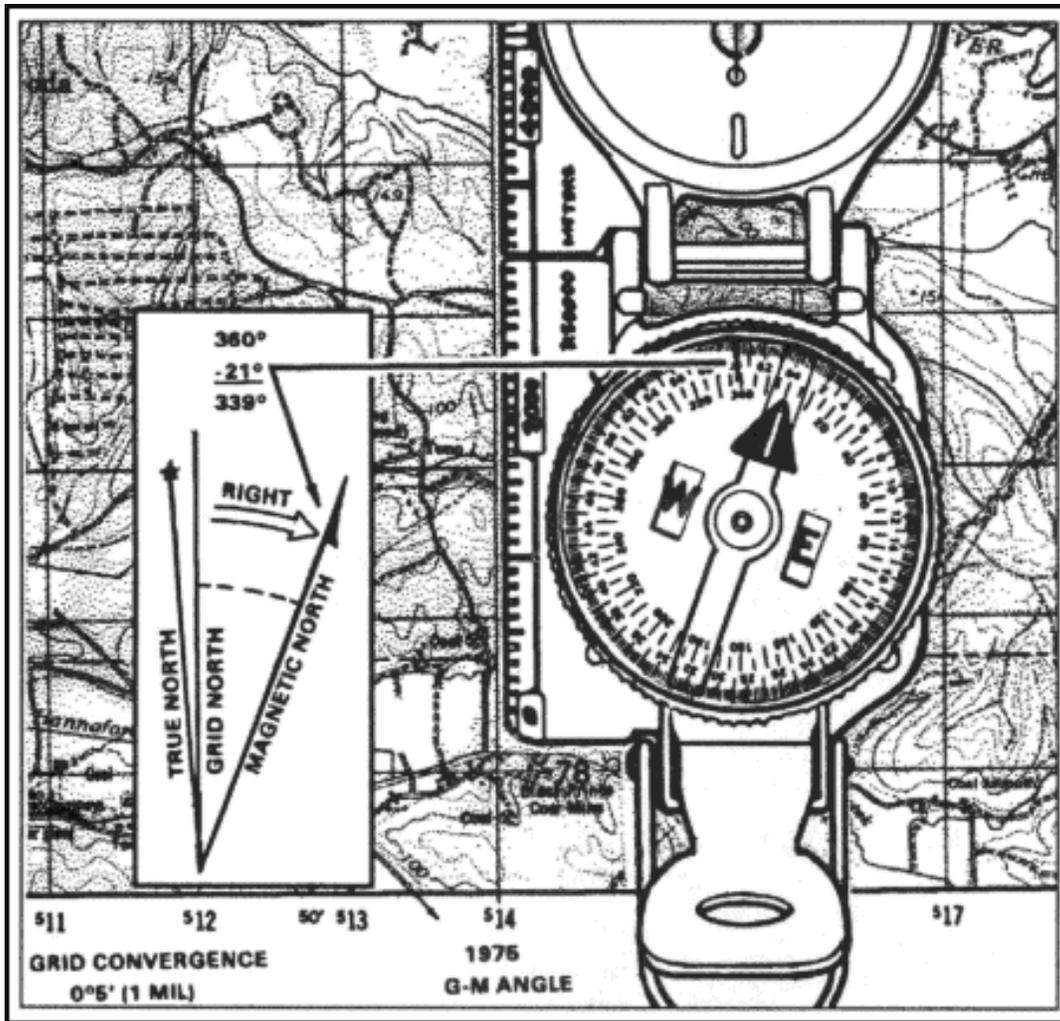


Compass Deviation / Declination Method

This third method is good for people who like to use maps and understand how to use a compass.

Here is the simple explanation of how you do it (*I almost deleted this section from this book because it is not that easy for many people, but some find it useful, so I kept it for them*):

1. Find your location and see what the compass deviation (or angle of magnetic declination) is by looking on a topographical map.



Source: <http://www.globalsecurity.org/military/library/policy/army/fm/3-25-26/image139.gif>

For example, when I lived in Lincoln, NE (1990's) solar south is 9 degrees east of magnetic south according to the deviation. The main solar heating hours for the Lincoln area were between 8AM and 2PM each day. Since so many of the hours to receive direct gain are in the morning hours, many people choose to have some windows on the east side as well as on the south. *But beware: any windows facing more than 30 degrees off solar south (either way) start to lose efficiency at a rapid rate.*

Another example is for El Paso, TX (in the 2000's) where solar south is about 11 degrees east of magnetic south according to the deviation. The main solar heating hours for the El Paso area are between 9AM and 3PM each day.

Magnetic *declination* is the angular difference between true north and magnetic north.

I personally like either the 'stick method' or the 'shadow at solar noon' method best if you want simplicity; however, for those who enjoy using a compass on paper, I have included some explanatory information below. In order to understand this you will need to know what a few terms are, which might be new to you. Sometimes a picture better explains a concept than words, or vice versa, so when appropriate I will include those below, along with their sources.

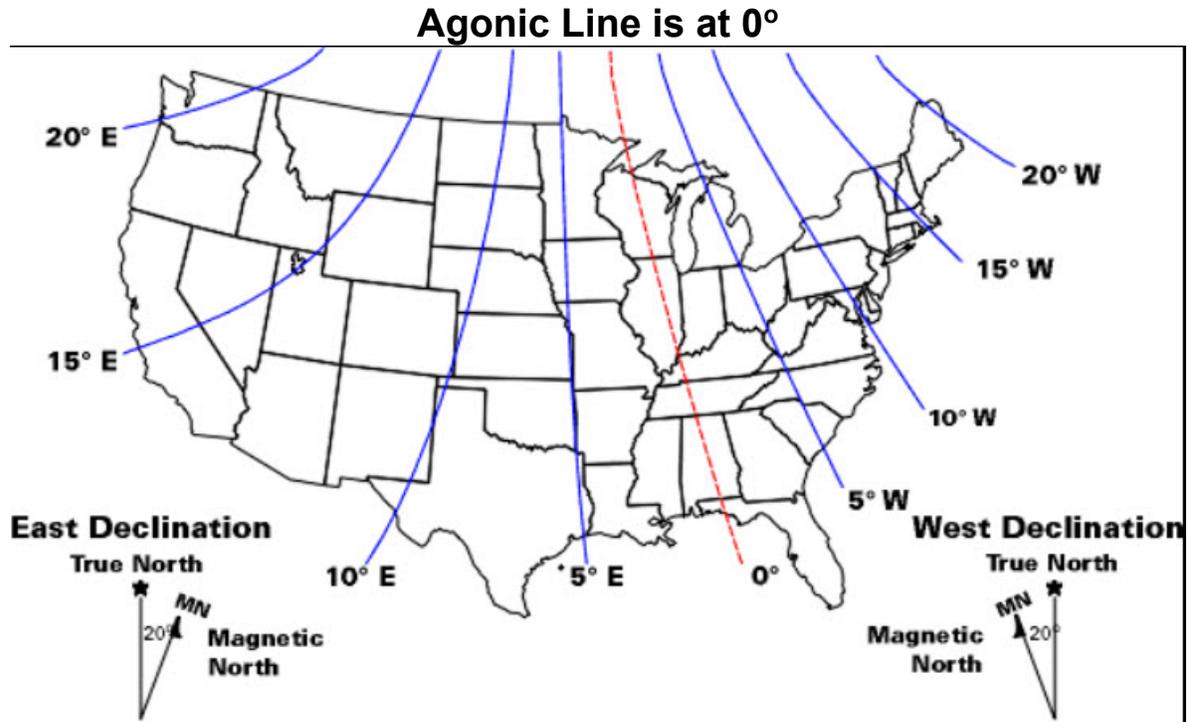
Compass Deviation



By Audrius Meskauskas, Wikimedia Commons

In order to find solar south, or true south, you must focus on finding its opposite, true north. The lines on a topo map (topographic map) are called meridian lines, which run north and south. They are in grid form. You will want to line up your compass to the meridian lines. However, an agonic line shows magnetic deviation / declination.

The **Agonic line** is an imaginary (longitudinal) line that passes over the surface of the earth and connects the north and south magnetic pole, and which has zero magnetic declination (true north).

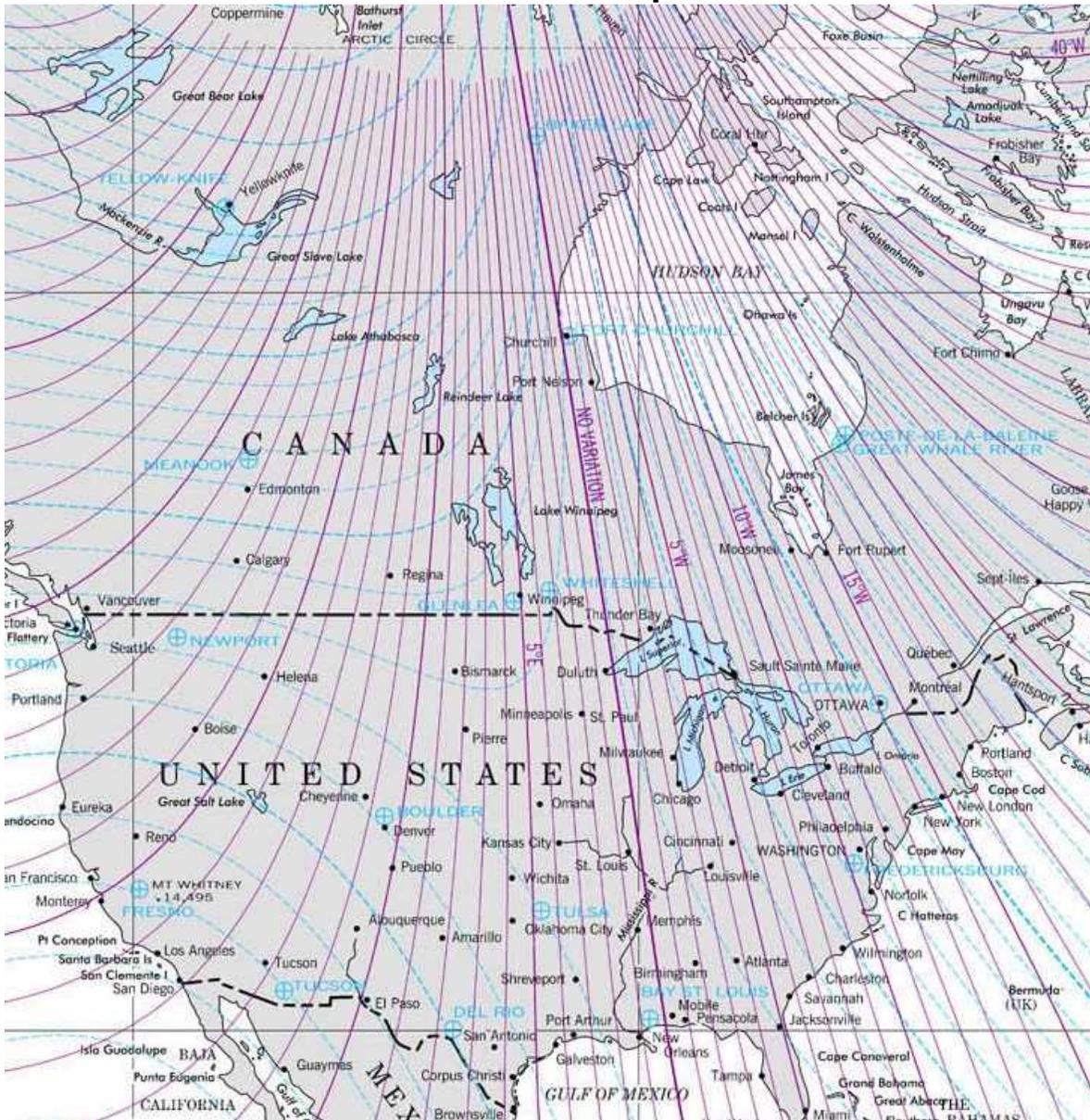


Source: <https://sites.google.com/site/profdavidkatz/state-society-and-culture-in-early-modern-europe/theagonicline>

If you are east of the Agonic line you will have a (negative) westerly declination. (hence, solar south is west of magnetic south in Maine) – turn your compass wheel clockwise (for true north) and your housing to the right (facing true south).

If you are west of the Agonic line you will have an (positive) easterly declination. (hence, solar south is east of magnetic south in California) – turn your compass wheel counterclockwise (for true north) and your housing to the left (facing true south).

Declination Map 1



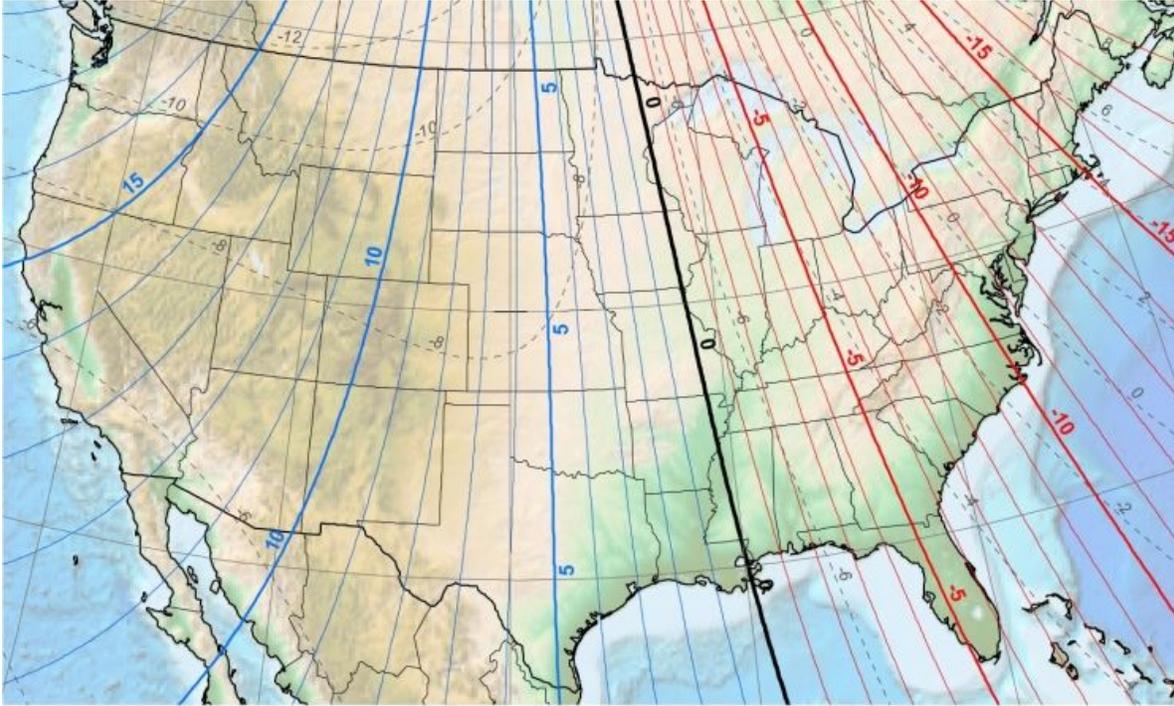
Source: <http://meridianintl.co>

Finding your magnetic declination

1. Use a compass with degree marks on it.
2. Line up the needle on the compass with north-south direction.
3. Find out how many degrees, and the direction magnetic north is relative to true north (this is the magnetic declination—see declination map below)

4. Rotate your compass (left or right based on the Agonic line) by the amount indicated by the declination.
5. “N” should point true north and “S” on the compass will now point true south.

Declination Map 2

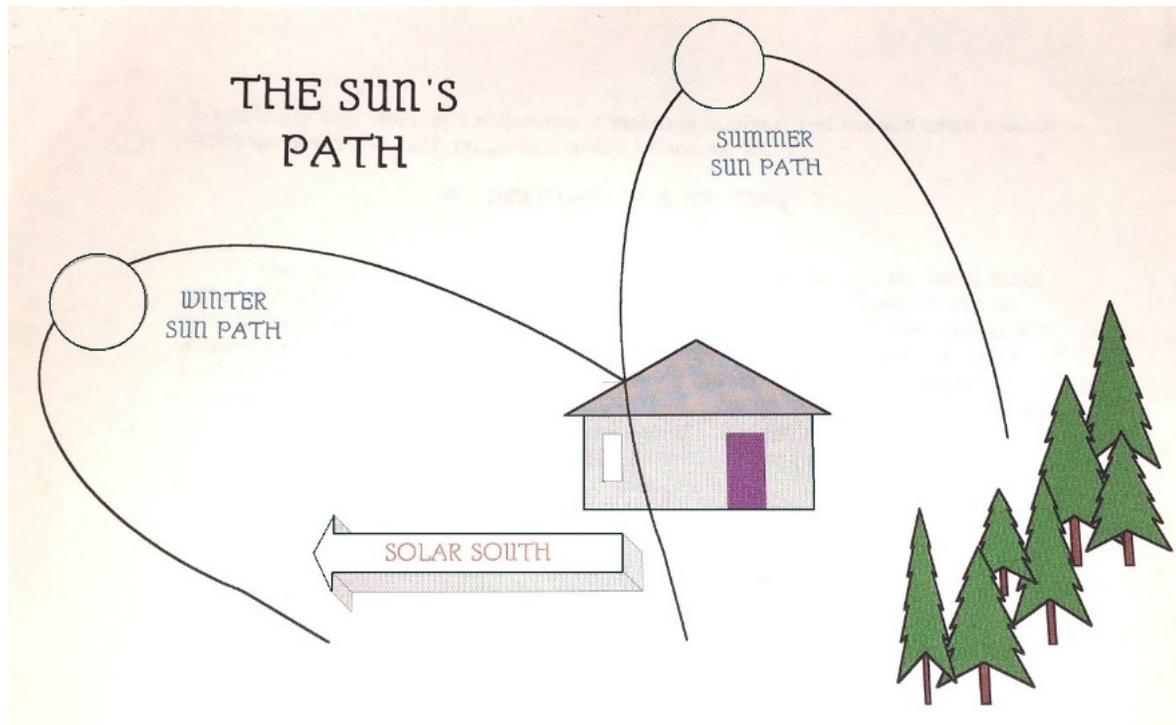


Source: westcoastweathervanes.com

The only problem with agonic lines and magnetic deviations is that they change over time, and so the maps also have to be updated. In contrast, using the shadow at solar noon or stick method will always be correct no matter where you live or what time of year it is as it is not reliant on maps or calculations that change, but rather the sun, which is about as close to a constant as you can get for these purposes.

Understanding the Sun

The point of finding true south / solar south is so that you can point your home's longest wall (with the most windows for solar access) towards that direction to maximize solar gain. If the main solar collecting side of the house is off by too much it will reduce efficiency.



Since the main hours to receive direct gain are in the morning and noon hours, many people choose to have some windows on the east side as well as on the south. But beware, any **windows facing more than 30 degrees off solar south (either way) start to lose efficiency at a rapid rate.**

Another few pointers besides the use of **thermal mass** (acts as a heat sink), is the **glass-to-mass ratio**, and **insulating efficiently**—on the exterior of that mass (rather than the interior like in standard stick-and-brick construction). Lastly, be sure to have a **properly designed southern-facing roof overhang**. When we get to the chapter on overhang calculation you will learn how to accommodate your home for the different angles of the sun in the sky (based on time of year)—

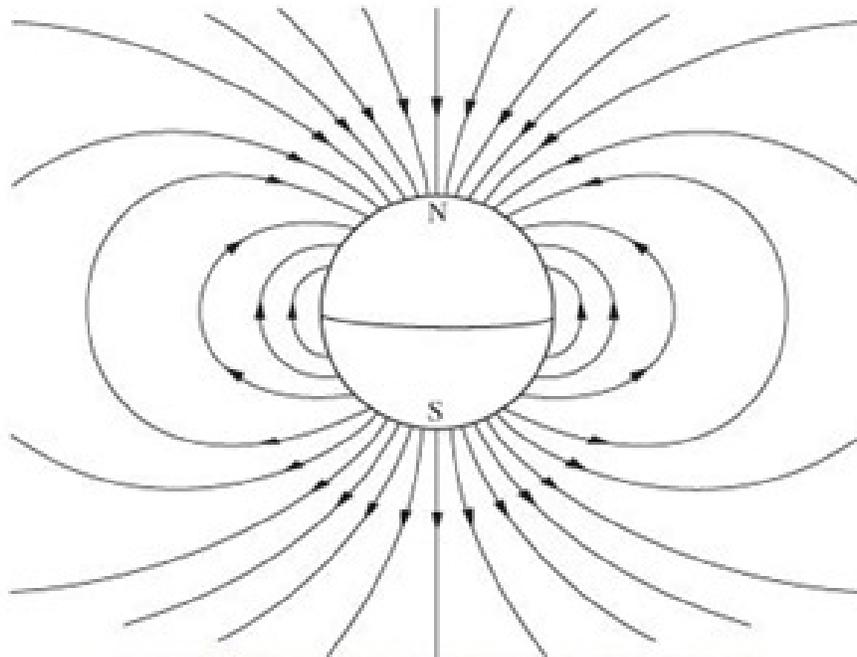
the sun is high during summer, and low in the sky during winter months.

In the meantime, here are some terms and information that may be useful for you to know regarding the sun—it is not required knowledge, but for solar nerds (like me) it is fascinating and adds to understanding.

Solar and Earth Cycles

Besides understanding solar declination and magnetic and true north / south, it is good to have an understanding about the earth as it relates to the greater heavenly body in encircles, the sun.

Earth's Magnetic Field (dipole)

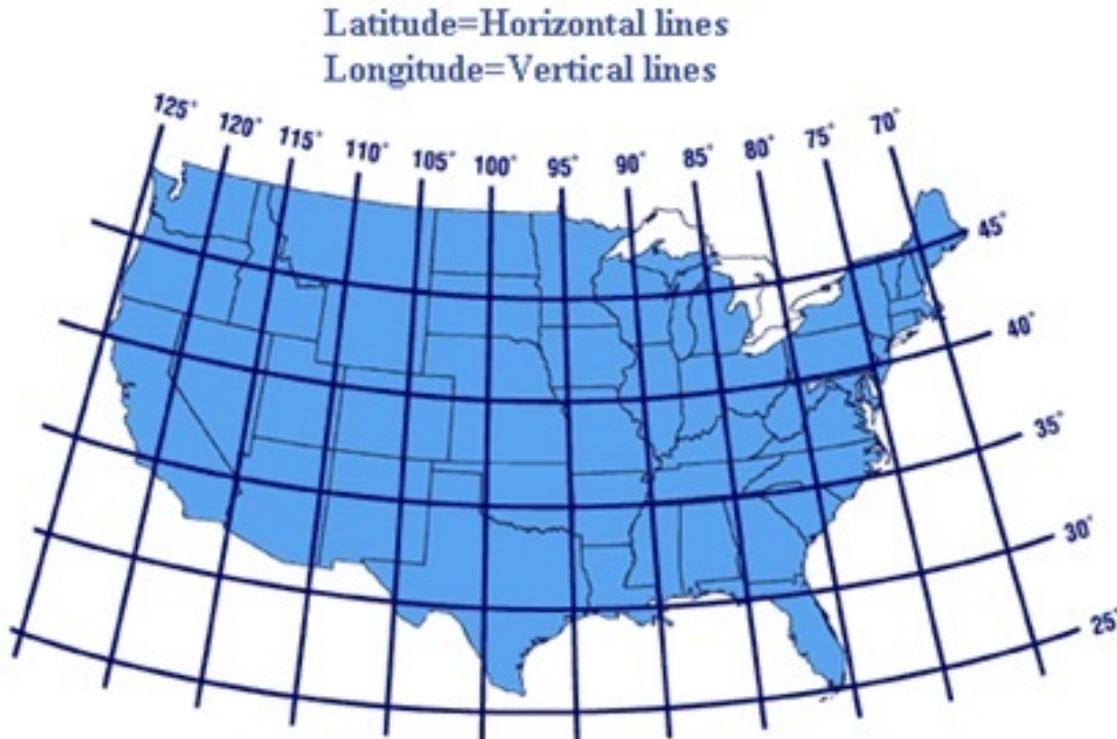


Source: <http://geomag.usgs.gov>

Latitude & Longitude

Latitude lines and parallels go east-west.

Longitude lines and meridians go north-south.



Source: www.spacecom.com

Tools for finding your Latitude and Longitude location:

Latitude – Longitude Finder

<http://www.lat-long.com/>

Satellite Signals, Latitude and Longitude (interactive map)

<http://www.satsig.net/maps/lat-long-finder.htm>

Definition of Declination:

“The latitude that the sun is directly over at a given time. The declination is $\sim 23^{\circ}\text{N}$ at the summer solstice, $\sim 23^{\circ}\text{S}$ at the winter solstice, and 0° (over the equator) at the spring and autumn equinoxes.”

Source: www.crh.noaa.gov/glossary.php

Solar Declination Angle:

“The angle between the rays of the Sun and the equatorial plane of the Earth. It is zero during an equinox and 23.5° during a solstice.”

Source: www.meted.ucar.edu/tropical/textbook/ch6/moistprecip_glossary.html

Azimuth Angle:

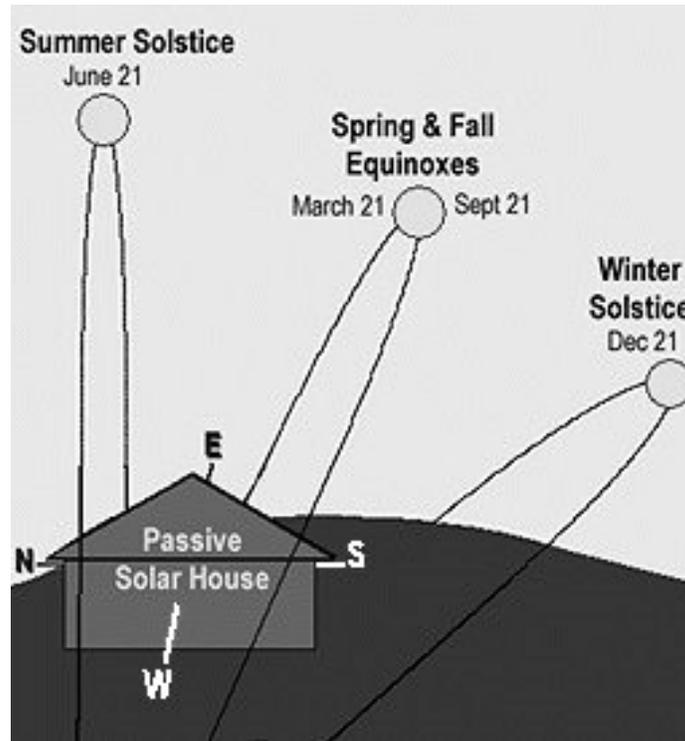
“The azimuth angle, also known as the bearing angle, is the angle of the sun's projection onto the ground plane relative to south.”

Source: <http://www.wbdg.org/resources/suncontrol.php>

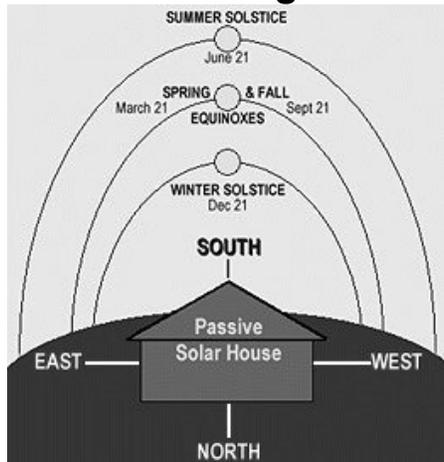
Because of the 23.45° angle of the earth's axis, the sun appears to be higher in the sky during summer, and lower in the sky during winter. This oddity is really a great help when it comes to passive solar design since it allows roof overhang to keep the “high” sunlight out in summer, and lets in the “low” sunlight in during winter.

If you take a look at the approximate (not to scale) paths the sun takes around the earth (from an earth-centric view) at different times of the year you can see what I mean. Here I revisit the two images I used earlier in this chapter.

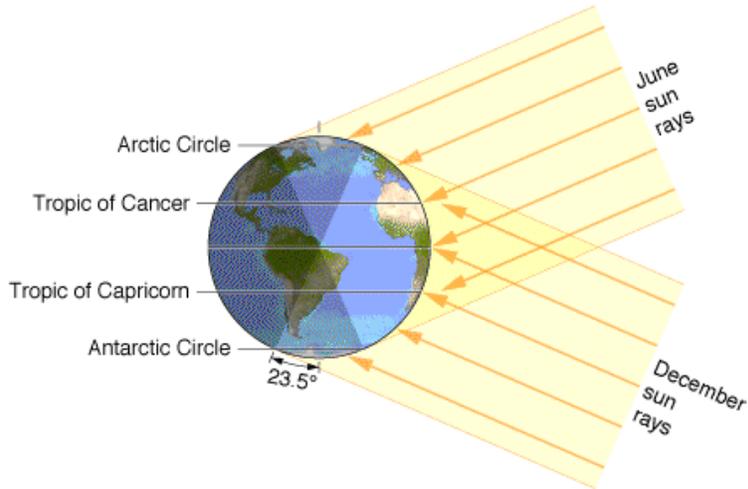
Side View of the Sun's Path



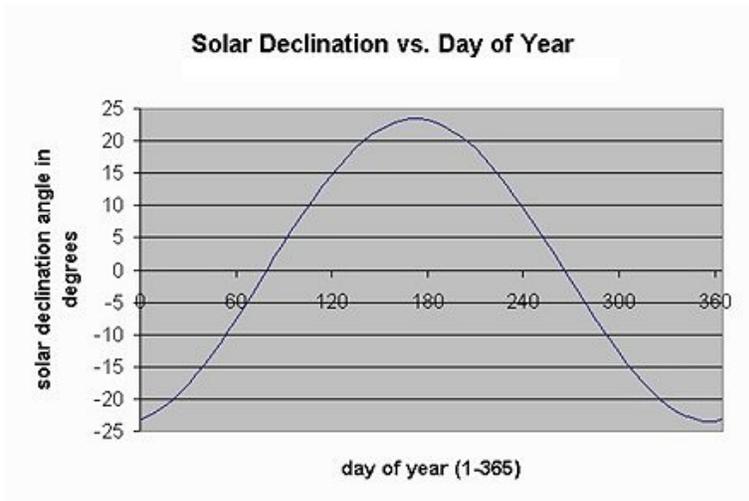
Sun's Path if Facing Solar South



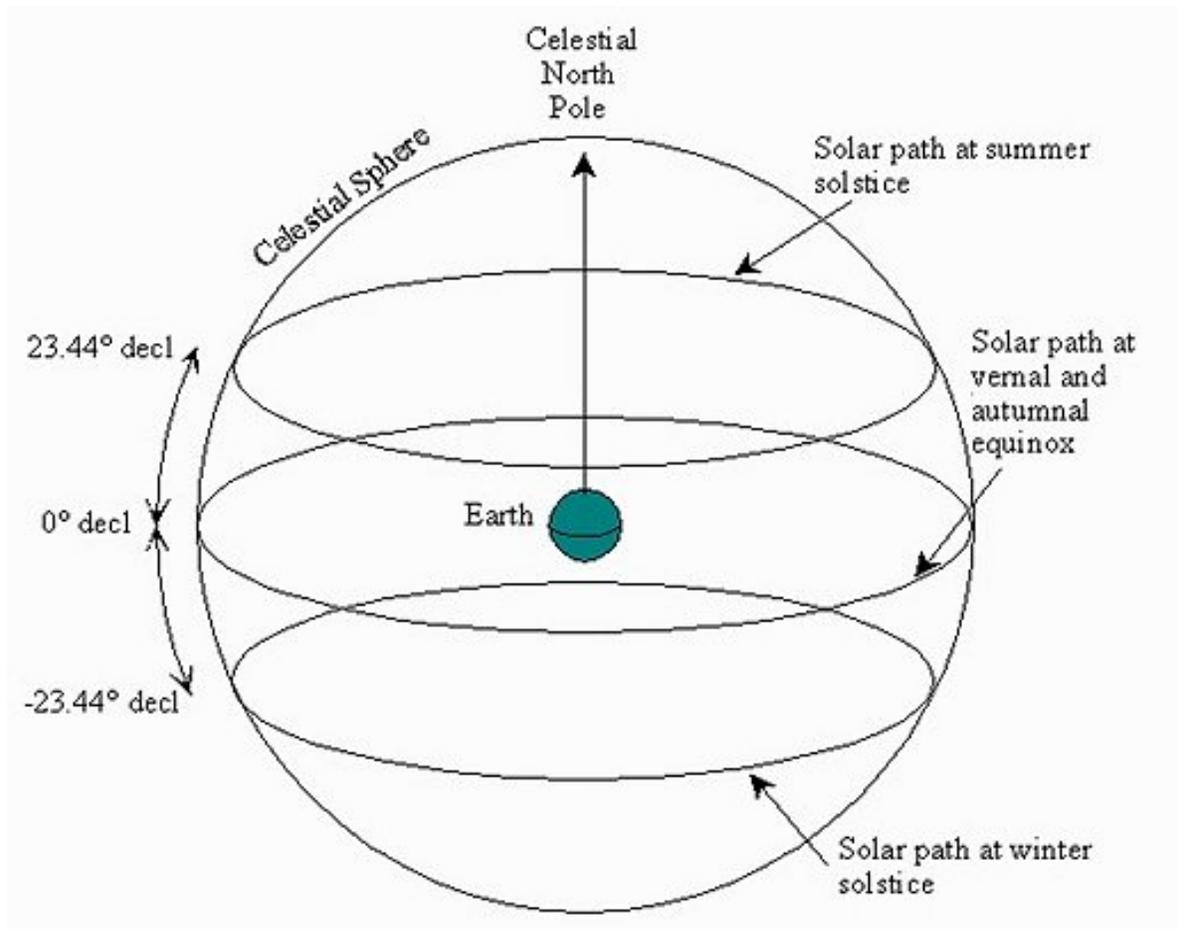
23.45° angle of the earth's axis



Source: <http://physics.weber.edu>

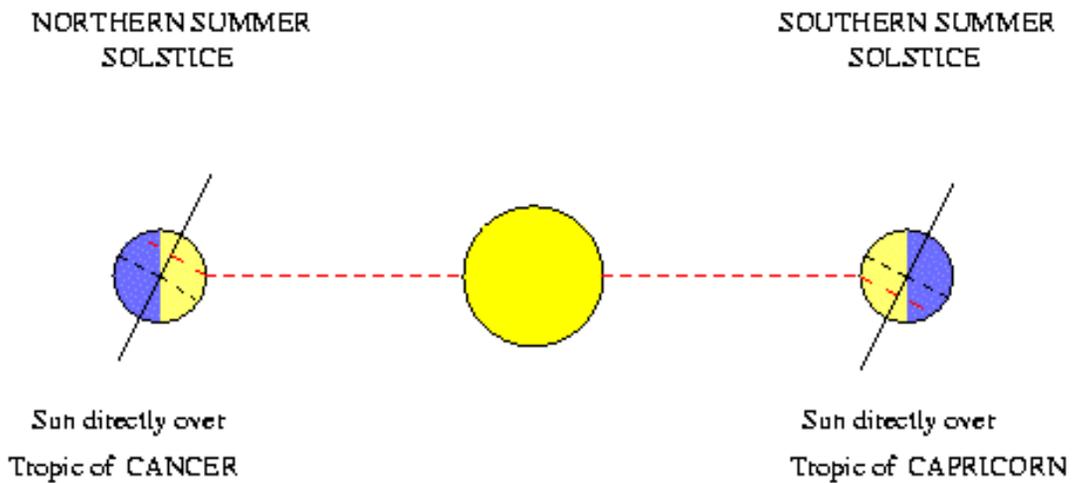


Source: www.srrb.noaa.gov



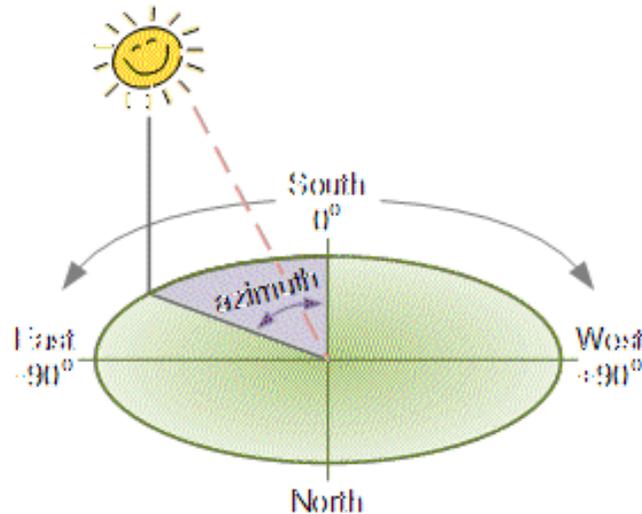
Source: www.srrb.noaa.gov

Why the Sun Hits the Earth at Angles



Source: <http://solar.physics.montana.edu/>

Azimuth



Source: <http://www.alternative-energy-tutorials.com/images/stories/solar/alt19.gif>

Now that you have a better idea on the “big picture” of our earth and sun, I can move on to how solar energy can be used by storing it in earth materials (thermal mass) to help warm the home in winter, and to cool it in summer. This is done through both direct gain, and indirect gain.

“Wondrous is this great, blue ship that sails around the mighty sun and joy to everyone that rides along.”

~ Unknown Author

DIRECT GAIN & INDIRECT GAIN

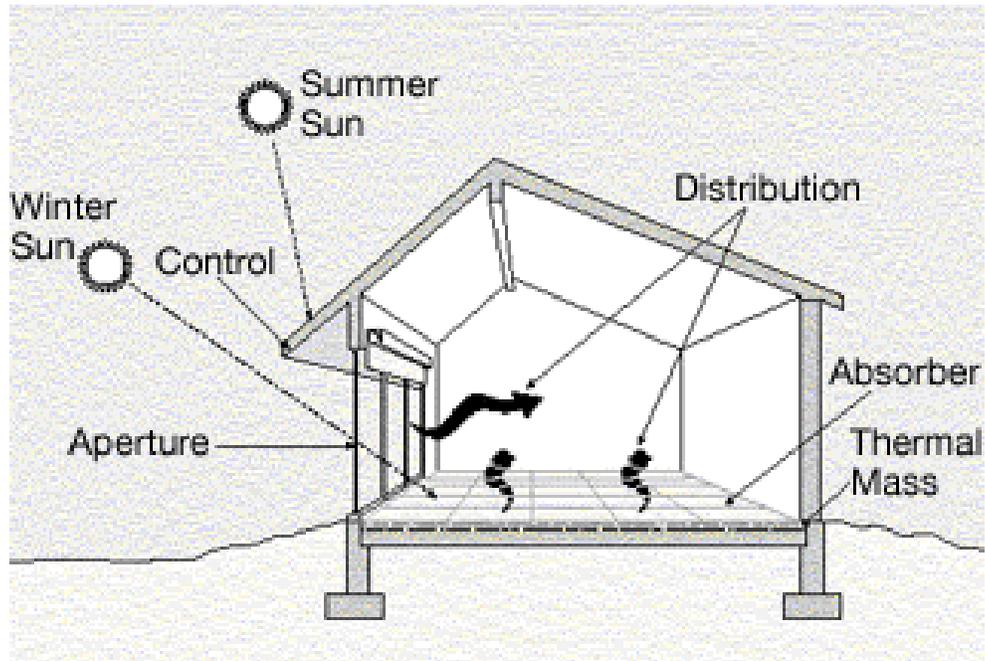
Passive solar typically works by two different methods of collecting the sun's energy:

1. Direct Gain
2. Indirect Gain

Direct gain is where the sun shines directly into the living area (which acts like the solar collector). In this way, the home receives and stores solar energy directly through windows into the main living space. Direct gain tends to be the most cost efficient way to gather sunlight into the house because the energy is stored by shining directly onto walls, floors, and other surfaces or objects does not need to be transferred to the rest of the house. The sun heats the walls and floor during the daytime and then slowly radiates that energy back into the room(s) during the night.

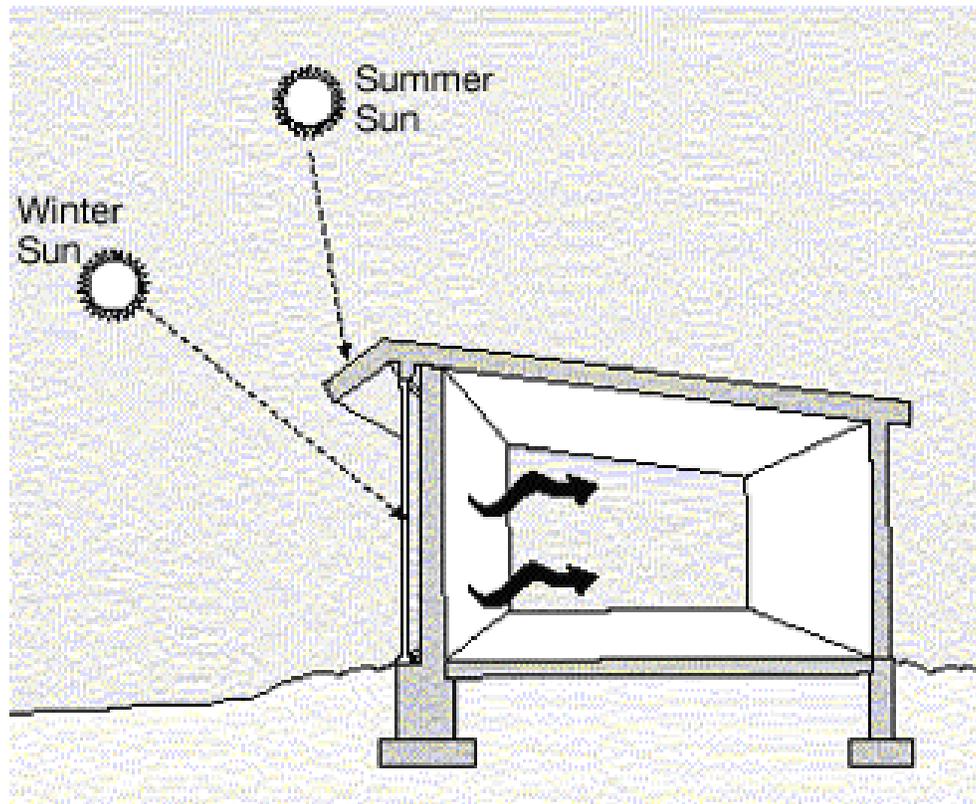
Indirect gain is where the sun's energy is stored indirectly, such as in a mass wall (trombe wall) that is juxtapositioned next to the living space. Mass walls like trombe walls are typically made of masonry or adobe and located 3-6 inches away from an exterior window or glass wall that faces solar south. In this way the wall collects the energy rather than letting it directly into the living space (as it does with direct gain).

Direct Gain

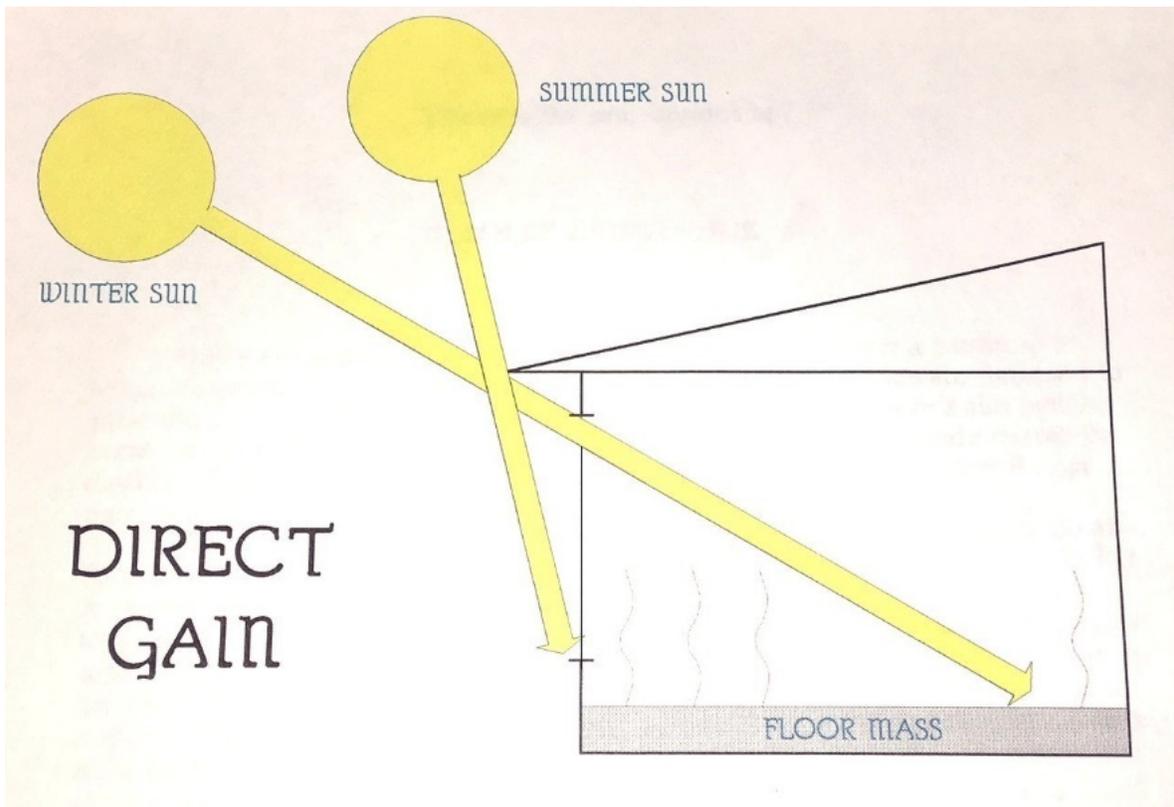


Source: <http://www.eere.energy.gov>

Indirect Gain



Source: http://www.eere.energy.gov/de/passive_solar_design.html



Passive solar design relies on the home facing solar south, and having proper glazing in a glass-to-mass ratio of about 1 sq ft of window area for every 3-5 sq ft of floor area. Anything outside of this ratio will be unbalanced, and you will find that too much glass overheats the house (just add thermal mass to compensate), or too much mass may stay too cool without proper sunlit areas.

Basic Physics Rule:
Heat seeks out cold

A good physics rule to remember is that heat seeks out cold. For example, a glass of hot water will *release* its heat (heat seeks out cold) and cool off and stabilize at the cooler room temperature, whereas a cool glass of water will *absorb* the heat from the room. Temperature changes can go both ways. If you are ever unsure of which direction the temperature will go, just remember the “heat

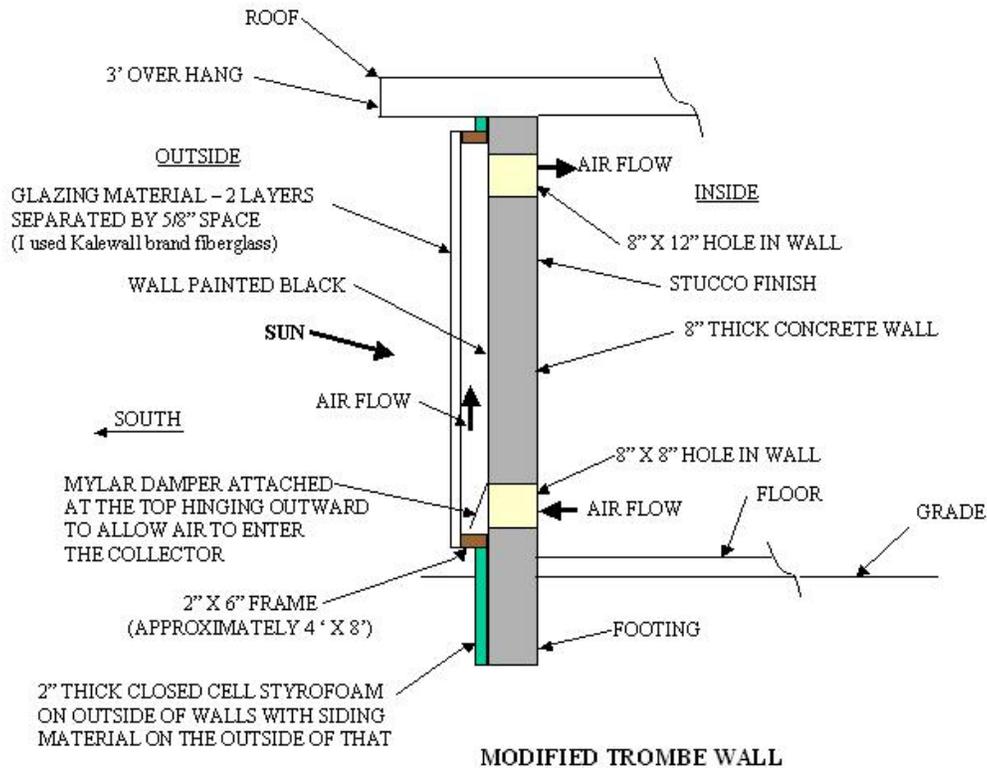
seeks out cold” rule. Heat *wants* to leave your house in winter, and heat from the outside *wants* to come into your nice cool house in summer. We must buffer these tendencies with insulation and break the thermal bridges (areas or materials that transfer heat in or out) in those areas. In solar gain, you would actually want the heat to transfer through the mass material into the room. That is the point of passive solar stored in thermal mass... to absorb sunlight while the sun shines, and then release it back into the cooler room at night when temperatures drop.

This means that if you have a cold room and a warm trombe wall (indirect gain), the heat from the wall will radiate into the colder room, making it warmer. This can also mean that if your windows in a direct gain living room are not insulated at night then warmed air in your house will travel through the glass towards the cold night air (because heat seeks out cold) outside and cool down your living space that much sooner. Insulated window shutters or insulated curtains would create a buffer zone and slow down heat loss.

Indirect gain systems like trombe walls have evolved a bit over the years. At first they were just a solid wall behind the glass, but it was soon discovered that vent holes at the top and bottom helped keep temperatures more or less even due to the natural convection processes to provide air exchange.

The only issue some people found with trombe walls was that if their glass was mounted without a way to open it from the outside, dust could build up, making cleaning difficult, so keep that in mind if you design such a system. Another alteration that occurred was to create a half trombe

Modified Trombe Wall

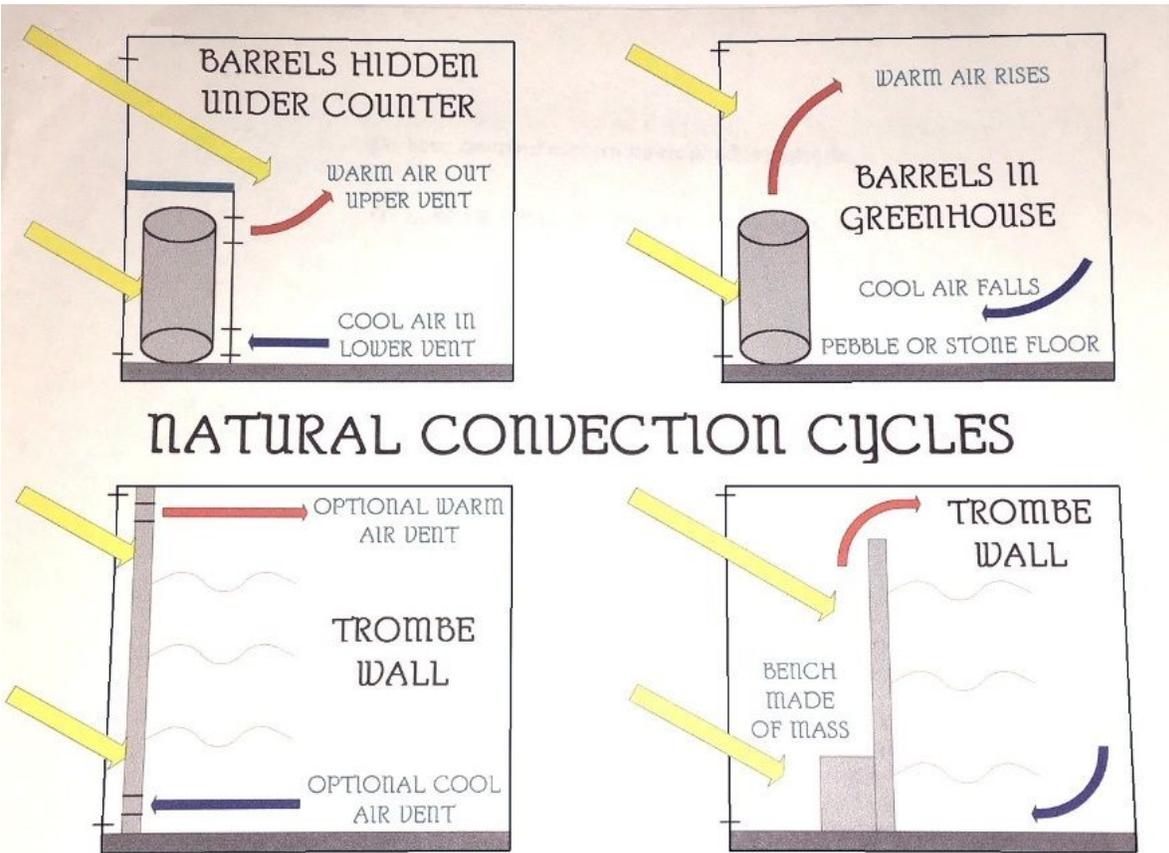


Source: F. Koester, Creative Commons

wall in front of the glass, so that dusting and even vacuuming the floor behind it was an option. This design also allows sunlight to enter the room via the top half (over the partial wall), much like a window. In fact, some of the full trombe walls had “window” holes placed into the wall for that purpose (actually for access and light, both).

Later, a design came from the desert southwest that included an adobe banco (“banco” means “bench”), which was made out of earth adobe block, while also pushing the wall further back away from the glass so a person could easily walk behind it. This allowed open cleaning as well as creating usable space. The half wall or full trombe wall could include a built-in sitting banco, or bench, that faced the sunny side, but could easily be placed further inside the room as well. At this point, however, one starts questioning just how much usable space this is, and how much of a hybrid design starts flowing over into a direct gain room, rather than an indirect gain system. There is no

right or wrong here, just preference. Of course, some designs work better than others.



When using thermal mass in either direct gain or indirect gain systems, there will be a lag time for the heat to transfer through the mass material, depending on the thickness, any insulation values, and of course the material itself. This lag time is used to your advantage. Although it takes longer to heat up initially, the warmth will last longer as well. I will never forget what one of my El Paso, Texas teachers, Mike Cormier, said about the passive solar adobe house he built: "In a regular house you open the door in winter and the cold wind blows inside, and then the furnace has to kick on because the temperature dropped too suddenly. Whereas in a passive solar home, once the door is shut, the warmth is already present because the thermal mass is already stable and warm. There is no need to warm it back up." You are heating thermal mass rather than air. Thermal mass holds its temperature much, much longer than air ever will. Passive

solar design acts as the energy input system through which this occurs. Both direct gain and indirect gain methods work, although in some warmer climates an indirect gain system (trombe walls in particular) may tend to overheat.

In general, you will want to place the majority of your glazing on the south side of the house, and combine that with enough thermal mass to store the heat, and prevent overheating. Make sure you have at least 3-5 sq. ft. of 4"-thick mass for each square foot of glass (called the glass-to-mass ratio) since this ratio is required for adequate storing capacity of solar heat within the mass.

Additionally, the south-facing glazing should range between 7-12% of the total floor space, otherwise the home could overheat. Remember that this 7% holds for the proper glass-to-mass ratio. Generally you do not add more glass unless you design additional mass into the system to compensate.

Rule of Thumb for most climates:

7% of floor space for south facing glass

4% of floor space on north and east facing glass

2% of floor space for west facing glass

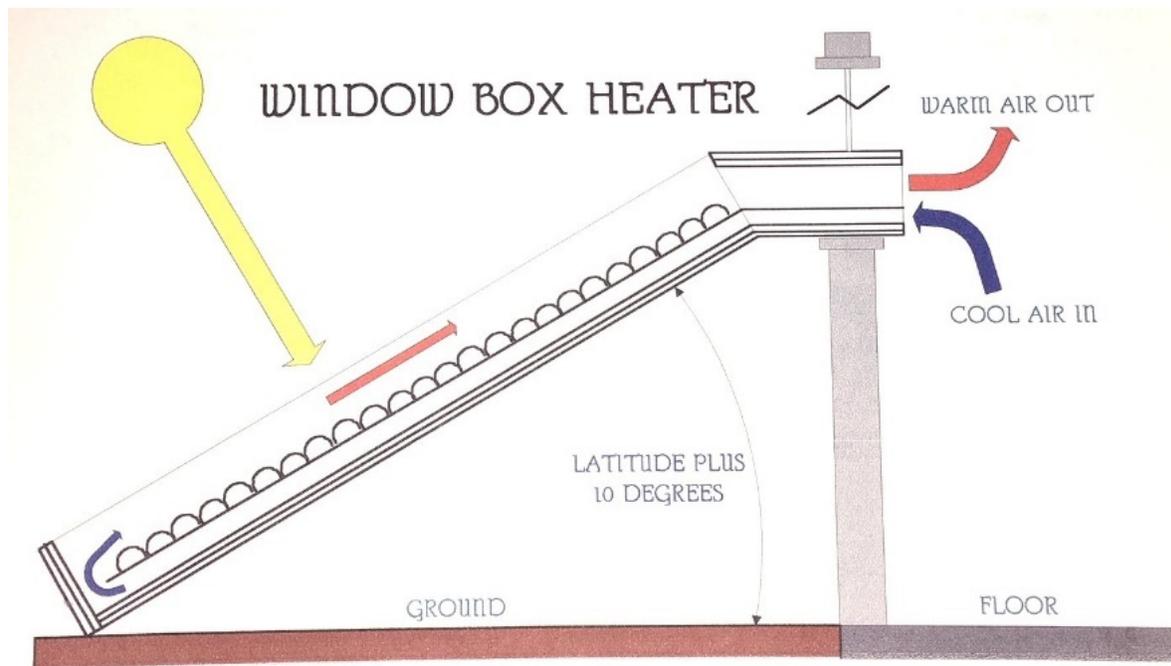
Use double pane or triple pane windows

Arrange furniture so sun hits bare as much thermal mass floor as possible

Utilize insulated curtains or insulated shutters, roman shades, or automatic exterior roll shutters to reduce nighttime heat loss

There are numerous other types of passive solar systems, including earth sheltered homes (like Earthships), attached sunspaces (be careful of overheating with these), day heaters / solar air heaters (window box heaters can be built as a separate heating aid using half-aluminum cola cans painted black in an insulated glass-topped box, but these are not typically needed in a well-built passive solar home—some companies also sell professionally manufactured

units), Isolated gain (see next page), or even roof pond (where water is pooled in a roof system to help warm the home—these tend to be expensive and can leak, and are very heavy at 8 lbs/gal, so are rarely done anymore).



Isolated Gain

Isolated gain systems, like direct gain or indirect gain, are a passive solar system, but they often need mechanical fan assist, which makes them a hybrid system and so are not truly passive anymore. Convection systems of this type are rare, and tend to be less efficient.

That said, however, Don Roscoe who teaches solar courses at Nova Scotia Institute of Technology in Halifax, Nova Scotia has devised a solar air heated system that pumps air into an 8" insulated concrete slab that produces up to 60-80% of the heating needs for solar homes in Canada. It is a hybrid system. He helped write a \$40 book on passive solar home systems that is sold through the non-profit organization, Solar Nova Scotia.

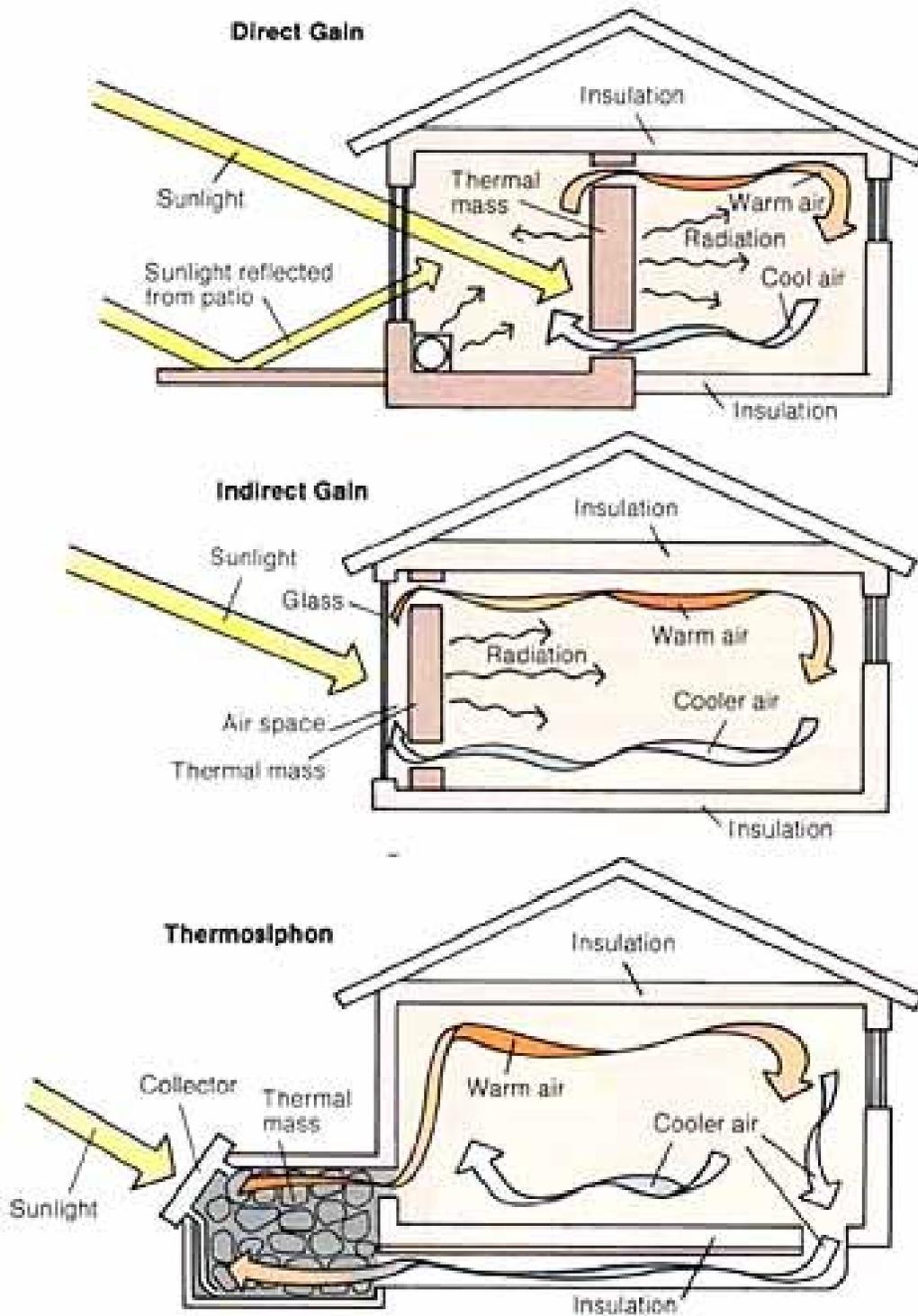
Roscoe's version is more modern and wisely engineered (he is an engineer) than some of the old thermal storage systems from the

1970's, such as thermosiphon heaters.

One of the issues with the old thermosiphon (isolated gain) systems, like the rock storage heat unit (see picture on next page) is that rodents were infiltrating them and urinating and defecating inside the systems, which caused many people to get quite ill, including contracting Legionnaires disease. I have seen many systems come and go over the years, and it just seems that the more complicated people try to make it, the more potential problems it has... from break downs, to health problems, to cleaning challenges, and more. Direct gain systems are #1 for ease of use and simplicity in design.

The idea behind isolate gain systems is that the heat storage area was isolated, or separated, from the rest of the house. Where some systems worked better than others, many did not. Another type of isolated gain system is the sun space, also known as a solarium or greenhouse space. These tend to overheat unless shaded in the summer; and unless they are completely separated from the house, they can actually lose heat in winter. Even so, they seem popular for some people and do add beauty to the home, when attached as a type of porch. Keeping them attached, but isolated from the main living space, seems to work best.

Passive Solar Systems



Source: <https://i.pinimg.com>

Do what works. Fancy does not necessarily mean better. There is nothing wrong with a window that lets the sun shine in to heat a mass

floor that is insulated underneath. You can't beat simplicity when it comes to low maintenance, low building cost, and ease of use. Seriously folks. I cannot stress this enough. The whole point of my book here is to show that anyone can do this. It is not rocket science, but it is science. Simple science. Heat seeks out cold. The rules are so easy a child can understand.

Improving Efficiency

I repeat many solar principles in this book for a couple of reasons—to ensure that you, the reader, will grasp the concepts, as well as ensuring that things are covered in more than one place in case some people are “here and there” readers, rather than “beginning to end” readers. Therefore, some of the things you have read in the previous chapters may be covered here, along with some new information.

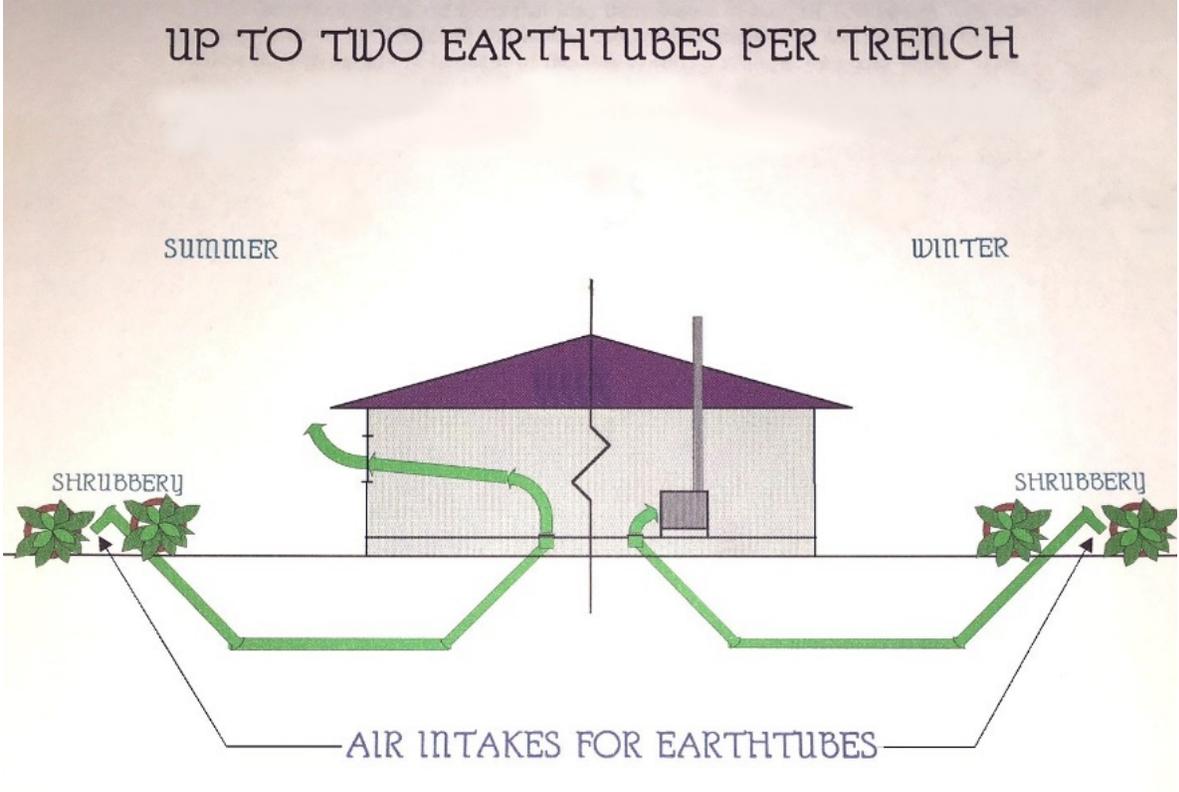
Once you choose the location to build your home, and ensure that it has an adequate solar exposure, then find solar south and orient your home to that direction (try not to deviate more than 10°—any more than 30° results in a sharp drop in efficiency), with the longest axis facing solar south, and the majority of your glazing on that wall. Add adequate thermal mass on the interior, provide a proper overhang length, and superinsulate. Again, it is that simple. Why pay more utilities than you have to? Why be more uncomfortable than necessary? This is your home. It matters.

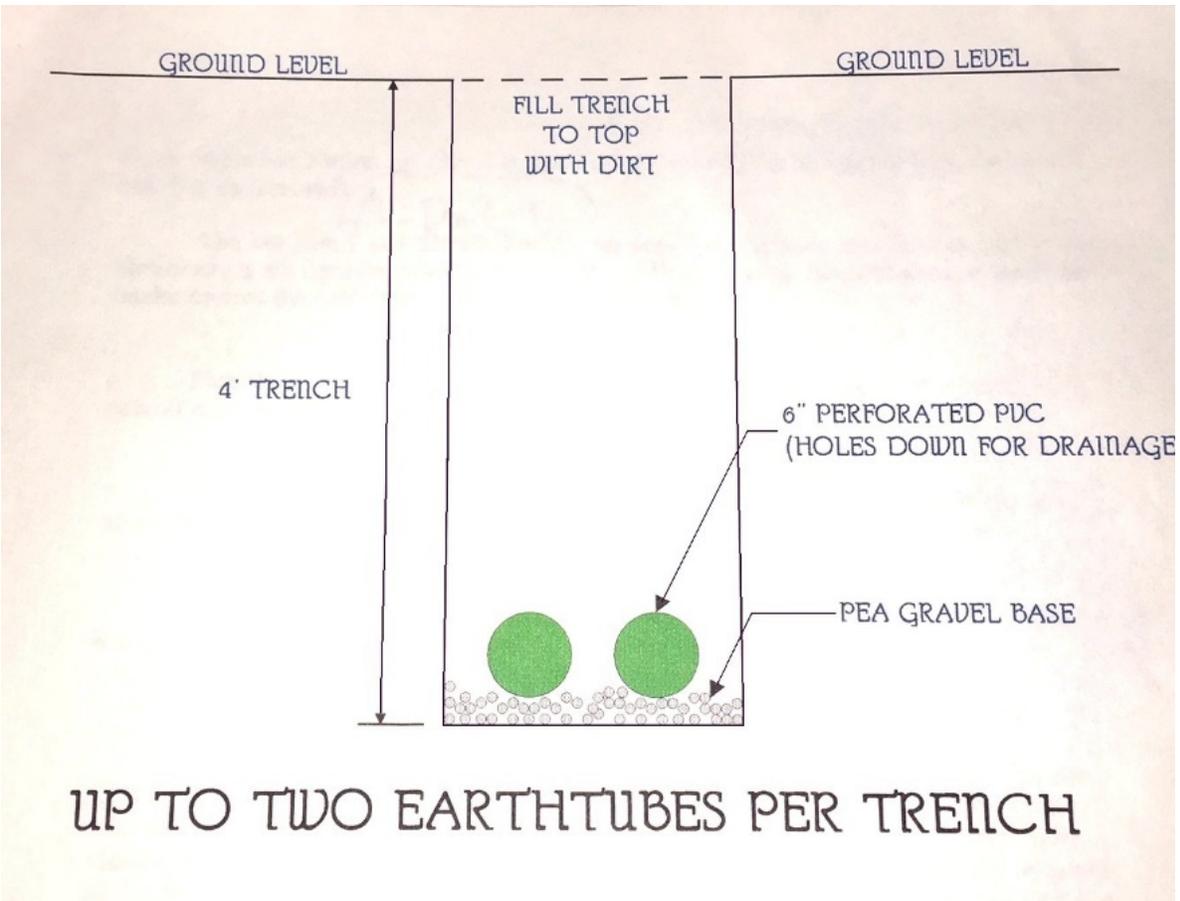
Plan for your home to have open spaces (open floor plans), and feel free to use zone heating (blocking off rooms you don't use and heat only the rooms you are in for the time). Open areas and large openings between rooms for your main living spaces allow passive heat to naturally convect and spread evenly. Your mass floors can be made out of concrete, brick, tile, slate or stone, or other thermal mass materials. It is good to choose darker colors for areas that obtain direct sunlight so more is absorbed instead of reflected. Lighter colors can be used on walls and ceilings to reflect light and give an open, airy feeling. Passive solar homes are known for their excellent daylighting—no need to turn on lamps during the daytime.

Ventilation, Cooling, & Earth Tubes

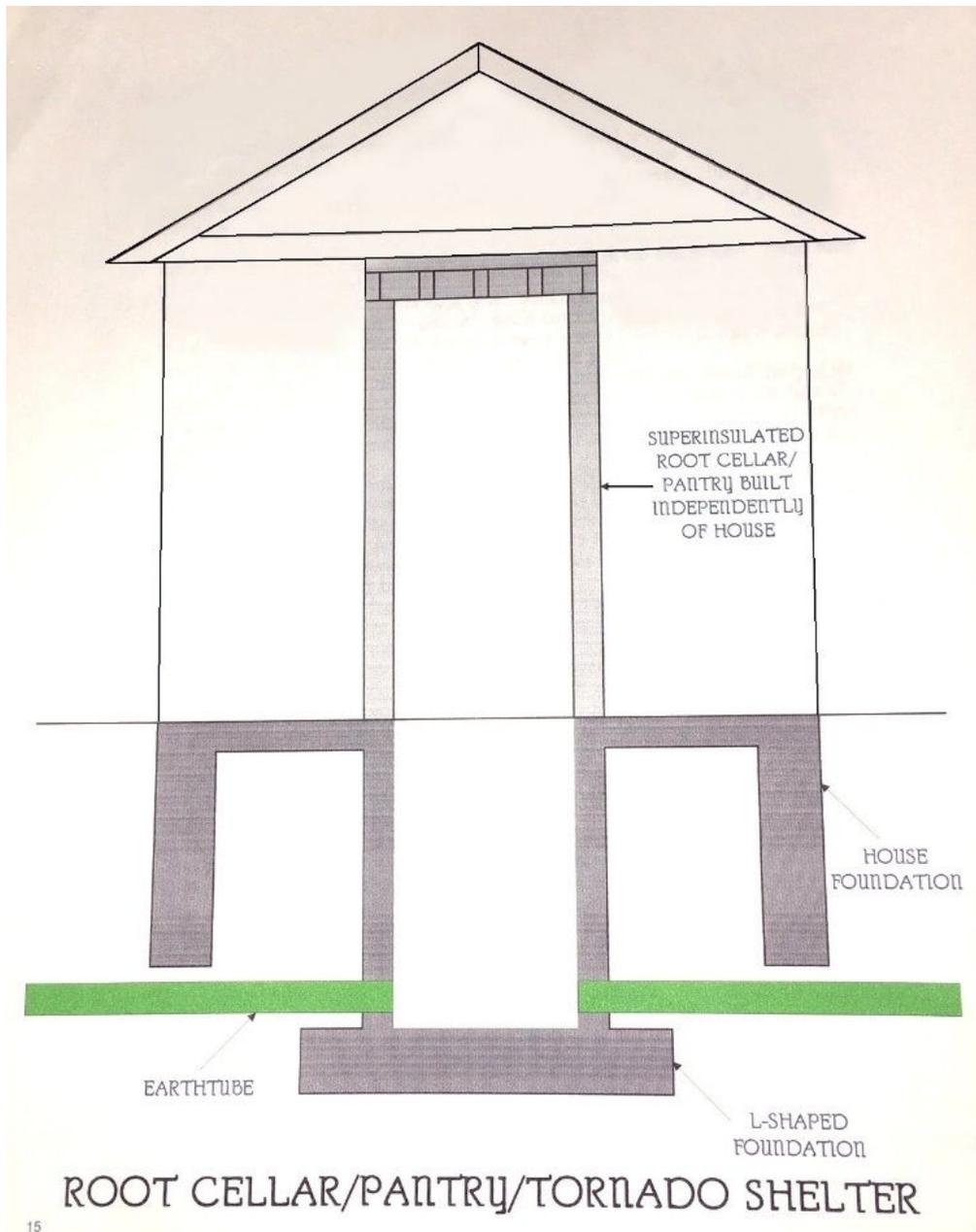
Ventilation is particularly important in an airtight house, to prevent moisture buildup and mold. Ventilation can be implemented via a HRV (heat recovery ventilation) or MVHR (mechanical ventilation with heat recovery) unit, or by utilizing a cross breeze by opening windows on opposite sides of the home, or by a whole-house fan, or even ceiling fans or space fans along with vents. Some people consider their woodstove flue as an exit vent, although it typically only works in

winter while a fire is burning. If you are so inclined, you can design earth tubes to feed the fire (instead of drawing from windows and doorways), or for extra cooling for the house in summer, or use them to create an above ground root cellar style storage pantry (see my other section on how to make air conditioning earth tubes. Earth tubes utilize passive cooling techniques, so work naturally without electricity.

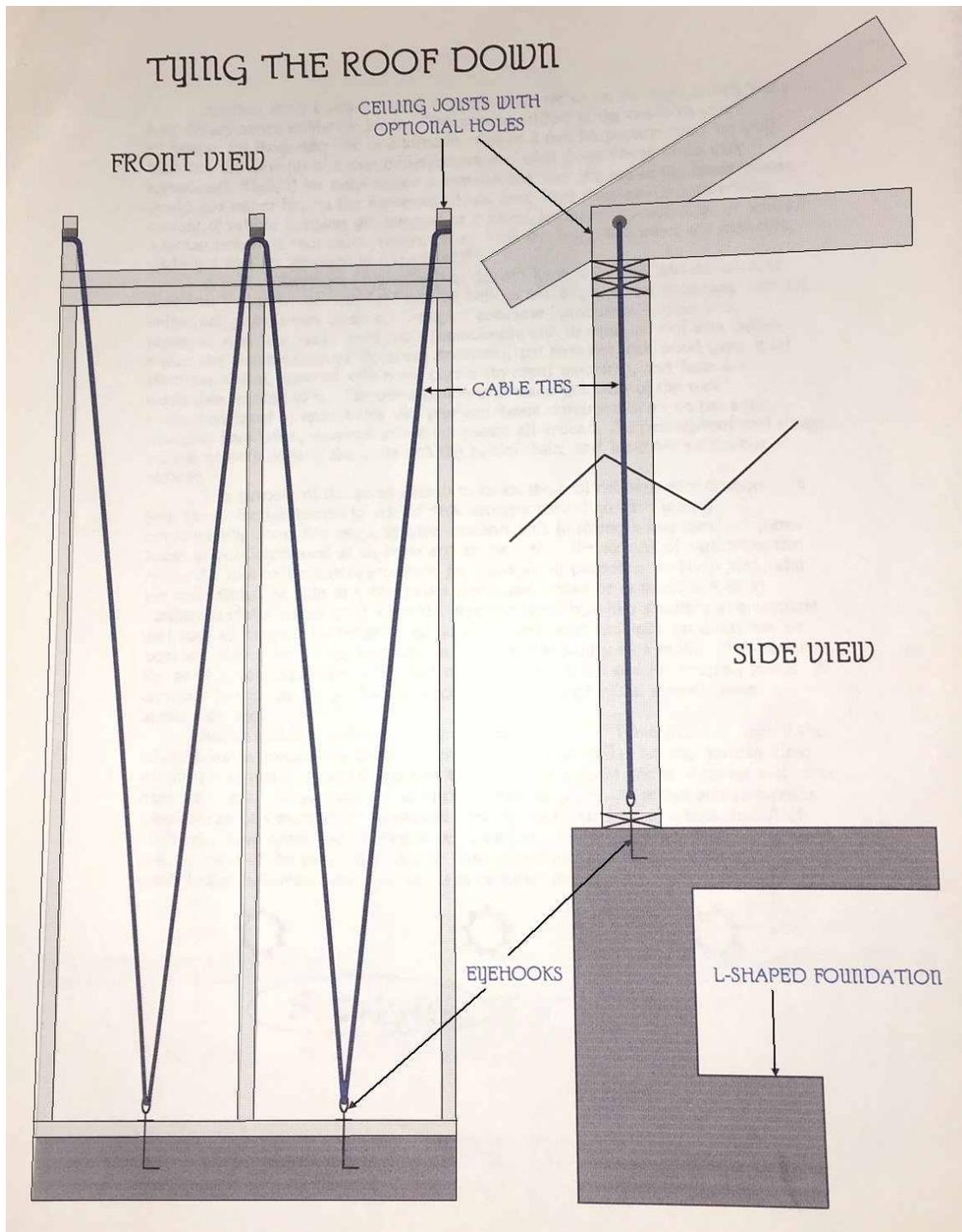




Multiple earth tubes can also help cool a superinsulated room inside your house, which can serve as an above-ground “root cellar” type of pantry. Because of this, it can double as a tornado / storm shelter if you design it with extra strength and ensure the room framing is strongly connected to the foundation. What better place to be during a storm than inside a specially made room that is full of food, fresh air, and stored water (blankets and flashlights would also be a good idea)! You can bring in ventilating earth tubes into the shelter section of the home, and put an L-shaped foundation for that room so the winds will not rip it off the foundation. The house could fall down around it and you would still be safe inside.



In order to make the truly safe, you can tie down your rafters with cable or chain when you build it, to make the entire house storm resistant. Be sure it is well above the flood zone, however.



Although this room can be placed above grade, some people place their earth tubes for fresh air into the sides of an actual underground root cellar. The earth can keep temperatures stable in this way.

The best option to me was to use a HRV system (heat recovery ventilation) without the “mechanical” part, meaning completely passive without the need for electricity, but finding a company that sells proven systems was difficult... until now. I finally found one out of the U.K. that was innovative enough to invent and manufacture a completely passive HRV unit that uses 0 watts of electricity to help regain up to 72% heat recovery of air exiting the house in winter, while cooling the air at night in summer. This company, for those interested, is called Ventive.

**Completely passive HRV unit that
uses
0 watts of electricity to help regain
up to 72% heat recovery
Ventive:
<http://www.ventive.co.uk/>.**

Aside from ventilation, earth-sheltered or earth bermed homes can also protect a dwelling from outside temperature fluctuations, although they should be insulated on the exterior prior to berming the earth around them. This also often requires special construction to deal with the heavy loads that earth (especially wet earth, which is very heavy) places on the structure, not including that waterproofing is essential to prevent mold and leaks and rot. Although some special preventative measures are required for any direct gain or indirect gain earth-sheltered home, the rewards are that you will have a house that reduces outside noise, provides additional privacy, reduction in temperature swings, a measure of fireproofing, and overall comfort.

Lastly, you can use plants for natural cooling. Be sure to plant trees or shrubs that are appropriate for the site. Deciduous trees (trees that lose their leaves in the fall) are excellent at providing shade in summer on the south side of the house, while allowing the sun to shine through the bare branches and into the home during winter. Lines of evergreen trees are great for wind breaks further

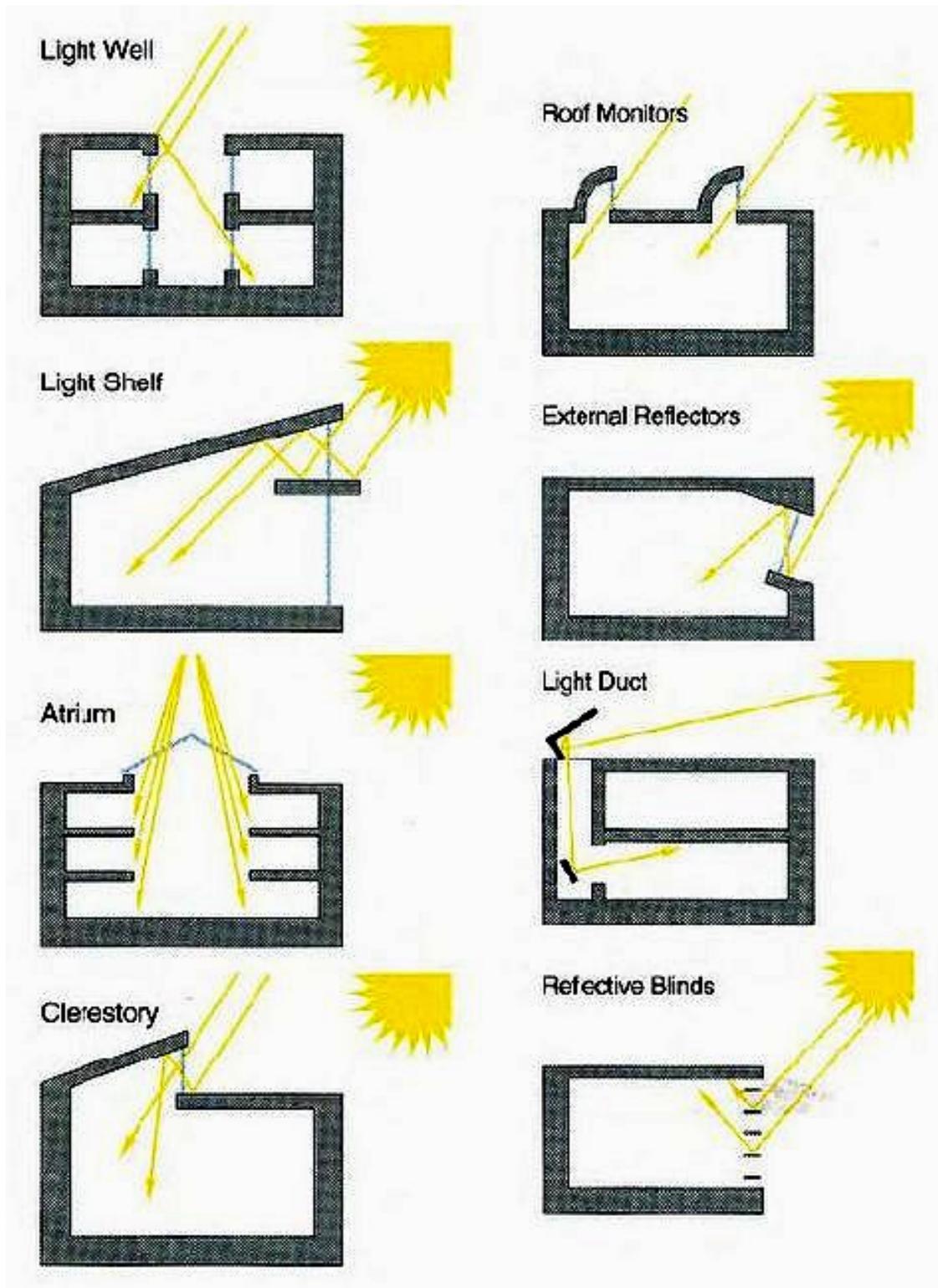
away from the house. Pay attention to which way the winds blow to and from during different seasons at your location and plant accordingly. Windows on opposite sides of rooms can also help bring in a cross breeze.

Other Passive Solar Designs

There are different ways to design a passive solar house, but some of them are more radical, or fall into alternative lighting design rather than actually being passive solar. Pay attention to this next collection of images, which show numerous ways to use glazing on a “passive solar” home... can you see why some of them might not work?

Not-So Passive Solar Systems?

Although some of these designs above are intriguing from an architecture standpoint, they are not very practical in terms of passive solar design. A few of them that reflect light are merely causing indirect light to bounce around, and therefore will not be producing any real direct gain or indirect gain benefits for heating. Clerestory and roof monitors listed above are about the only direct gain methods I would use in order to keep the house passive solar. Indirect



Source: <https://i.pinimg.com>

light is NOT nearly as efficient as direct gain. Also, any light coming from overhead, meaning through flat or slanted glazing, will always

gain too much heat in summer, and lose it in winter when you need it most. Atriums and skylights and greenhouse or solariums are all excellent examples of what NOT to do in a passive solar home. Keep your glazing vertical, let the sun shine in directly to heat thermal mass, insulate the envelope, and adequately design your south-facing overhang to deal with seasonal changes. Sometimes it is as important to know what *not* to do, design-wise, as it is to know what you *should* do. Now you know.

THERMAL MASS & INSULATION

Thermal mass is any medium that has mass for absorbing and storing energy. This could be materials like rock, ceramics, tile, brick, concrete, plaster, earth, adobe, rammed-earth, or a host of other materials found naturally or that are manmade. The #1 material for absorbing heat and releasing it is water, which is 4 times more efficient than concrete or rock at absorbing and releasing stored energy (water is used to heat and cool homes such as in solar roof ponds); however, water is not always the easiest way to store energy in a home (unless you are using a solar closet – see other books or information from the Internet for that information). In most homes choosing a thermal mass product of concrete or tile (on top of concrete) is the most popular method of utilizing passive solar energy. Concrete is not the most eco-friendly ‘green’ material, however. In this chapter I will focus on solid types of thermal mass rather than water; even though water is an excellent storage medium, it is also not structural.

Remember that thermal mass is typically a CONDUCTOR of energy, whereas *its opposite is an* INSULATOR.

Insulation materials inhibit the transference of energy. Insulator examples include wood, cellulose, Styrofoam, Papercrete, Hempcrete, standard fiberglass batt-insulation, straw bales, blue-board (also known as pink-board, which is foundation insulation – extruded polystyrene), carpeting, gypsum board / drywall / sheetrock, and so on.

- Place thermal mass heat storage on the INSIDE of the house.
- Place insulation materials on the OUTSIDE of the house (the house envelope, or exterior walls).

REMEMBER: Every home is a solar home! Homes have windows that allow the sunlight in (south side is where the most gain occurs). It is just that many homes on the market are designed poorly, while others, using the principles you are learning in this book, are designed far more efficiently, with thermal mass and adequate insulation. Here are some important things to remember about thermal mass and insulation in passive solar homes:

- A passive solar, energy efficient home will have the majority of their glass south-facing, less on the east, little to none on the north, and none or almost none on the west. The greatest insulation will be in the roof and envelope, plus the foundation, and a balanced amount of thermal mass will be inside the house as interior walls and flooring, or even as mantles or other features or fixtures.
- The absolute worst, or most inefficient home design will have the opposite: little to no south facing windows, a lot or too little on the east, the most on the west, and too many windows on the north side. There will be inadequate insulation in the building envelope, and almost no thermal mass inside the house (carpeting, wood floors, or drywall are all examples of insulating materials in standard homes, which are inadequate for energy efficient or passive solar homes).

There are some specific things concerning thermal mass and insulation that need to be understood, as well as how the sun tracks through the sky, how to properly harness this sunlight / heat in the wintertime and keep it out of your house during the hot summertime.

Insulation and Insolation

Two terms you should be familiar with are insulation and insolation, and what the difference is.

Insulation is material used to insulate a building, to inhibit the transference or loss of energy. Insulation can be fiberglass batts, blown-in cellulose, or a number of other alternative materials like straw bales, hempcrete, or rockwool, and so on. Insulation is typically

used in the building envelope. Insulation is like putting a blanket on when you are cold—it prevents heat loss.

Insolation is how much exposure to the sun's rays there is, or the amount of solar radiation that reaches an area. Solar radiation (insolation) is emitted by the sun and captured in a passive solar house through direct gain. The more insolation you have, the more sunlight you can collect, store, and spread inside your home for natural heating purposes.

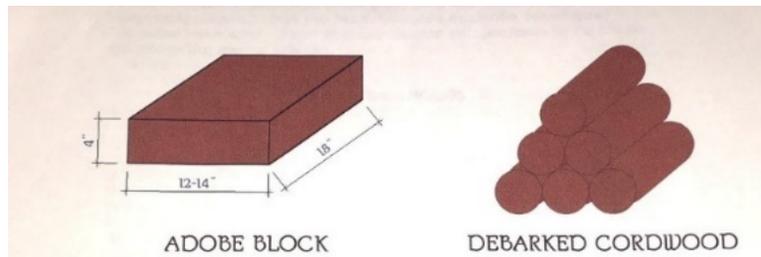
The solar energy (insolation) transmitted is captured and stored in thermal mass materials inside the house. The mass holds the heat longer when it is insulated. Thermal mass heats up slowly as it absorbs the sun's energy during the day, then at night when the temperature in the house cools down, the heat radiates out from the mass (such as your floor) into the cooler room (remember that 'heat seeks out cold') to keep it warm throughout the night.

Indigenous Building Materials

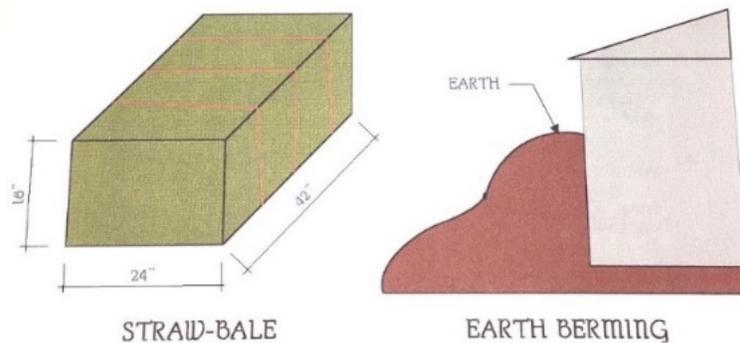
You can use a number of materials to build a house, from standard construction (wood, such as 2x4's or 2x6's) to alternative construction materials. There are many indigenous (natural, local) building materials that can be utilized, which are either inexpensive or free, depending on how resourceful you choose to be. People give away free materials on [Craigslist.org](https://www.craigslist.org) or [Kijiji.ca](https://www.kijiji.ca) (in Canada) all the time, if you are diligent in watching for them—from building materials, to furniture, and even free hot tubs (some of them even work). These materials may be insulating materials, or they may be thermal mass materials. Alternative construction is an option for people who prefer to build 'green' (eco-friendly), as well as who want natural building materials over manmade (which tend to be filled with chemicals or glues / resins, or may be cheap like particle board). There are many green standard building materials on the market now, too.

There is no rule or limitation as to the choices you make for your building envelope, as long as you follow the principles of thermal mass and insulation, plus the rules for building codes and permits in your area. If you build with straw bales (R-40 / 50 wall insulation), for instance, you will likely need to erect your main house frame using

post and beam construction, or some kind of adequate framing to accommodate the bales while properly holding up the roof. Other material examples could include adobe (earth) blocks, debarked cordwood, or simply making an earth-bermed house.



INDIGENOUS MATERIALS



It is good to make sure the different materials you choose are compatible. It is better to combine thermal mass and insulating materials in parallel wall systems (**side by side**, pressed together along their length, like a sandwich) *rather than* connecting them within the same linear wall (**end to end**—where joints meet are weak zones). This reduces thermal bridges, as well as reducing the chance for weak joints where different types of materials meet, which may crack and allow in air, moisture, or bugs. Also, if you use mortar with alternative or indigenous materials, be sure it has a similar consistency or make-up as the wall system you use (dissimilar materials create cracks or air leaks where they touch / meet). Below are two lists for both standard and green (alternative) building materials—one for thermal mass CONDUCTIVE materials, and one

for INSULATING materials. These are only examples of things you can use to build with.

<p>Standard CONDUCTIVE Materials</p> <p>Sand Cement Concrete (cement with rocks in it) Drywall / sheetrock / gyprock Metal posts / beams Metal roofs Plastics Masonry brick / block Stucco Plaster Glass</p>	<p>Green & Alternative CONDUCTIVE Materials</p> <p>Adobe (earth block) Cob (clay and straw) Earth (berming) Earthbags (sand) Rammed earth Sod (earth with grass) Living roof Rubber Fidobe (adobe-papercrete hybrid) Water Wattle and Daub</p>
<p>Standard INSULATING Materials</p> <p>Residential insulation products Commercial insulation products Rigid foam sheathing Spray insulation Fiberglass insulation Cellulose Cotton Wood planks / boards</p>	<p>Green & Alternative INSULATING Materials</p> <p>Straw bales Bamboo Hemp / hempcrete Mushroom insulation Mycoboard Cordwood Papercrete / fibercrete Fidobe (adobe-papercrete hybrid) Cork</p>

Engineered wood	Homasote
Logs	fiberboard
Vinyl siding (insulated)	Mineral wool / Rock wool
	Natural wool insulation
	SIPS (structural insulated panels)
	Pumice

Some of the materials above (such as fidobe) are on both lists because they are hybrid materials, consisting of both thermal mass (such as earth) and insulating materials (like paper / cellulose), so they have both conductive and insulating properties; where some find this a strength, I find it a weakness as it does not really bring the full benefits or qualities of either. It is for this reason that I personally use caution for utilizing such hybrid materials. In the right climate (such as the dry desert or mild climates) fidobe works very well, but in extreme or cold climates it is probably better to use two separate materials so that you have a strong insulator on the exterior walls and a strong thermal mass product on the inside of the home.

Next I will cover a smattering of different types of both thermal mass materials, and then insulating materials. Standard construction materials are commonly found at your local hardware store so I will not cover them much here.

Thermal Mass Materials

Thermal mass materials are conductors. They conduct both heat and cold. Places in your house called “thermal bridges” are made out of thermal mass materials, and they act like a bridge between one place to another; for instance, an old wooden house sitting on a rock foundation stem wall—the rock acts as a conductor of cold temperatures in winter and radiates it through the wood (a very weak insulator). In short, the frigid outside temperature conducts cold through the basement wall into the basement, and sucks the heat right out of your house, causing the floor to feel cold. Old homes without floor insulation are typically cold for this reason, which is why people put down throw rugs. It is far better to insulate underneath the floor to stop the cold from seeping up into the house—this helps close off the thermal bridge. Better yet, insulate the exterior of the entire basement walls and seal all gaps to prevent the cold from entering in the first place to slow down or stop the thermal bridging process.

In homes using the Passive House standard, thermal bridges are eliminated throughout the house. In a standard house thermal bridges are hidden all over the place. Another aspect of this is to create an airtight house, so all leaks are prevented. This creates a warm interior. It is important that when you have an airtight house that you install a MVHR (mechanical heating ventilation recovery) or similar unit for fresh air and to recover up to 80% of the temperature during air exchange. This also helps prevent moisture build up and prevents mold from growing. I have found passive HRV units for sale, but they still rely on HVAC systems and mechanical fans to blow the air through.

Place thermal mass inside the house!

Consequently, while thermal mass is necessary inside the house to adequately stabilize temperatures, the more weather-resistant

varieties can also be used on the outside to weatherproof a home. For instance, a large stone fireplace mantle and wall can add thermal mass to the interior, while thinner brick veneer on the exterior walls should never require painting and is considered low maintenance due to its high weathering resistance (veneer is also thinner so has less embodied energy than wider bricks). Be aware that brick veneer comes in actual real brick that is thin (a thermal mass product) and the faux brick veneer, which reminds me of fake molded plastic and has no thermal mass properties—not that you need thermal mass on the outside, but if you want a product that will last for centuries, then consider the real brick product rather than a manufactured faux product.

Below are some examples of thermal mass conductors... conductive materials that people use to build their homes, or some part of the home such as interior walls, floors, half-walls, or features such as benches, etc.

Metal

An excellent conductor, but with high embodied energy (it must be mined and then processed, and its weight makes it expensive to transport). One advantage of using metal in buildings is that it is long lasting, and therefore considered a fairly good 'green' material overall. Except for rock, metal is one of the most durable of building materials and can last for decades or even hundreds of years, can be recycled, or reused once the house has reached the end of its life cycle. Wooden studs or wooden beams do not hold a candle to the resistance to fire that steel exhibits, whether for the roof or wall systems. Additionally, the strength that metal beams can achieve when it comes to spanning large open areas (post-and-beam style construction) means fewer members are required in constructing with metal for the same amount of square footage of space.

Concrete

Concrete is an excellent conductor. The statistics on GHGs and the manufacturing of concrete show that it is strikingly against its use if we intend to stay green for buildings. Concrete is the second most used building material on the planet, and it has cost us between 5-

10% of all human-related GHGs. Of course, there are some 'greener' types of concrete, including that using fly ash as part of its ingredients, which you can use. There are different options.

Fiber-Cement Siding

Both an insulator and conductor. Fiber-cement siding is fire resistant, does not rot, and is termite-proof. Made of Portland cement, clay, sand, and wood pulp fibers, it is a rather low-maintenance product. It adds value to your house because of that, and because it is long lasting. Even some of the low-maintenance finishes may last for many decades. However, the embodied energy (heating raw materials in kilns) is quite high, which makes it less environmentally friendly, yet it remains a popular green building material. Recycled fly ash is added to some brands, making the planks more sustainable. Newer varieties on the market may have more recycled material content in its make up plus may be lighter. Its R-value is negligible as it is more of a conductor than an insulator. If you install this yourself protect yourself from silica dust by wearing a respirator and cut the product outside.

Masonry

An excellent conductor. Masonry in the past included building brick and similar products that used mammoth amounts of embodied energy for their production; in fact, they still do. Some modern masonry products, however, are not as thick so are actually a type of veneer that you can install over the main wood framed walls. They are more for looks than for structural stability. This can include brick facing, natural stone, or even manufactured stone (note that the latter is cement-based). Brick and stone are also fire-resistant and durable, so require very little maintenance. Although they are made from nonrenewable resources, the materials are abundant; the real cost comes in firing the bricks. Watch for used brick sales from buildings that have been taken down, salvage yards, or local stone that was quarried, or even brick that was made locally. Sometimes people give it away online free through Craigslist or Kijiji (or sell it cheap).

Some alternative brick sources include Timbercrete "sandstone" brick, hempcrete brick, recycled glass brick, 100% recycled scrap

brick, microbial-induced eco brick (microbial-induced calcite precipitation) are some choices. Even an experimental biodegradable fungi-brick that is grown rather than made (mushroom mycelium with corn husks) may be available.

Stucco

A conductor. Regular old-fashioned stucco is made from Portland cement and sand and water, which forms a workable plaster-like material, yet is stronger than plaster (less cracking due to weather extremes). Watch out for modern stuccos that have hardening epoxies in the product. Stucco is fire resistant and is long-lasting, resists pests / insects, and is strong. When maintained properly it should last throughout the full life cycle of the home. Sustainability varies with stucco, being 'not very sustainable' if it has epoxy in it, and being 'eco-friendly' if it does not—natural stucco is made from a lime-and-earth mixture rather than Portland cement-and-epoxy, which reduces both the embodied energy and the carbon dioxide emissions (from manufacturing cement). Stucco is a conductor rather than an insulator, but it does allow moisture vapor to permeate while reducing air infiltration. If painted it will require repainting.

Other Thermal Mass Materials

Other materials, which are considered 'alternative construction' materials rather than standard construction materials, may include:

- Cob
- Adobe
- Woodchip-Clay
- Light Clay-Straw
- Reused Concrete

Insulation Materials

If there is one thing I can say about insulation it is this...

Insulate the Envelope!

Heavy insulation can be offset by frames and studs according to my colleague, Olan Volan (he aids me with mathematical calculations due to his background in physics), who is from Holland; he says that the trick is to have insulation all around (meaning the envelope). Superinsulating the envelope (outer walls) of the house, making sure all thermal bridges are buffered, and the joints are sealed for airtightness will ensure that your house is properly insulated.

There are building contractors who will say that adding extra insulation past the drop off rate—of normal amount of insulation for a standard home—is not worth the extra cost. While that can be true, according to Jan Shuster who studied architecture at City College of New York, the first inch of insulation saves you one dollar, and you have to double that amount of insulation to save another dollar, then double that amount yet again to save the third dollar, and so on, regarding energy savings. So there is a drop off rate at which contractors consider it no longer cost-effective to tack on more inches of insulation, especially since each inch of insulation is not just in one spot but has to be installed onto every square foot of wall around the entire envelope. However, that said, when you superinsulate a house the requirement for heating also drops significantly. You go from an standard house with “average” insulation to an above-standard house with superinsulation (such as with Passive House) for several hundred dollars more, and the difference is seen in the thousands of dollars of lower energy bills, which over the lifetime of the house pay you back in droves because it significantly lowers both the heating and the cooling load. So much for the drop off rate.

There are many green ways to insulate a house, and some are better than others. Next are some different options...

- **Blown cellulose insulation** (made from recycled newsprint but is professionally blown in—drawbacks include that it settles in the walls over time and produces empty air cavities if it is “loose pack”, so be sure to use “dense pack” (3x as dense with the same R value of 3.7/inch))
- **Reflective insulation** (brands like *Reflectix* come in rolls)
- **Spray insulation** (brands like *Dura Foam* are a polyurethane foam but have no VOCs)
- **Foam insulation** (all foam products today are not supposed to have damaging chloro-fluorocarbons (CFCs), however, they do use hydrochlorofluorocarbons (HCFCs), which is better but still not good for the ozone layer)
- **Fiberglass insulation** (be sure to buy formaldehyde-free, 20-25% is recovered glass cullet, but be careful in handling it)
- **Mineral wool** (up to 75% is recovered slag, so be careful in handling it)

Note that foam plastic insulation products have a higher environmental impact but also a higher R-value per inch, whereas fiber insulation products (fiberglass, mineral wool, cotton, or cellulose) have a lower environmental impact but also a lower R-value per inch.

Alternative Insulation Products

- **Natural wool insulation** (sustainable sheep’s wool uses very little energy to produce, is noncombustible, and has an R-value of 3.5-3.8/inch—greater than fiberglass—and is breathable plus lets vapor escape)
- **Cork** (cork granules help fill spaces between joists and gaps, but are not good for drafty areas as they can blow around. Flooring cork works well in cellars / wine storage for climate control)
- **Recycled polyester insulation** (brand Supaloft Green is itch-free and sustainable, 90% of it is made from recycled plastic bottles, available in the UK, check to see if there is a local dealer or similar product)

Rock Wool / Mineral Wool / Stone Wool

While rock itself is typically a conductor, rock wool is spun, so it is porous, meaning it has thousands of tiny air pockets that provide an

insulating quality. This is a product worth mentioning because it is often misunderstood as insulation goes. There are some definite differences between mineral wool (also known as rock wool or stone wool) and standard fiberglass batt insulation.

Here is a comparison:

Mineral Wool	Fiberglass
2x4 stud walls = R-15	2x4 stud walls = R-11/13
2x6 stud walls = R-23	2x6 stud walls = R-19
2x8 stud walls = R-30	Not available
Firm and dense – retains shape, pushed into wall cavity for tight fit	Flexible and limp – must staple or slumps / leaves gaps
Easy to cut and install for small or odd spaces	Not made for small or odd spaces

Mineral wool may have some green building concerns for some people. For starters, there is formaldehyde in the binders used in mineral wool, which is used in the “glues” that keep it together. Formaldehyde is in standard fiberglass insulation as well but that trend is changing. Mineral wool has less formaldehyde than standard fiberglass insulation. Embodied energy for mineral wool is considered low since 75%-93% is made from recycled slag or other raw materials like basalt (volcanic) rock, and the *Roxul* company’s mineral wool is a “zero waste to landfill” facility. The materials are melted and then spun into the mineral wool fibers.

Here are some facts about mineral wool (*Roxul* brand):

- Moisture resistant
- Vapor permeable
- If it gets wet and dries out it retains its shape and performance characteristics
- Is inorganic so has no food value, therefore does not grow mold or fungi
- Questionable if it is rodent resistant but *Roxul* claims no negative feedback has been received from customers

- Is not blown insulation—manufactured only in board, batt, and pipe forms
- Is not combustible (melting point up to 2150°F)
- No off-gassing
- Only requires a vapor barrier on an exterior wall that requires it by code (vapor barriers block water vapor transfer from the warm-to-cold side of the wall, and vapor barrier is attached to the warm side)
- Can be used in exterior walls and attics (two layers (laid perpendicular) of R-22 will provide R-44)
- Will pass insulation building code inspections (Roxul information—see [FAQ](http://www.roxul.com/stone+wool/overview/faq) at [website: http://www.roxul.com/stone+wool/overview/faq](http://www.roxul.com/stone+wool/overview/faq))

Sustainable Building with SIPs

Insulated wall panels called SIPs (Structural Insulated Panels) are used both for insulation as well as wall panels in construction. SIPs are considered by some as a sustainable building materials. Sustainable buildings obviously use less energy, meaning that they reduce CO2 emissions and help combat global climate change. Since buildings require an incredible amount of natural resources to produce and operate, it is important to reduce pollution and resource use in order to make the building industry more sustainable. SIPs are extremely airtight and are well insulated, so are inherently a green product due to how they function for the home. They are also easy to assemble and go up rather quickly. SIPs are made out of OSB (oriented strand board), which is a composite building material. Although they take a smaller amount energy and raw materials to create than other building systems, they are more efficient than site-built 2x4 / 2x6 framing. So far SIPs sound like a pretty good deal, but there are some environmental pros and cons regarding these wall panels.



SIPs Panel

(source: Wikipedia)

It is important when calling a product 'green' that we look at more than just the embodied energy and resources used *before* the product is made, or the efficiency of the product *after* it is being used, and actually look at the process and materials or ingredients that are used in making the product. For instance, check out this example of what SIPs can be made out of:

The Board:

Plywood

Sheet metal

Cement

Magnesium oxide board (MgO)

Oriented strand board (OSB)

The Core:

Expanded polystyrene foam (EPS)
Extruded polystyrene foam (XPS)
Polyisocyanurate foam
Polyurethane foam or composite honeycomb (HSC)

Based on what we know about chemicals and glues, off gassing of emissions, CO2 or formaldehyde use, etc., do the above materials appear 'green' to you? This is where we need to pay attention. Cork would be the ideal core material because it is green and insulates well. Be sure that if you use SIPs panels that their manufacturer is using green materials and methods for producing the product (note: they claim to be 'green'). Indoor air quality and your health, as well as how it affects the atmosphere and climate change, are all important reasons to consider before investing your money into a particular company's products and placing any potentially toxic materials into your home. Just something to keep in mind as you compare similar products from different companies.

Pros and Cons of Using SIPs:

According to the NAHB (National Association of Homebuilders) constructing a 2,000 sq. ft. house yields about 3.5 tons of waste. The pro is that by using SIPs this can be significantly reduced if automated fabrication technology and advanced optimization software are utilized. The con is that you may not have this software technology, or the manufacturing company may not have automated fabrication tech either, so weigh that out.

SIPs use insulation sandwiched by OSB board. Another pro is that OSB is usually made from underutilized wood scraps / chips from fast growing trees in sensibly managed forests. The highly automated machinery makes OSB extremely effective for utilizing raw materials in an efficient way (85-90% of the log may be used for the panels, and any leftover sawdust, bark, or saw trim can be converted to energy, bark dust, or pulp chips). Automation also reduces emissions and energy use compared to powered hand tools used by people. I suppose there are some cons to this, but I cannot think of any outside of possible reduced jobs for people, but at what environmental

expense? Every corporation has placed jobs at a higher value than the environment (tar sands oil is a blatantly obvious example), but at least jobs in renewables now outweigh the number of jobs in the oil industry. Let us make our lives easier and our environment cleaner.

SIPs uses EPS (expanded polystyrene) insulation so is mostly composed of air—only 2% of the EPS is actually plastic. The pros are that the EPS utilized in the SIPs boards will actually save—over the lifetime of the house (life cycle)—numerous times the amount of energy embodied in the petroleum used to create the EPS insulation itself. The cons are that any petroleum-based products are used at all, so a trade-off is in place here and would need to be evaluated by your personal scruples on the matter as to whether it is worth it to you to use SIPs with EPS if a greener form of SIPs are not available to you. As a comparison to standard fiberglass insulation, know that it takes 24% less energy to create EPS than equivalent-R-value fiberglass batt insulation, and that scraps from manufacturing EPS can be recycled into new EPS products (which takes more energy, but at least it does not go to waste).

In the US the cost of constructing wood framed homes is less than using SIPs, but this is not necessarily true for the rest of the world, so the con is you may have to pay more—if it is worth the extra energy efficiency and airtightness then you may consider it worth it.

SIPs, due to their easy and quicker installation factor (interior skin, insulation, and exterior skin are all-in-one, and can be erected fast), can reduce construction time and the amount of labor needed to construct it; not to mention, the same SIPs panels can be put in place as the walls, floor, and even the roof of the house, making the life cycle cost much lower than a framed house—perhaps as much as 40% in savings! This can make it much easier for you, the owner-builder, since not as much help or time is needed, or detailed knowledge about framing. The con is that you still need to know how to construct a building out of SIPs, which is beyond the scope of this book.

The indoor air quality (IAQ) is affected in a SIP home due to its airtightness. Controlled ventilation would be a necessity since the

envelope is so tight that it limits incoming air. Only with controlled ventilation can you properly filter out allergens or contaminants, and deal with humidity so that mold growth does not occur. This is both a pro and a con. The con is that you have to install a controlled ventilation system, and the pro is that you would want fresh air in your home anyway so that the IAQ is supreme. There are different ways to do this. Simply opening a window in the middle of winter is not the best method for gaining fresh air as it reduces the temperature in the room(s), and winter is when IAQ most affects people's health negatively. It depends on your climate and whether it is automated or not, but ventilation systems are fairly inexpensive, and you can also use an HRV / MVHR (mechanical ventilation heat recovery) system, which reduces heat loss in winter.

Here is the best news, in my opinion (besides energy efficiency and savings aspects)—the SIPs panels do not contain any VOCs or chemicals that can damage the health of the home's occupants, and they meet stringent requirements for IAQ standards. EPS uses pentane (a non-CFC blowing agent) that dissipates quickly once it is produced so off gassing does not occur (look to make sure they are GREENGUARD certified). They are even accepted under the American Lung Association's Health House® IAQ standard. No con here that I can think of.

No measurable amount of VOCs are used in the SIP adhesives. OSB adhesives also do not have urea formaldehyde so meets the emissions standards of numerous air toxic control and manufactured housing standards in both the US and Europe.

Overall it appears that SIPs panels are an excellent trade-off for reduced petroleum products for the greater gain over the lifetime of the home. This could ideally be an easy owner-builder way of creating the envelope of your home.

Drywall / Gypsum Board

I have heard debate between whether gypsum materials are actually an insulator or a conductor. In general, they are considered an insulator.

Gypboard, gypsum wallboard, plasterboard, gyprock, sheetrock, drywall—these are some of the many names for the most commonly

used interior wall board in North America, and I may use these terms interchangeably below (favoring sheetrock or drywall). A 2,000 sq. ft. home uses about eight tons of sheetrock in its ceilings and walls. However, if you are building a house using alternative construction methods (such as straw bales, light-clay straw, hempcrete, cob, cordwood, wood chip clay, etc.) then what is best for using on or as interior walls? It might be personal preference.

If you have ever lived in or rehabbed or seen an old house with the interior of its walls exposed you would find people—for hundreds of years—used lath (skinny wooden strips) and wet plaster (made from gypsum and lime, or cement) smeared between them to make walls, which was laborious work. Each coat of plaster on the laths had to dry before more layers were troweled onto the surface. Since gypsum board was dried in the factory it reduced the time to complete a wall by about 90%, and since it was dry when applied it was called drywall.



Drywall itself is a fairly benign product since most of the constituents in it are basically inert. However, looking at the embodied energy we see it is not so benign. Although drywall is only 50% of the work to make compared to plywood, it is about 25x more work than straw bales. Manufacturing the product has the most impact, however, due to crushing of the gypsum, milling and blending, pressing, making the paper, and cutting and heating, it equals about 80% of the embodied energy in order to get the finished product made so it can be delivered to the homes, not including the waste of 12-17% (installation cuts and fits, which is about a quarter of

all waste in new construction)—equaling about a ton and a half of waste per house.

Drywall waste

Remember that it is the manufacturing process that uses the most energy, so keep that in mind. This is why many owner-builders utilizing green building methods and principles have moved away from using drywall altogether and are using less energy-embodied products, such as materials that already serve as wall surfaces (brick, rock, wood, etc.).

Wood for Homes

A weak insulator. Wood, in its natural state, should technically be one of the most green products available. For one, it is a renewable resource, a natural resource, and requires very little change (milling) to gain the final product. Exceptions would include waferboard or particleboard or OSB or similar wood products, which require glues and further processing. Trees have the energy input of sunlight (photosynthesis) and water, and it takes its nutrients from deep underground. The delay of 40+ years is the only drawback, which is why some people prefer rapidly renewable products (such as hemp, which can be grown annually for its hurds (pithy inner core of the stem) to make hempcrete—a carbon negative product). Trees also produce oxygen for the atmosphere and clean the air of toxins. New growth of young trees produce far more oxygen due to their faster growth rate than old growth trees. Wood is totally biodegradable, too, and its leftover products can be turned into other products (from particleboard to woodstove pellets) or used in ways so that there is no waste.

Siding

Metal siding is conductive, vinyl is not, but siding is placed on the exterior of the house, and is typically a thin product, so does it matter much? Weatherproof aspects should matter more. Siding can be a challenge for many homebuilders. It should be as green as possible, and also longevity should be a strong consideration in choosing which type you prefer. That said, there are some trade-offs including

whether it is biodegradable, how much insulation value it has, maintenance required for upkeep, and of course cost.

Consider the sustainability aspect when choosing your siding product... how long will it last? Is it recyclable? If damaged, can it be reused? Can it be repainted (or should it?)—anything that requires updating or maintenance takes more energy over the long haul, making it less sustainable (think about rock and how it never needs painting but can basically last forever).

House Wrap

Consider whether you need house wrap, which is a tough but thin semi-permeable membrane. This is outside of the wall sheathing, placed underneath the siding. It blocks water, yet allows vapor from moisture to pass through. House wrap improves energy efficiency for framed houses or homes made of similar construction.

A few examples of house wrap are Low-E Housewrap, and Tyvek ThermaWrap by DuPont, plus heat-reflective layers can improve insulation values by a factor of R-2 while reducing wind or air infiltration, so a double benefit. In some places using it is required by code.

Rigid-Foam Sheathing

Although rigid-foam sheathing is easy to apply, comes in many thicknesses while remaining lightweight, and covers an entire wall like a blanket (over existing wall materials like stucco, wood, hardboard, which makes it suitable for attaching new siding over top of it), it is also not necessarily the best of materials when it comes to sustainability.

Rigid-foam sheathing is manufactured as XPS extruded polystyrene and therefore produces CFCs (chlorofluorocarbons) that damage the ozone layer; however, some manufacturers claim to have CFC-free sheathing. Another product called EPS (expanded polystyrene) is a foam sheathing material that does not produce CFCs plus it can be recycled; however, it cannot degrade easily if put in a landfill, so you will want to ensure that if you use it the life cycle plans for its end use are clear.

Vinyl Siding (Insulated)

Vinyl siding that is insulated is like regular vinyl siding, but with an EPS layer of insulation on it, which makes this product more rigid and easy to work with. Insulated vinyl siding can last 30-50 years and needs very little maintenance; however, it is made of PVC (poly vinyl chloride), which is a chemical compound that does not degrade properly once in a landfill, plus its manufacturing byproducts include dioxin. Vinyl siding can be recycled.

Wood Siding

Wood siding is highly valued as siding. Although not fire resistant, it is beautiful; however, it will require maintenance (paint, stain, or waterproofing) or it will degrade more quickly. Wood siding is a renewable product, can be recycled, reused, and degrades naturally in landfills. Call the source of the wood siding products you might use to ensure they come from companies that use certified forestry (FSC- Forest Stewardship Council) practices or are sustainably managed like from the SFI (Sustainable Forest Initiative). Although wood is an insulator it has poor insulating qualities of about R-1 per inch.

Engineered Wood

Wood products that are engineered / manufactured are made using wood fibers that would otherwise be waste material, plus resins and wax. This mixture is placed in molds and the end product looks like lap siding or wood shingles. Finishes that are baked on at the factory help minimize maintenance. The waste wood fiber materials make this product closer to sustainable than not, but it lasts a couple of decades less than other kinds of lap or shingle products.

ENERGY EFFICIENCY

Be sure to begin with an energy efficient house. You can either design and build it that way, or else you can make your current house more “tight” (energy efficient) by doing small things that make a BIG difference.

Heat rises naturally, so most heat is lost FIRST through the ceiling and then secondly through the walls in an energy IN-efficient house. However, in an energy efficient house, up to 30%- 40% of heat loss can occur through the foundation alone (uninsulated slab on grade)! A *properly* insulated energy efficient house, then, will have foundation insulation to avoid this through-the-ground heat loss. Remember that earth is a conductor, so heat will sink into your thermal mass floor (rock, cement, brick, etc.) and transfer straight into the ground, which will suck the heat right out of your warm rooms, making them colder faster.

Make sure that BEFORE you insulate your walls / ceilings that you:

- Using a mere \$50 worth of wood glue at all joints in wood framed homes makes your building 30% stronger and resistant to high winds or severe storms.
- Use caulk, expanding foam, or insulated pads (designed for this use) to close any gaps in doors, windows, electrical, and areas where plumbing enters.
- Seal up all air leaks using aluminum tape or tape intended for that purpose.
- Install ductwork in a heated area, NOT in the attic. Use furdowns, sealed and sheathed prior to installing ductwork. Seal or tape ductwork.
- Insulate furnace closet walls.
- Install ceiling fans in main living areas to reduce air conditioning usage.

- Be sure that your house has insulation values (called R-values) of the amounts shown below at the very least.
- Prewire for ceiling fans (ceiling fan is not required) in living room and master bedroom.
- Furnace AFUE should be rated at 80% or better.
- Water heater efficiency rating should be .60 or better.
- Install programmable thermostat (the prewire remains the same).
- Seal the return air plenum. Install sheetrock / gyprock around the inside of walls and below the furnace closet platform, plus tape and bed or caulk joints.
- LED lights should replace all compact fluorescent and especially incandescent light bulbs. Replace nightlights with LED versions.
- Low flow plumbing fixtures and 1.6 gal toilets (already code in many places).
- Compare energy usage comparison label on any appliances (range, dishwasher, refrigerator, etc.) as the savings from the lower energy consuming appliance will easily offset any higher initial cost.

NOTE: These recommendations below are minimal requirements only —PLEASE CHECK YOUR LOCAL CODES as these may need to be slightly altered / improved to meet code in some areas. No two cities, counties, states, provinces, or countries are the same. If in doubt you can use the Passive House standards for energy efficiency, which are the highest in the world, and voluntary. They will both meet and exceed codes just about anywhere.

The Passive House standard can be found here:

USA: www.phius.org/

CANADA: <http://www.passivehouse.ca/>

In the meantime, here are some things you can do to at least meet some goals of basic energy efficiency.

MODERATE CLIMATE

ATTIC/CEILING = R-30 insulation (blown in cellulose insulation is preferred since it fills in small gaps, although it may compact over time and need to be reapplied).

WALLS = R13 in 2x4 walls / R-20 in 2x6 walls, plus 1" expanded polystyrene R-4 rigid insulated sheathing boards. Use foam / caulk to fill all top plate and exterior wall penetrations.

SLAB/FOUNDATION = R-5-10 extruded polystyrene (i.e. blueboard / pinkboard (may also be green)) around the perimeter to the depth of the footing.

SILL PLATE = Exterior walls have a bottom plate (sill plate / sole plate) that need to be sealed with a foam strip / sill sealer (top and bottom floors). Caulk the inside of the exterior plate (to seal the joint between slab and bottom plate) with 25+ year caulk.

DOORS = R-5.9+ steel clad or fiberglass insulated doors. Lower R-value doors can use a storm door along with it to aid in less air (and temperature) infiltration. Seal gaps at door edge with spray foam, backer rod, caulk, or insulation.

WINDOWS = Any window frame and glass that meets this criteria: U-factor of 0.65 or lower and Solar Heat Gain Coefficient (SHGC) of 0.40 or less. Clear insulated glass (do NOT use low-E as it will reduce solar gain ability) on south side. Vinyl clad or aluminum clad, insulated windows are best. Triple pane is superior to double pane. Do not use single pane windows. Seal gaps between window with spray foam, backer rod, caulk, or insulation.

HOT WATER = Insulate all pipes with pipe insulation and make sure it is properly secured. Use a hot water heater blanket to wrap the hot water heater, or install point-of-use / on-demand hot water heaters.

COLD CLIMATE

ATTIC/CEILING = R-38 TO R-50 insulation (blown in cellulose insulation is preferred since it fills in small gaps, although it may compact over time and need to be reapplied).

WALLS = R20 in 2x6 walls, plus 1" expanded polystyrene R-4 rigid insulated sheathing boards. Use foam / caulk to fill all top plate and exterior wall penetrations.

SLAB/FOUNDATION = R-10 extruded polystyrene (i.e., blueboard / pinkboard (may also be green)) around perimeter to the depth of the footing.

SILL PLATE = Exterior walls have a bottom plate (sill plate / sole plate) that need to be sealed with a foam strip / sill sealer (top and bottom floors). Caulk the inside of the exterior plate (to seal the joint between slab and bottom plate) with 25+ year caulk.

DOORS = R-5.9+ steel clad or fiberglass insulated doors. Lower R-value doors can use a storm door along with it to aid in less air (and temperature) infiltration. Seal gaps at door edge with spray foam, backer rod, caulk, or insulation.

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HOT WATER = Insulate all pipes with pipe insulation and make sure it is properly secured. Use a hot water heater blanket to wrap the hot water heater, or install point-of-use / on-demand hot water heaters.

As mentioned before, always have a light colored roof instead of a dark one. The last thing you need is the heat GAIN of a black or dark roof adding to the heat inside the house during the already-hot summertime, AND consider all that heat LOSS that a dark or black roof give off during wintertime! You simply cannot afford this! Why risk your COMFORT level and increase your utility bills just because of the color of your roof!

Use light/white colored (at least on the inside of) *insulated* shutters on the outside of your windows to help reflect more sunlight into your

home during wintertime (angle the shutters at a diagonal to reflect the light inside the windows instead of reflecting it away from the house).

Hint: Close the insulated shutters at night to help keep the heat IN the house and prevent temperature loss since heat loss occurs through windows (glass only has an R-value of 1 or so). The white color will help reflect the heat back into the house while the insulation also prevents additional heat transference/loss).

No Cost and Low Cost Efficiency Tips

This exact list was originally provided by the Energy Center at UTEP as a free handout. Many thanks to Steve Cook for his many years of service to the El Paso community.

“It’s cheaper to save energy than to make energy.”

No Cost Tips

- Turn water heater down to 120F (49C)
- Clean refrigerator coils
- Switch refrigerator to power miser setting
- Set refrigerator temperature to 36-39F (2-3C)
- Set freezer to 0-5F (-18 to -15C)
- Keep refrigerator / freezer full (water)
- Turn off water while shaving and brushing teeth
- Use cold water for laundry, and wash full loads
- Collect rainwater
- Use the right size pot / pan on the stove burner
- Do not preheat your oven except for baking
- Cover pots / pans when cooking
- Drain some water from your water heater to remove sediment

Winter Tips

- Turn thermostat down 10 degrees F (5.5C) at night
- Turn thermostat down 10 degrees F (5.5C) when leaving for 4 hours or more
- Keep curtains open on the south side of the house during the day
- Keep curtains closed on north windows
- Dress in layers of clothing

Summer Tips

- Close curtains on the sunny sides of home
- Turn off furnace pilot light
- Open windows on the cool sides of home
- Wear loose, light colored clothing
- Use fans to circulate air in the home

Low Cost Tips

- Install low flow shower heads and aerators on faucets
- Insulate water heater
- Insulate electrical outlets and switches
- Caulk on the inside of doors and windows
- Insulate / caulk all pipe penetrations in walls and ceiling
- Install a bleed line on the evaporative cooler and run line to a tree
- Replace furnace filter every month in winter
- Replace light bulbs with compact fluorescent bulbs
- Insulate the bottom and sides of waterbeds
- Use a quilt or comforter on waterbeds
- Purchase a water saving toilet or use toilet dams
- Make a draft dodger for use on doors or windows

The Direct Gain System: Glass and Mass

The direct gain system is the easiest and most cost effective way to use solar energy. The structure itself is the solar system. The south windows are the collectors. The walls and floor are the storage (mass). Orientate the structure and windows as close to true south as possible.

- The ideal thickness for mass materials is 4 to 5 inches.
- Use mass materials in the construction, for floors and walls. (adobe, concrete, brick, rock)
- Water is the best mass, storing far more energy than other materials, BUT it's not structural.
- A masonry fireplace adds thermal mass but should be located on an interior wall.
- An interior mass wall performs better than an exterior wall.
- Insulate the exterior of your walls, keeping the masonry inside, protected from outside temperature extremes.
- Provide for night time insulation on large glass areas. (insulating curtains, moveable insulation, shutters)
- Provide adequate overhangs on the south side to prevent direct gain during the cooling season.

- Use light colors on low mass construction. (ceilings, and partition walls)

Glass to Mass Ratios

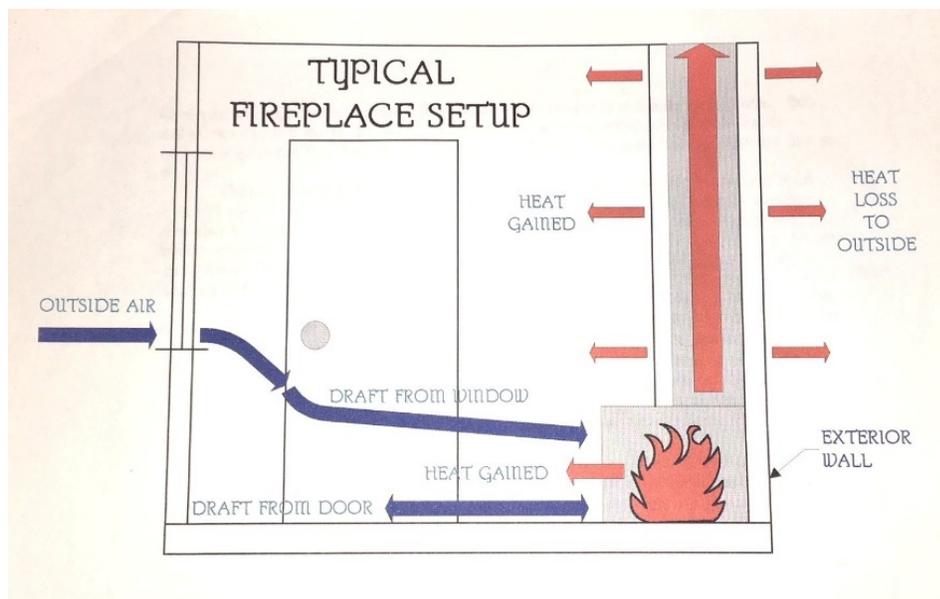
- Each design starts with 7% south glazing. (net) To increase beyond 7% we must also add thermal mass, usually starting with floor mass and then walls.
- An additional 1 sq. ft. of south glass may be added for every:
 - 5.5 sq. ft. of sunlit thermal mass floor*
 - 40 sq. ft. of floor not in direct sunshine
 - 8.3 sq. ft. of thermal mass wall

*The maximum amount of sunlit floor is 1.5 times the south window area.

- The recommended maximum amount of south glass for direct gain is 12-15%

6 Ways to Make a Fireplace More Efficient

Many people think that having a fireplace is a great idea for light and heat when the electricity goes out, but the fact is that fireplaces are probably the most inefficient way of heating that you can choose. However, there is nothing that can equal the warmth and atmosphere that a fireplace provides in a home, which is why so many people still use them. If you are buying a new or resale home with a fireplace, or you are building a house, you need to know that standard fireplaces with a brick chimney are known to be 90% inefficient (yes, that means only 10% efficient) for heating purposes. Because of this they are typically used only in emergencies (such as when the power goes out) or special occasions, rather than for regular heating needs of the home. However, there are several ways to improve this while still having a beautiful fireplace.



How to Make Fireplaces More Efficient

Fireplaces are inefficient because most of the hot air generated by the burning of wood goes straight up and out of the chimney. Fire also consumes oxygen to burn, so it sucks the heated air right out of the room, causing cold drafts around doors and windows, which scoop across the floor and the room and escape out the chimney.

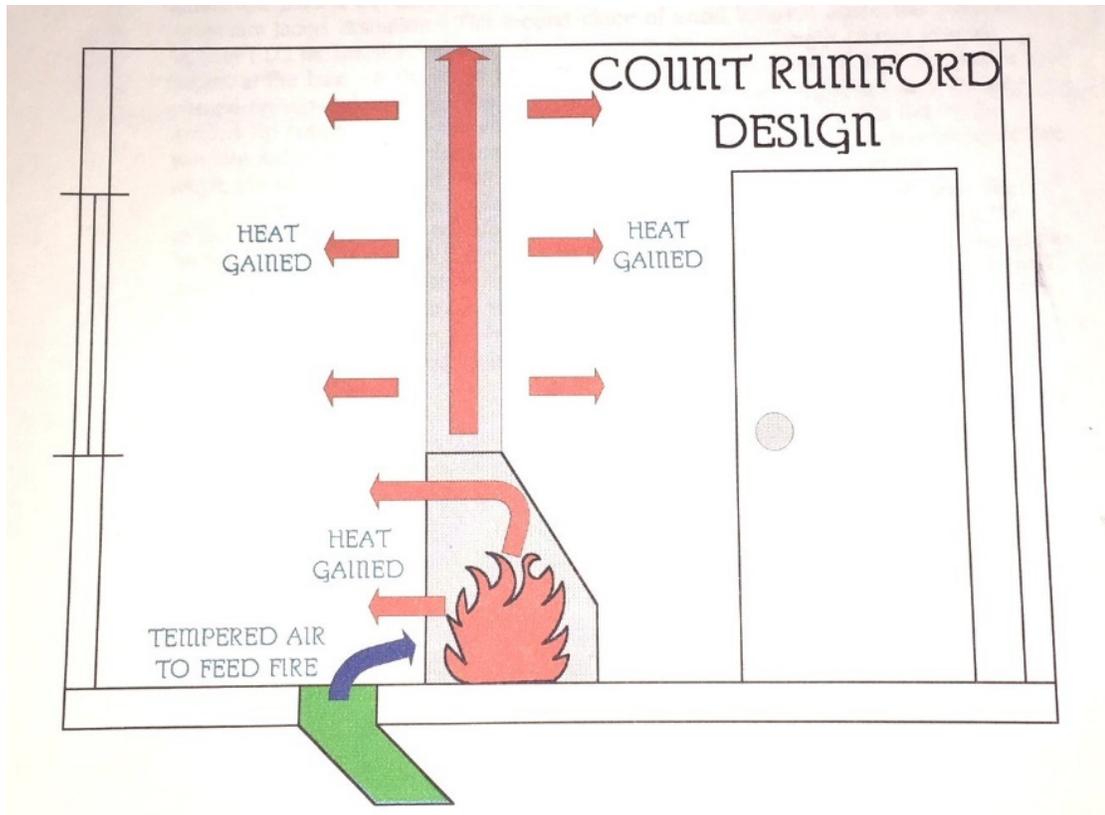
So with this in mind, here are six tips to look for if you are purchasing or building a home that has a fireplace:

1) Placement – middle of the house vs exterior wall

Make sure that the placement of the fireplace is in the middle of the house, or that the chimney is inside the house rather than outside. Rock and brick heat up and help radiate warmth into the house from the chimney if it is placed inside, whereas if the chimney is located on an exterior wall the heat escapes to the outside of the house and is wasted energy.

2) The Design - Count Rumford

Consider a Count Rumford or similar design for the fireplace. These offer a shallower box where the fire burns, which allows the heat to be closer to the edge to throw off more heat into the room. Furthermore, the opening is higher, which allows those little sparks to ignite and burn, allowing more heat to be radiated out into the room. Lastly, the upper back wall of the firebox is angled to reflect more heat into the house.



3) Feed it Tempered Air – Earth tubes

If you install an earth tube (air tube made of PVC pipe that is buried in the earth) it can bring in fresh tempered air into the room to feed the fireplace right near where it burns, rather than the fire sucking air from doors and windows, which cause a cold draft in the room. Check with a contractor to see if an earth tube can be built in your area. Also spelled “earthtubes”, a number of these installed into the ground (as a geothermal heat exchanger) can also help cool a house during summertime, if designed properly. For pictures of earth tubes see the “Ventilation, Cooling, & Earth Tubes” section of the chapter on Direct Gain & Indirect Gain.

4) Replacement – Energy Efficient Fireplace Insert

Woodstoves are more efficient than fireplaces because they radiate heat from all sides rather than just the front like a

fireplace does, and they do it before all the heat goes up the flue. Some people have placed woodstoves on a stone pad in front of where their fireplace used to be, and placed the flue out through the chimney; however, this more unsightly version no longer has to be the case.

These days the fireplace inserts, which are basically like a woodstove that fits into a fireplace, can also serve a similar function, yet still maintain a fireplace look and feel. They can also be run on gas fuel or electric, or they can burn wood. Fireplace inserts have become much more energy efficient than in the past, and are quite popular so the cost is fairly reasonable.

5) Masonry Stove Fireplace – The King of Fireplaces

Masonry stove fireplaces, also called masonry stoves or masonry heaters, are specially designed large fireplaces that have a double burn chamber. A wood fire burns in the main chamber, just like any fireplace, but the smoke and heat run through a channel into a second chamber, where it burns off the extra toxins and particles in the smoke.

Because of this second burn, which is even hotter than the original fire, it makes masonry stove fireplaces both 65-85% efficient, as well as ecologically “green” as the emissions are vastly reduced compared to a standard fireplace. The air leaving the chimney, at that point, is barely warm and nearly pollutant-free because the majority of the heat and airborne particles were removed inside the stove. The only thing that comes out of a chimney flue is carbon dioxide and water vapor.

Wood is not only a renewable resource, but a single hot fire can keep the massive stonework (well-placed in the middle of the house or interior wall of the living room) warm for 12-24

hours, which allows this to be a main source of heat, if designed. These stoves fit well with passive solar homes. Additionally, you can cook in masonry stoves (pizza and breads are common)! The negative side of masonry heaters is that they are labor intensive and must be built by a professional mason, which can cost upwards of \$10,000. However, there is an alternative...

6) Build a Rocket Mass Heater

“Rocket stoves” are small homemade stoves for cooking on more efficiently than an open fire; however, their front-loading or top-loading design is borrowed in the “rocket mass heater”, which is basically similar to a masonry stove fireplace. It burns a fire as efficiently as a masonry stove fireplace (masonry heater) so uses about 90% less wood fuel than a regular fireplace. They can be made using free or used materials and can be as simplistic (using fire brick, cob, a flue, and metal barrel) or encompass amazing designs that are not only efficient but pleasing to the eye.

Basically, the wood is fed into the burn chamber and moves through the barrel where it burns off the toxins in the smoke, and then runs through a flue that runs through a long cob bench before exiting the chimney. The majority of the heat is stored in the cob bench, which is the thermal mass heat storage. One good hot fire can heat the house for 12-24 hours.

Rocket mass heater in tipi



Source: Bryce Phelps, Creative Commons

The downside is that they have to be constructed by hand and are labor intensive (but simple compared to a masonry stove heater) and home insurance will likely not cover them since they are not professionally built / installed. The good news is that most anyone can build one—cheap!

WINDOW GLAZING

As in all passive solar design, one must first consider energy efficiency; however, there are some specifics about windows that everyone should become familiar with because it could "make or break" a passive solar house. Since solar design hinges on the sun and allowing sunlight in to heat the thermal mass, getting the most efficient design out of the windows themselves and how many sq ft to put in, and where, etc., are important. Improper slant of windows can create a hot-box rather than a comfortable house. Window glass is referred to as glazing.

People are often mistaken that putting glazing on your windows is something that makes them energy efficient (they are thinking glazing means "window treatments"); however, that is not entirely true. Glazing is just the glass itself, which is installed in the window frame. Windows come in many different types and styles, but traditionally come in either single or double sheets, or panes. Single pane windows have one sheet of glass, whereas double-pane windows have two sheets. Single pane glass is a big no-no for passive solar homes (or for any home, for that matter)—they transfer temperatures straight through the glass, and tend to ice up and also accumulate condensation in cool / cold or inclement weather. Energy efficient windows usually have double-pane glazing. The "double hung" style windows means both top and bottom sections are able to be opened and shut both directions (up and down), as well.

There are also options for a triple-pane window, which is the most energy efficient of all, although they are heavy and cost more. Gases (like argon, etc.) can also be placed inside to help with energy efficiency, but be aware that these can leak out and also may not be what you want. Argon, for instance, makes a low-E window, which keeps infrared (the heat part of sunlight) from passing through—this

means that you do NOT want this type of window on the south side of the home as it will keep the sun's warmth from passing through and entering your home. It is not a passive solar home without the sun's heat! Low-E is okay to use on west and north, and sometimes east windows. So be careful here. Also, stay away from tinting. Additionally, solar tempered glass (known as "solar glass") has low iron, so it lacks that green hue when viewed from the edge—this means a small percentage of extra sunlight passes through, although it is not totally necessary as it can be an added expense (if you have access to solar glass at a good price then it may be worth it).

It is often better to replace windows and upgrade to energy efficient ones rather than to try to re-glaze old windows. Many windows are also not insulated, so they act as thermal bridges for heat and cold transfer from the outside to the inside, or vice versa. Insulated windows are best, but they do cost more; they are worth it.

Stay Away from Horizontal Glazing

Glazing that is laid horizontally (such as skylights, or sunspaces) will likely overheat the house in the summer since the sun is high overhead and comes directly inside the house. Skylights also LOSE HEAT in winter since they are located overhead, and since heat rises, the greatest loss will be there in winter. Winter is when you want to trap the most heat inside the house, not lose it!

Slanted Glazing in Appropriate Area of the Country

Glazing set at a slant or diagonal should not be used unless you live up north where the winters are colder and summers are cool, and only then if the proper amount of thermal mass is adequate to absorb the heat. Slanted glass (at any angle, but the more horizontally placed, the more heat gain you have in summer, and the more heat loss you have in winter) tends to be very inefficient, but properly designed can help gain winter sun in winter in northern climates, as long as some type of exterior (exterior is superior to interior) insulated shutters are used once the sun goes down. Shading them in summer also helps, but then reduces the natural lighting you may need to rely on.

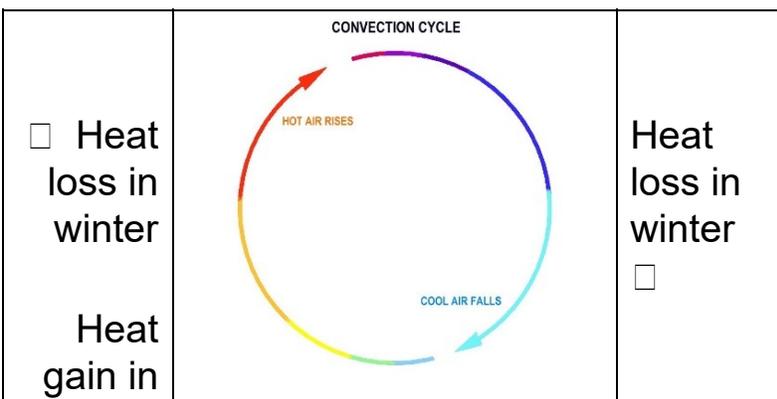
Vertical Glass is Best

The most easy and efficient way of using passive solar design for the comfort and ease of year-around use of the home is to keep the glazing vertical, which helps home-owners live comfortably in the same house all year long. This also makes it easy to figure out your overhang lengths and how much sq. ft. (net) of window area is needed. Also, keep in mind that vertical glass is far less likely to break during hail or other storms as compared to glass installed horizontally or at angles.

Double-Pane VS. Single-Pane Windows

It is highly recommended to use double-pane windows rather than single-pane windows. Although each piece of glass is only about R-.5 (that's point five (.5) rather than 5... VERY LOW) a double-pane window is only about R-1 rather than R-.5 but the extra piece of glass creates a dead-air space, which reduces the convection. This dead air space in between the panes serves as a buffer and stops the majority of the condensation and transfer of moisture into the room. In fact, double-pane windows can reduce heat loss by 50% compared to single pane. Most spaces between the glass are fairly thin on purpose; large air spaces greater than 1" tend to accelerate the convection cycle.

Avoid windows (or even storm windows over regular single pane windows) that have more than 1" space between the glazing. Remember hot air rises, and cool air falls, creating a convection cycle that can cause heat loss or gain, depending on the weather or season.



summer <input type="checkbox"/>	1.5+ inch space <- between window panes -> is NOT recommended	<input type="checkbox"/> Heat gain in summer
------------------------------------	--	--

Triple-pane windows are all that is used in the Passive House design because they are the most energy efficient, so keep that in mind. Triple-pane windows do not add much more insulating value than double-paned, although it does make a difference, and they are preferred in cold climates. Triple-pane windows also cost more and weigh a lot more too, so are more difficult and potentially more expensive to install. Some double or triple pane windows are filled with argon (cheaper) or krypton (more expensive) gas, which helps insulate them—making them improve efficiency by up to 20-30%—but be aware that many times this gas can leak out over time, making an expensive triple-pane window worth hardly more than a double-pane in the end. If the company selling the windows has a guarantee for no leakage, or refilling them, then ensure that the testing for this is included, and realize that you just purchased a more complex and unreliable system. Increased complexity tends to increase cost and work, as well as causes waste, so you may want to consider all of these factors before deciding which windows you buy.

For a properly designed passive solar house Low-E windows should NOT be used on the east side (to allow the light/heat inside on those early morning winter days) and especially do NOT use Low-E windows on the south side. However, you CAN use Low-E double-paned windows on the north and east sides of the house (this reduces heat loss in winter, and reduces heat gain in summer).

Remember Orientation!

Remember how to find "Solar South" from a previous chapter? Orient your home so that the longest side, with the most amount of windows faces solar south. The longest wall, therefore, should run east to west. For a direct gain passive solar home there is a vital connection and balance between how much glass / glazing you have

and the amount of thermal mass inside the home. This is call the glass-to-mass ratio.

Glass-to-Mass Ratio

The glass to mass ratio is pretty simple... there is a simple ratio of how much window area you need for a certain amount of thermal mass.

Glass-to-Mass Ratio:
3-5 sq. ft. of 4"-thick mass
for each 1 square foot of glass

If you get the glass-to-mass ratio wrong the result will be too little heating or overheating. The ratio is best calculated through the “7% Rule”, which means that the south-facing glazing in any direct gain passive solar home should be 7% (of the NET—meaning the glazing only, do not include the window frame as part of the calculations—I will give you the key to figuring this out shortly) for the home, without adding any extra thermal mass inside the house.

Remember the 7% Rule!

This rule means that the windows’ surface area (facing solar south) equals 7% of the total surface area of the floor. If you want to add more windows, you will need to also add more thermal mass to the interior or your home will overheat!

Here is an example:

A three-bedroom house with 2,000 sq ft of floor space has a 7% window area of:

$$7\% \text{ of } 2,000 \text{ sf} = 140 \text{ sf}$$

This means the home should have 140 square feet of glazing (net) on the south side without any need for added thermal mass outside of

the regular amount.

So if you WANT to add more glazing, then how much extra mass do you need to add to compensate?

This part is a little more complicated since there are three types of thermal mass:

1. Floors in sunlight
2. Floors out of sunlight (but in same room)
3. Walls (whether in sunlight or not)

Remember that thermal mass in the walls and floors need to be at least 4-6" thick. Here is a guide to how much extra thermal mass you will need if you use more glazing above the 7% (net) amount.

FLOORS IN DIRECT SUN: 5.5 sq ft of surface for EACH extra sq ft of glazing (over 7%)
FLOORS NOT IN DIRECT SUN: 40 sq ft of surface for EACH extra sq ft of glazing (over 7%)
WALLS (WHETHER IN SUN OR NOT): 8.3 sq ft of surface for EACH extra sq ft of glazing (over 7%)

Okay, so I will give another example for a home that has more square feet of glazing above the 7% (net).

We can have 140 sq ft of glazing using the 7% rule. So if we want to have 210 sq ft (that's 140 + 70) of window area on the solar south side, then how much thermal mass do we need to add extra?

- Floor space in sun = $70 \times 5.5 = 385$ sq ft
- Floor space not in sun = $70 \times 40 = 2,880$ sq ft

- Wall area = $70 \times 8.3 = 581$ sq ft

However, in reality your thermal mass could be made up of all three types. When you build a new house you will want to calculate your numbers from the beginning, and work out how much thermal mass you actually need compared to the window area you should install. How come? Because there is no inherent thermal mass in place like when you already have an older house that's already built. This can be easier or harder, either way, but generally speaking it is easier to design a new home compared to a retrofit.

HOW TO FIGURE WINDOW AREA (NET)

“South windows should have 7% (net) of the homes' total square footage. That's not 7% NET of window - frame edge to frame edge.... the GLASS AREA itself should be 7% (do not include the frame)!

Example: 2,000 Sq. Ft. = 140 Sq. Ft. of glass

Multiply the entire window by .8 to get the net glass area.

Example: A 3'X5' window is 15 sq. ft.

$15 \times .8 = 12$ sq. ft. net

Do not exceed this 7% of the NET (glazing only) amount or overheating may occur. This 7% is the amount used for conventional home construction with wall-to-wall carpeting. If you want to increase your glass at this point, then you **MUST** utilize extra thermal mass qualities within your house by placing mass within your house such as tile floors, concrete, brick, rock, slate, adobe, concrete block, stone fireplace & mantle, etc. Remember that interior mass WALLS are 4 times better than interior mass floors (if they do not have direct solar gain) for heat storage.

IMPORTANT TIPS!

An additional 1 sq. ft. of south glass may be added for every:

5.5 sq. ft. of sunlit thermal mass floor *

40 sq. ft. of floor not in direct sunshine

8.3 sq. ft. of thermal mass wall

* The maximum amount of sunlit floor is 1.5 times the south window area

The recommended maximum amount of south glass for direct gain is 12-15%”

(Source: www.epsea.org)

NORTH WINDOWS

Glass area on the north should be greatly reduced (to **4% of the homes' total square footage**) as solar gain is rare to nonexistent on the north side of the house (in North America) but heat loss occurs most there. Utilizing this principle will reduce both the heating and cooling loads.

EAST WINDOWS

Glass on the east is the **same as north windows (4%)**. Reason being is that although most solar gain does not occur here; however, it is the **FIRST** place where gain occurs. Morning hours spent by the east window drinking your coffee or hot tea while you read your paper are a nice way to begin the day, while at the same time the sun is already starting to warm up your house (*thanks to Mike Cormier for that tip!*).

WEST WINDOWS

Glass area on the **west should never exceed 2%** of the homes' total square footage. West windows are terrible for solar gain because they do not allow sun in during the time of day when you need it, and

can gain TOO MUCH in the already-hot summertime afternoons when the sun is low in the sky. West solar gain during a hot evening during summer can overheat your house and make your A/C work even harder in order to keep the house cool.

Remember those Low-E windows? Here on the west side of the house is the ONE place they might do some good! Exterior insulated shutters are even better to stop the light / heat before it ever enters your window, but if you want to see some indirect light or peek out the window then exterior louvered shutters work well when you are not standing there peering out, or you can place a trellis covered in plants / vines to shade the window.

Evergreen trees planted in alternating rows starting at 25' away from the west wall also works great to shade the west wall on a late summer day, plus they double as a wind break (wind will rob heat from a house during winter VERY quickly!).

Window Types

There are a multitude of types of window frames and glazing. You can customize your home's windows by choosing suitable glazing type and combining it with energy efficient frames. Frames today have improved thermal resistance that are adequate for energy efficiency standards, namely the U-factor. The lower the U-value, the more efficient the window (in terms of thermal performance). It is important to understand the pros and cons to different types of frame materials, but nearly all types (wood, vinyl, fiberglass, composite materials) will provide a better thermal resistance than will metal frames.

Metal and Aluminum Frames

These are strong, lightweight, and pretty much maintenance-free; however, metal frames conduct heat quickly and they are poorly (if at all) insulated. The only way to reduce the U-factor (and heat transfer) is to make sure they have a thermal break, otherwise they act as a thermal bridge. However, if the metal is on the exterior and vinyl or non-conducting material is on the inside (with insulation in between), then this is an excellent combination because the metal resists weathering better than about any other frame material.

Fiberglass Frames

Although fiberglass is not a green product (lots of chemicals involved in producing it), insulation can be filled in the air cavities, which gives them excellent thermal performance over vinyl (uninsulated) or wood.

Composite Frames

Composite wood products are fairly stable, having an thermal performance equaling conventional wood, plus are moisture and decay resistant.

Wood Frames

Although wood frames can insulate averagely well, they also respond to weather, so expand and contract, which can bring maintenance issues. If they are clad in aluminum or vinyl, it may help.

Vinyl Frames

Vinyl frames are actually made of PVC (polyvinyl chloride) that has UV (ultraviolet) light stabilizers so they do not break down in the sun's light. They do not require paint nor are they susceptible to moisture. The cavities may be insulated, so in this they are an excellent choice, thermally speaking.

Glass or Glazing Types

Besides choosing your type of window frame, you will need to choose your glazing / glass type as well. There are a lot of choices on the market, but placing emphasis on energy efficiency rather than price, would do well for you in the long term. Considering all of your passive solar factors such as climate, site, building design, window orientation, and so on, you will likely want to choose different styles of glazing for different sides of the house.

Gas Fills

One way to improve thermal performance of windows is to insulate in between the double pane or triple pane glazing with inert gases such as argon or krypton, which resists heat transference. Gas may leak out.

Tints for Heat-Absorption

Be aware of the pros and cons of heat-absorbing window tints for glazing, which alter the color of the glass. Although they absorb a good part of the insolation (sun's radiation) that would otherwise penetrate the window and therefore reduces the SHGC (solar heat gain coefficient), VT (visible transmittance), and glare, there is some heat that still transfers through the glazing, which means that such tints do not really lower the window's U-factor. Black-tinted glass should be avoided in hot climates (they absorb more light than they do heat). Green- and blue-tinted glazing allow more visible light through but slightly promote a reduction in heat transfer (compared

with other colors). The common bronze- and grey-tinted windows reduce both heat and light. You would need to ask the manufacturer as to just how much heat and light are reduced compared to regular glass. Remember that north-facing windows rarely see the sun (except at sunrise and sunset near summer solstice, depending on your latitude). Also, take note that if windows allow less than 70% of visible light, then it can negatively affect indoor plant growth.

U-factor: A rating for the heat loss (in terms of U-value) of any window assembly. The greater the window's resistance to heat transference = the lower the U-factor (better insulating properties).

U-factor is the energy efficiency rating—the lower number the better. The Passive House standard requires windows with a very low U-factor (it is not uncommon to find window U-value as low as $0.5\text{W/m}^2\text{K}$ (Center pane U-value of $0.299\text{W/m}^2\text{K}$).

Low-Emissivity Coatings

Low-E (low-emissivity) coatings on glass help control the heat loss through glazing. Low-E coatings usually cost 10-15% more than standard windows; however, they can reduce energy loss up to 30-50% (just do not put any kind of low-E on the *south side* of the house or they can reduce solar gain!). The coating is a nearly invisible metallic oxide layer that is placed on the glass and affects the U-factor. Be sure to ask the manufacturer about which kind of Low-E you use because there are different types—some are designed for low, medium, or even high solar gain. So be careful! These coatings can also affect the VT (so be sure if it does that you choose one that is spectrally selective). Most low-E coatings are deposited onto the glass at the manufacturer, although there are some do-it-yourself types. The films are usually less expensive than replacing your windows and can last 10-15 years. Their benefits include saving

energy, should not peel, reduce fading of fabrics, and improve comfort levels in the home.

Reflective Coatings

Window glazing with reflective coatings reduce solar radiation levels from entering the home, which means they block more light than they do heat. Because of this they block more glare and VT; however, they can also reduce the glazing's SHGC. They can come in different colors and are usually utilized in hot climates to reduce solar gain, but may require extra lighting in the home to offset their effect.

Spectrally Selective Coatings

The spectrum is full of many colors contained within sunlight; however, spectrally selective coatings (a type of Low-E) filter out 40-70% of the heat that would normally be transmitted through the window, yet allows full light transmission. They are used to reflect the infrared (heat) part of the spectrum while allowing more visible light through. These might be handy on a western window for that reason. They make the window have a high VT, but a lower SHGC and low U-factor.

Window Treatments

Window treatments are used as a type of décor but may also help you save energy if you choose the right kind(s). This is where you can help reduce heat gain in summertime, as well as reduce heat loss during winter. They do not help with reducing air infiltration or leakage, so you will need to use weatherstripping or caulk for any air leaks. Here are some of the types of window treatments that may be beneficial.

Awnings

During the spring and fall, in particular, the sun may shine into the window on warmer days, just because the equinoxes are in between the summer and winter solstices. Ideally the summer sun stays out, and the winter sun is allowed into the home, but in between these times the home may get a tad warmer than usual. You can use awnings to reduce solar gain by up to 77% of west-facing windows, and 65% on south-facing windows. Make sure they are moveable you can adjust them accordingly.

Blinds

Blinds are either of the vertical or horizontal type and are available at most general stores. They can reduce some heat gain (remember, once the light has penetrated the window it is already trapped in the house) but are not very good at reducing heat loss during winter.

Interior blinds are particularly poor for controlling heat because of all the openings between the slats. You can adjust for light and ventilation, but not so much for heat. However, if they are reflective blinds they may help reflect up to 45% of the heat gain. Generally **exterior** blinds will work even better as it can block up to 100% of the light (and heat) before it ever enters the window. This is also true of awnings and shutters.

Draperies

Draperies may be a good or a bad choice, depending on the color, weave, and type of material, as well as whether they are insulated.

You can use opaque draperies to help reduce up to 33% of the solar gain in summer, but you also reduce the light in the room. They can help keep the room cooler, however, and reduce cooling loads. If drawn in winter they can help reduce heat loss by up to 10%, so be sure and close them at night. This number can go up if they are insulated draperies, and even more if they are reflective and insulated. Attaching magnetic tape or Velcro to eliminate gaps around the top, bottom, and sides, help even more (up to 25% less heat loss). Draperies hung in doubles (two hung together) may also improve heat loss compared to one (just as double pane glass helps reduce heat loss in windows) since the interior drapery will tend to maintain the same temperature in the room.

High-reflectivity Films

These window films block summer solar gain, so are best when used in areas with a long cooling season. Be aware that they also block solar gain in winter. See “reflective coatings” section for more information (above).

Insulated Panels

Pop-in shutter panels are usually made out of rigid foam board insulation. They can be pushed into the window box area and should be made to fit tightly. They can be covered with fabric, and made with magnetic tape or Velcro. Some people sew fabric handles to pull them back out easily. They can have an R-value of 3.8 to 7 and can be homemade inexpensively or purchased in a kit.

Window Screens

Screens (meshed) can help diffuse light, which helps reduce solar gain in summer; however, you will not want screens on your south windows. They can be effective on west windows, and east windows (in summer).

Shades

Shades are simple and can be installed close to the window so it creates a kind of seal. Lower to reduce sun infiltration in summer, and

raise during the daytime in winter but pull shut at night.

Cellular or pleated shades have a dead-air space to create an insulating space, but do not help much with air infiltration. Roman shades can be bought or made (homemade ones are good out of Spanish / Mexican rugs and both help insulate and block light) and can be made to seal around the window box area.

Shutters

Interior and exterior window shutters help reduce heat loss and heat gain inside the home. Interior shutters are not as effective as exterior shutters, however. Interior shutters can be combined with the insulated panel on the side facing the glazing for added insulation. Exterior shutters can also be insulated, and double as protection against high winds and falling branches during severe storms, plus provide extra security.

One of the best set ups is an exterior roll shutter (like Rolladen), which can be automated to open and close by themselves in the morning and evening, which help provide insulation and light at the right times. They can also have a hand-crank, or mechanical motor that can be utilized by a flip of a switch.

Storm Windows / Panels

If you have single pane windows you can add a storm panel to reduce heat loss by up to 50%, and are also not as expensive as installing double pane windows. You can add them to the exterior and interior of the windows (there are two types). Heat-shrink film is another choice for interior window coverings to slow the temperature swings, but they are very temporary and need to be replaced each year.

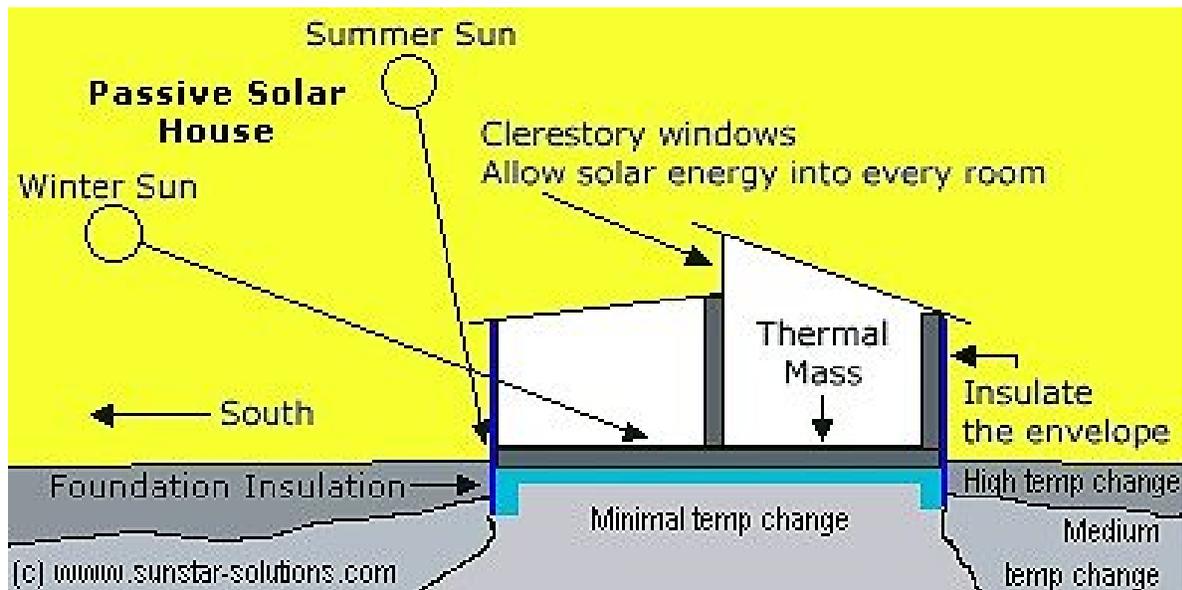
Window Overhang

By far the best window treatment is a properly designed roof overhang on the south side, which can effectively shade summer sun and allow it in during winter for maximum solar gain. This requires passive solar home design and construction considerations, as it

depends on climate, latitude, insolation factors, and window types / size. Adding a well-designed overhang to an existing home is extremely difficult (awnings are easier) so it's best that the design is done in the planning stages, prior to construction of the house.

HOUSE OVERHANG

Roof overhangs (eaves) on your house are an important part of the equation for a properly designed passive solar home. The idea is to allow the sun in during winter, and keep it out during summer. The overhang length calculation depends upon variables of window height, wall height above top of window, latitude, and sun position at any given time of year.



Recommendations from Chuck Reel

As you learned earlier in this book, my friend Chuck Reel is a solar energy professional. He taught me many of the principles that I am now teaching to you here in this book. He suggested some things regarding overhang design. He designed and built the passive solar straw bale house that had adobe walls inside for the Alamosa, Colorado area that uses almost entirely passive solar energy to heat it during winter. Supplemented only by a small woodstove, the home stays warm in -24° F (-31° C) weather in winter.

**Solar Energy and Straw Bale House
Construction Expert Chuck Reel.
Connect on Facebook:
<https://www.facebook.com/reelguy>**

Regarding overhang length, Chuck said (about the southwest area of the U.S.):

“Overhangs are a challenging subject but I keep track of the latest things we have learned over the years to see what we have learned from the mistakes of the past. New Mexico seems to keep track of the latest science and the NM Solar Energy Association's website (www.nmsea.org) says that in northern NM, angles of 36 degrees to the top of the window and 73 degrees from the bottom of the window gives a shadow a full 6 weeks around the summer solstice and a full 6 weeks of sun around the winter solstice. The angles would be 30 and 77 degrees if you just wanted the full effect only on the solstices. The 6-week idea produces an overhang that is higher and longer than the other overhang design.

“Many people say that 60% of your energy can be supplied by the sun. NMSEA says 80% and I think it can be even much higher if someone was to spend the money to do it right and be willing to go a little overboard.

“No fixed overhang will ever be perfect since it will give the exact same shadow on two different days of the year. On one of those two days you will want more shade than you have, and on the other day you will wish you had more sun than you are getting.

“From the pictures of the [Colorado] house in different seasons, you can clearly see the shadows I designed into the house from the overhang I worked out. I used info from New Mexico and that was physically close enough to the house that I went with it, but I have always wondered about designing a good overhang, for say, Oregon or Canada, etc.



**January 10th – full sun in windows
below overhang**

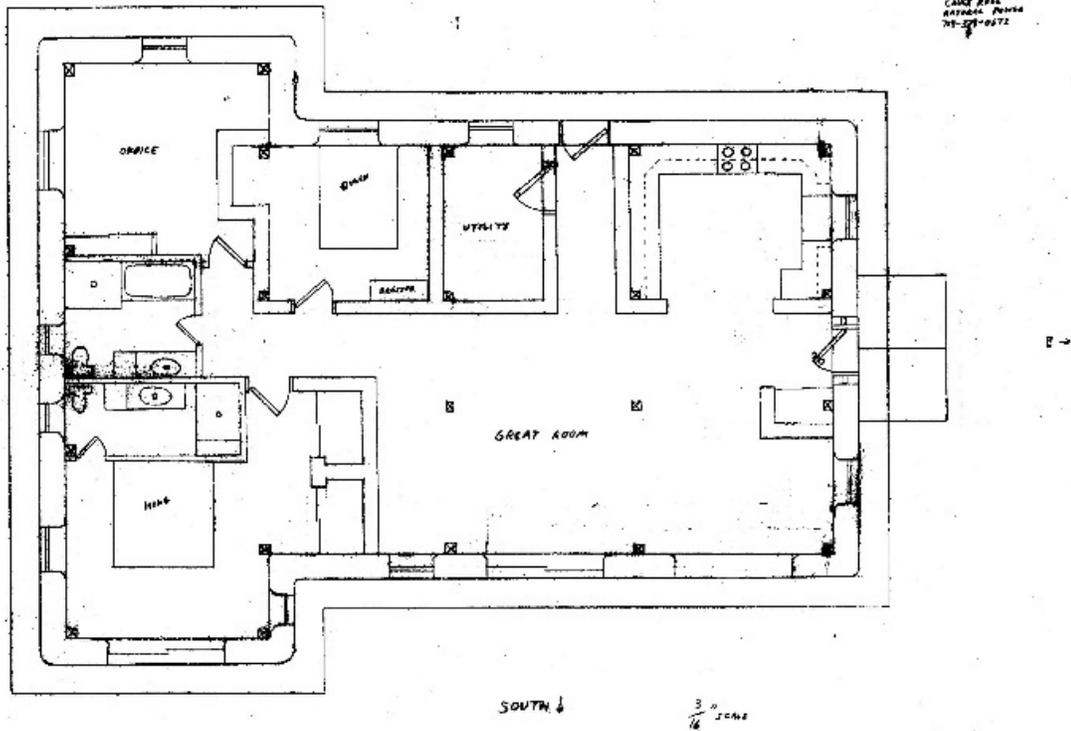
“By far the biggest design error made on most all passive solar homes is that they bring the overhang out from the top of the window. This top foot or so of the glass will never see any sun in the winter and since it is up high inside the room where the hottest air is in the winter, it will leak that heat through the glass 24 hours a day. I hate this when I see it



August 29th – towards the end of summer so mostly shaded windows

done to an otherwise well designed house. Look at the [Colorado house's] south wall in the photos and you will notice a large area around 2 feet vertically ABOVE the glass (before the bottom of the overhang); that super insulated straw bale wall will prevent any heat loss instead of the massive heat loss of normally designed and built overhangs, which project out from the top of the window.

“What I really need is pics from solar noon on the solstices and equinoxes to accurately compare the shadow patterns. I did the best I could at the time on her overhang design using Edward Mazria's *Passive Solar Energy Book* and *The Solar Home Book* by Bruce Anderson, which are both old books but we need what has been learned about overhang design in the last 40 years since those books came out.”



Floor Plan

Chuck said:

“This [Colorado] home is not a perfect solar design as any protrusion from a south wall will mess up the more perfect passive solar design—the protrusion will cast sideways shadows on any glass near it and this house does have a small protrusion on the west side for the master bedroom. The homeowner saw the first passive solar straw bale house I built, which had the perfect rectangular shape where the overhangs worked all along the south wall with no sideways shadows. She did not like that shape and said it reminded her of a mobile home, so wanted a more complicated shape and roofscape so I came up with that T-shape for her; however, I didn't like how the sideways shadow from her bedroom would shade the tall skinny window in the living room but she was the one paying the bill so I did it. You can see that shadow in picture here.



Shadowing from wall protrusion

“She also wanted an east-facing window in her master bedroom to bring in the sunrise and that protrusion allowed a place to put that window as in this next picture.



Solar gain and overhang lengths – side view

“She would not allow me to add an overhang over the sliding glass door in the master bedroom so I pushed it to the inside of the thick straw bale wall for a built in overhang as can be seen in this next one (and other pictures).



Sliding glass door inset under bale wall

“I will do professional consulting on helping anyone get a very energy efficient home built, but need to make a living doing it so I do charge for that service.”

Chuck Reel can be reached here:

5644 Ash Ave

Alamosa, CO 81101

Phone: [719-379-0672](tel:719-379-0672)

Email: reelguy@gojade.org

Chuck also teaches 'green home' building design for owner builders. He is my mentor and a long-time friend so I can highly recommend him. He is particularly good at making what seems complicated into something simple regarding design. If you prefer complicated and expensive, then hire an architect. If you want a simple oblong single-story ranch style house (alternative construction, built green, with passive solar design) that maximizes solar gain and is up to 90% efficient then you can choose Chuck for help with your home design, or to have him help you build it.

Calculating Overhangs

There are formulas available on the Internet for how to calculate an overhang, but they can be quite lengthy and involved. The EASIEST way I have found to do it is by drawing a simple sketch on graph paper. Figure out if you want one square per inch (or other measurement).

But first...

Figure in your summer and winter solstice sun angles (lowest and highest) from this next website – it is absolutely the easiest and quickest way to obtain the sun's angles for your specific area at any given time! You can transfer the degrees from the chart to your paper using a protractor to determine the overhangs.

You will need your latitude and longitude, which you can find here:

Latitude – Longitude Finder

[https://mynasadata.larc.nasa.gov/
latitudelongitude-finder/](https://mynasadata.larc.nasa.gov/latitudelongitude-finder/)

**GREAT SITE BY UNIVERSITY OF OREGON FOR
TAILOR-MADE SUN ANGLE CHARTS**

<http://solardata.uoregon.edu/SunChartProgram.html>

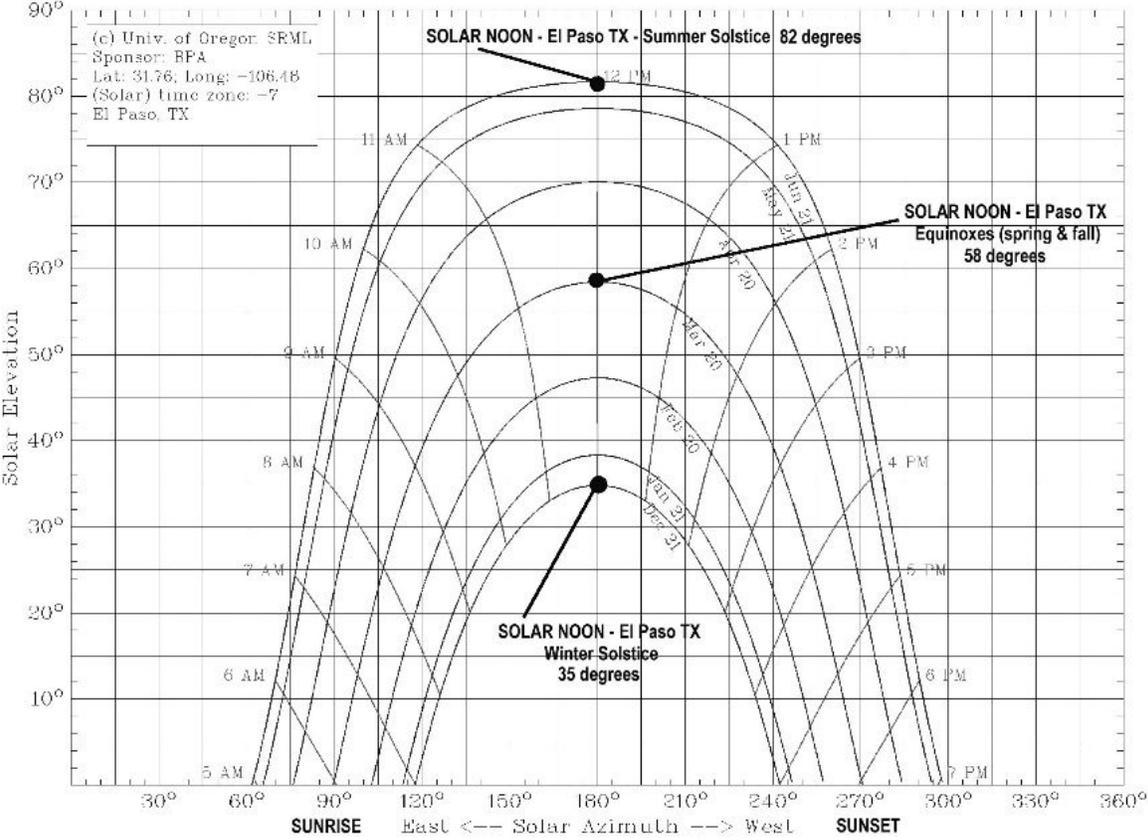
You will want to use the two websites above to help you determine your overhang. I really know of no easier way. Some people get frustrated with this part because there is not an easy way to do this without knowing your sun angles at summer and winter solstices, and using a quick online sun chart that is generated for your *exact location* is the most efficient way to do this that I know of. So if you do not have a computer, or know how to use one, please go to your local library and have someone help you with this part—it literally only takes a few minutes! Once you print it out, then you are on your way to the next steps.

Figuring out how long your overhang should be also helps determine where your window placement should go, not necessarily

the other way around. The sun chart, showing where the sun rises and sets, based on times of year, will help you when you begin figuring out your own overhang lengths (and do not forget that if you have trouble you can always set it to maximize the winter sun, and just use an adjustable awning that can be pulled out to shade more area in the summer).

We can take a look at an example...

From the website named above for a sun angle chart, it gave me a PDF or PNG version that I was able to print out. Here is what kind of chart you will generate (minus the added comments and lines indicating "solar noon")—this particular chart is specifically for the El Paso, Texas area, but you can set it for just about anywhere.



If you take a look at the solar chart above, you will be able to decipher the exact placement of the sun in the sky between summer solstice (June 21) and winter solstice (Dec 21). I will explain.



NOTE: Remember the equinoxes and solstices:

Vernal equinox – around March 21

Summer solstice – around June 21

Autumn equinox – around Sept 21

Winter solstice – around December 21

On the left side of the chart shows degrees, and to the right are a series of bowed lines that represent the sun's path through the sky at different times of the year; these lines show the elevation of the sun in degrees. For example, in this chart above, identify these:

Sunrises & Sunsets

Sunrises in summer starts at the lower left at 5AM, and at 6AM at the equinoxes, and closer to 7AM at winter solstice. Likewise, sunsets are at 7PM in summer, 6PM in spring/fall, and 5PM in winter.

Solar Noon

In all versions solar noon is at “noon” in this chart. The differences are at shown at the time of year, with the sun being lowest in the sky (35 degrees) in winter, mid-sky at spring / fall (58 degrees), and highest in the sky (82 degrees) in summer.

Now you know how to read the chart.

NOTE: This sun path chart shows where the sun is at in the sky throughout the year, but it does not show you what the annual temperature fluctuations will be. Check online (do a Google search) or go to your library to see what annual climate highs and lows are, as well as rainfall patterns, snowfall, wind directions, etc., are and compare that with your local solar gain times. Temperatures in some areas may not be the same as when solstices arrive. For instance, the coldest temperatures in Nova Scotia, Canada lag behind around eight weeks after the days start getting longer. This is due to the earth's distance from the sun, as well as time for the earth to heat up or cool down, and possibly other factors. That means even though the days are getting longer starting on Dec 21st, the temperatures remain very cold for the next two months due to the temperature lag. Similarly, the longest day of the year is June 21st, but it is not the hottest day of the year (the hottest time in Nova Scotia is typically eight weeks later in August). What happens where you live?

Next, you will need to apply the information gleaned in the sun path chart so you can draw a plan for your overhang distance on the south side of your house (east, west, and north do not matter).

With some graph paper in hand, a pencil (with eraser, because believe me you will probably need it!), and a protractor and ruler, you will be able to draw a southern-facing wall similar to the one below.

Please note: The wall could / should be inset further (left) on this example picture below. Be sure to draw yours to scale based on what should be real-life measurements.

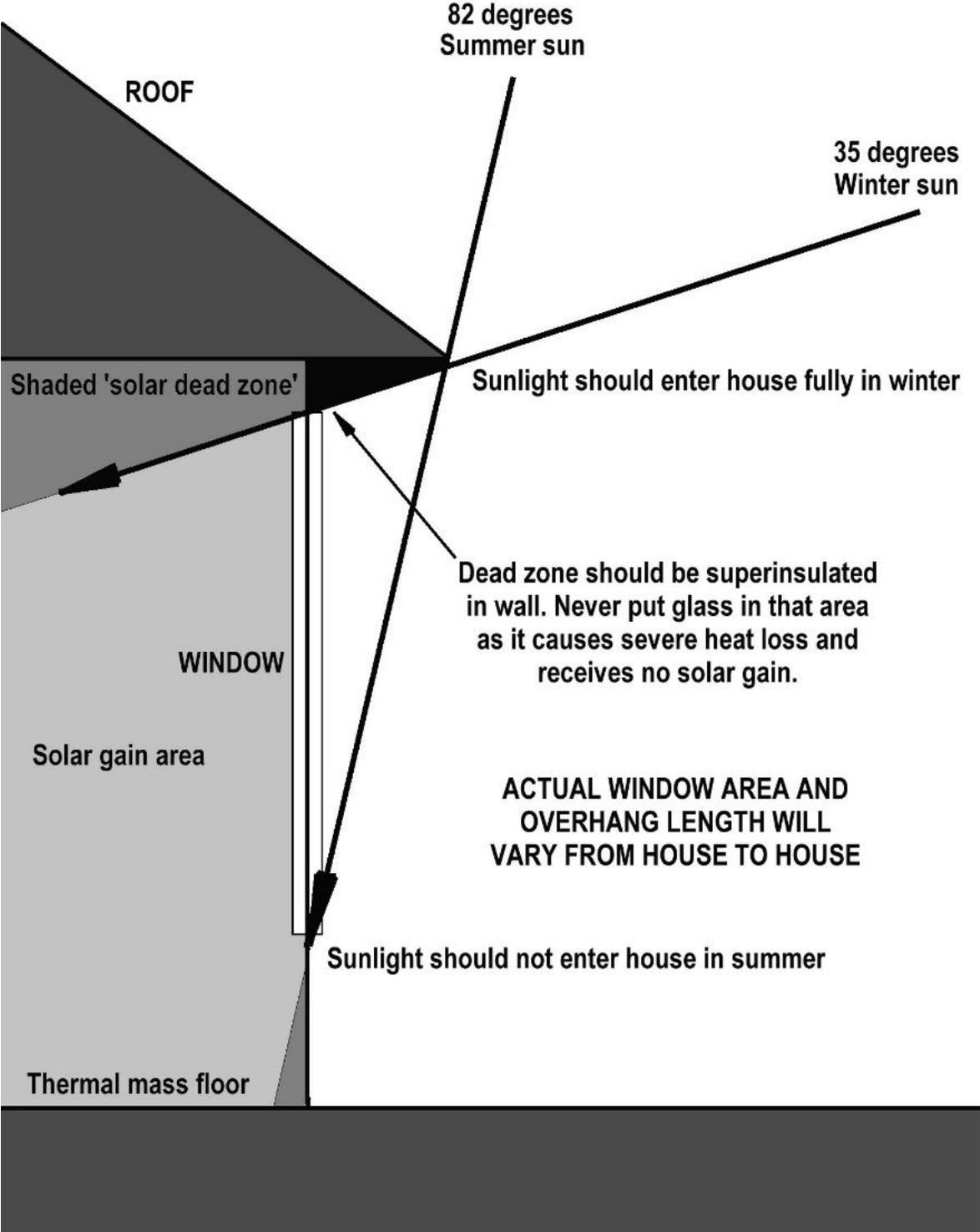
This example:

Summer solstice sun height approx. 82 degrees.

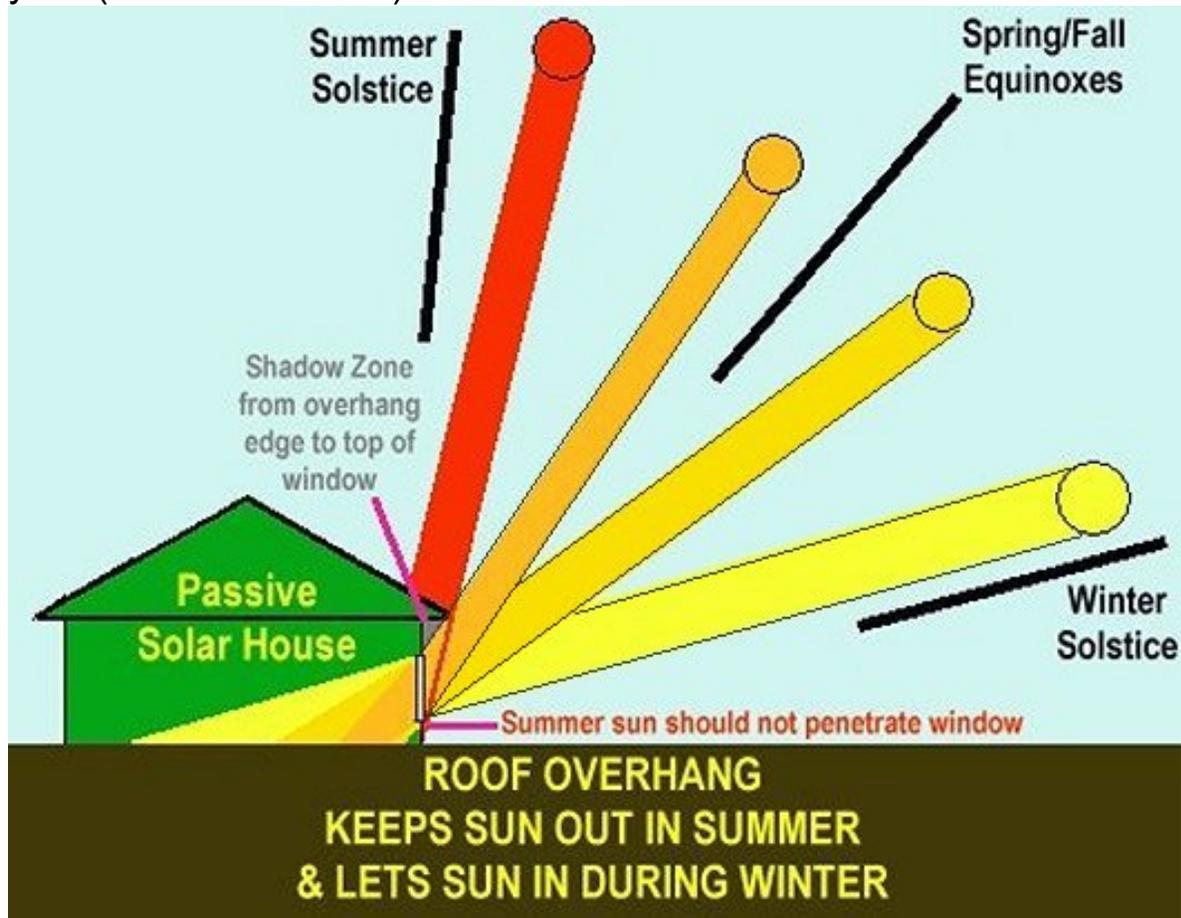
Winter solstice sun height approx. 35 degrees. (see picture next page)

The area above the window, between the top of the window and the soffit on the eave, will typically remain in the shade, and this area should also be superinsulated because it is a dead zone (stays shaded year around). You do not want shade on your glass during winter as there is no solar gain, plus will promote heat loss. Simply lower your window if it is too high / tall on a house plan; that way you can adjust it to fit for solar gain application.

Likewise, ensure that the peak summer sun does not enter the bottom of the window.



Doing these two things will ensure that you have full sun as much as possible during winter, all the way to the shortest day of the year (winter solstice) and no sun in your windows on the longest day of the year (summer solstice).



Create a drawing so that the window will fit where the sun should shine between the solstice times, and use the measurements based on that to determine the height of the wall and roof overhang. This method is only one way to figure out your overhang, but it works well for visual people who only have graph paper and a protractor and ruler.

I used a protractor (since it shows degrees) to determine window and overhang placement once I had my solar chart. I will take you through some of the steps I took to figure it out. Back in the 1990's I did mine on the computer, and put thin graph paper in front of the screen so could draw the lines behind it, but this could be done with

AutoCAD programs or using simple paper and pencil as well. First, start with the protractor.

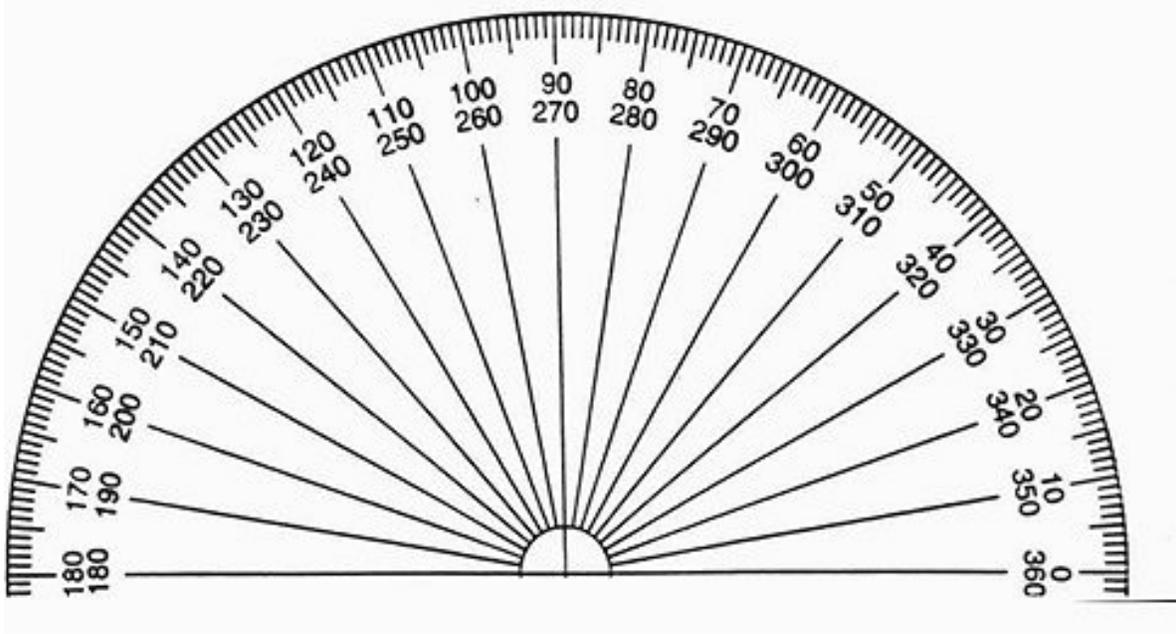


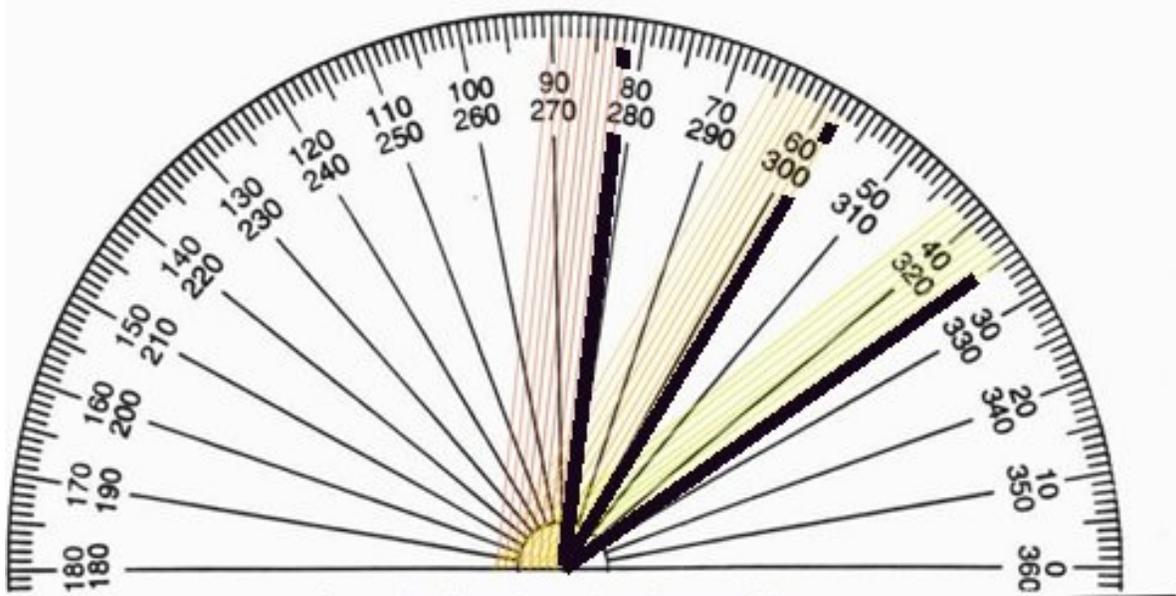
Photo source: www.dynapod.com/protractor2.jpg

The angles of the sun according to the solar chart were:

- Winter solstice: 35°
- Equinoxes: 58°
- Summer solstice: 82°

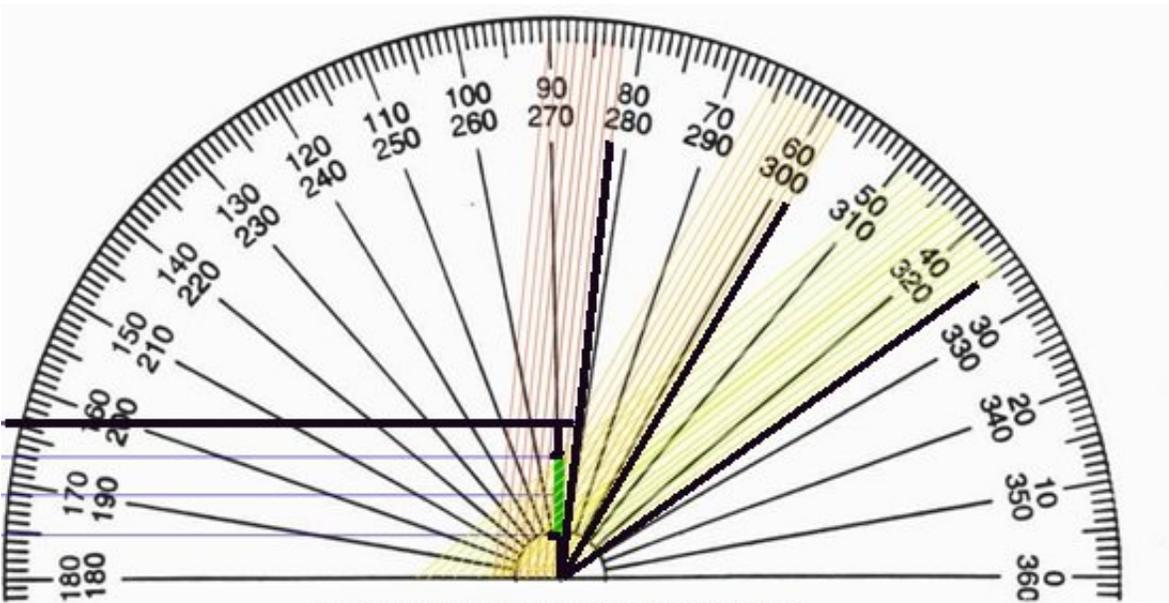
NOTE: Although I mentioned the equinox angles above, and show them below, you only need summer and winter solstice angles to determine overhangs (for maximum and minimum sun angles).

The first line I drew for each went straight from the degree mark to the bottom of the 90° mark. (see picture next page)



Source: <http://www.dynapod.com/protractor2.jpg>

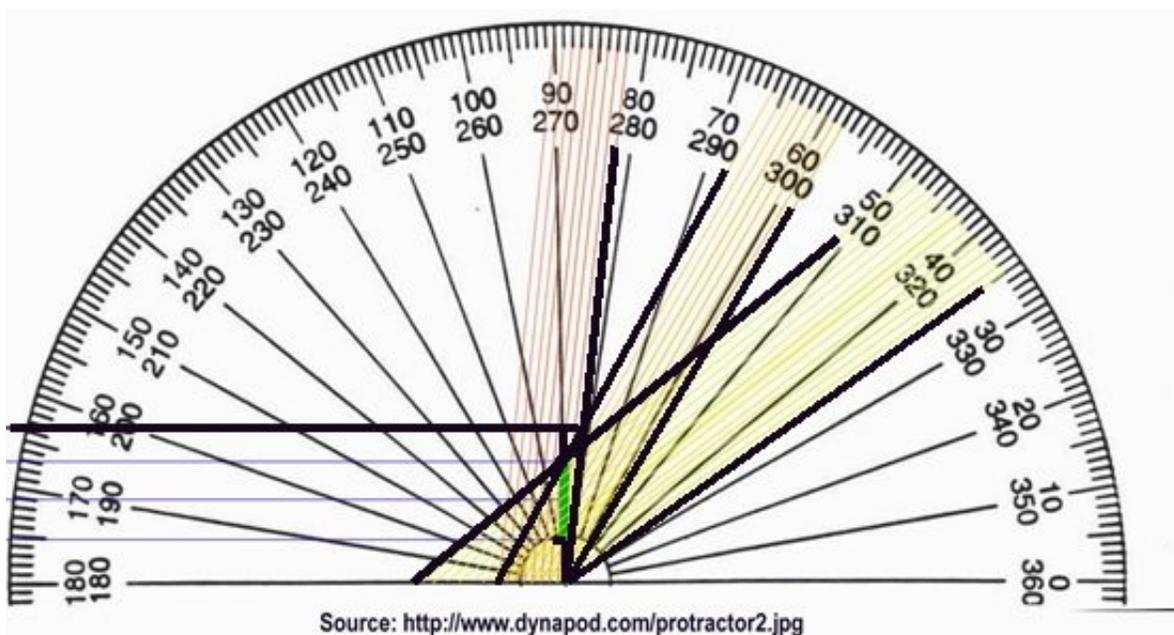
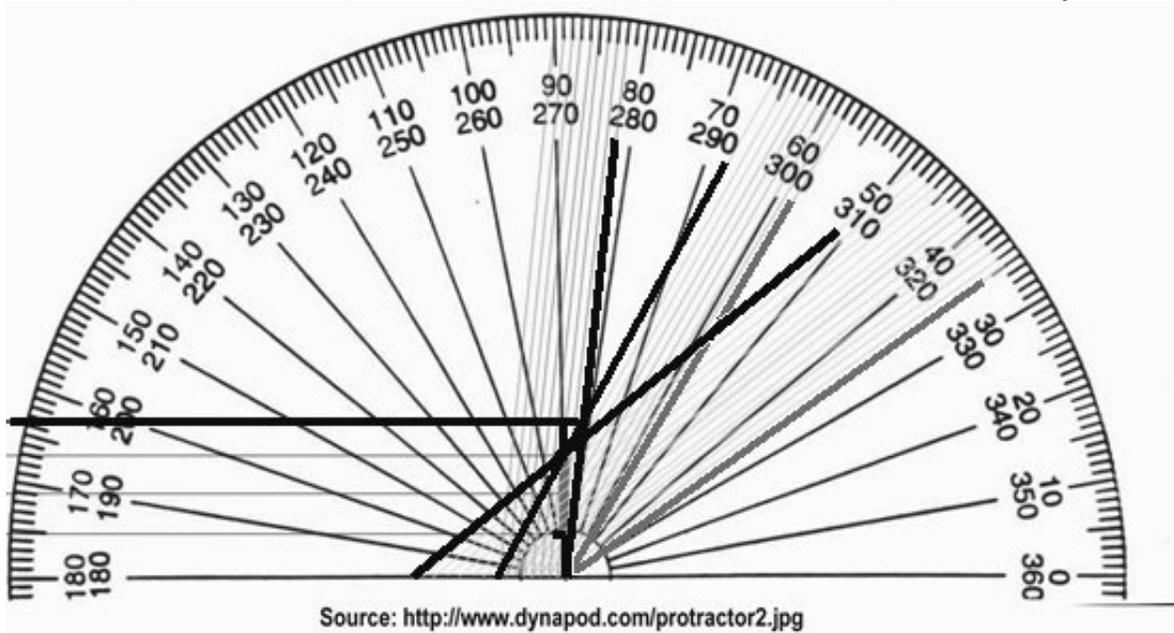
Based on the highest (summer solstice) line that fell to the bottom of the 90° mark I drew the edge of the overhang to the spot where it intersected the middle (equinox) line, because the idea is to ensure NO summer sunlight enters the windows, but we DO want it to enter as we approach fall / autumn. The “house” lines I drew in later, dividing them into arbitrary 2’ sections, for an 8’ tall wall. I drew in the window too. I planned to measure everything after I finished, to get the final heights and placement of the windows.



Source: <http://www.dynapod.com/protractor2.jpg>

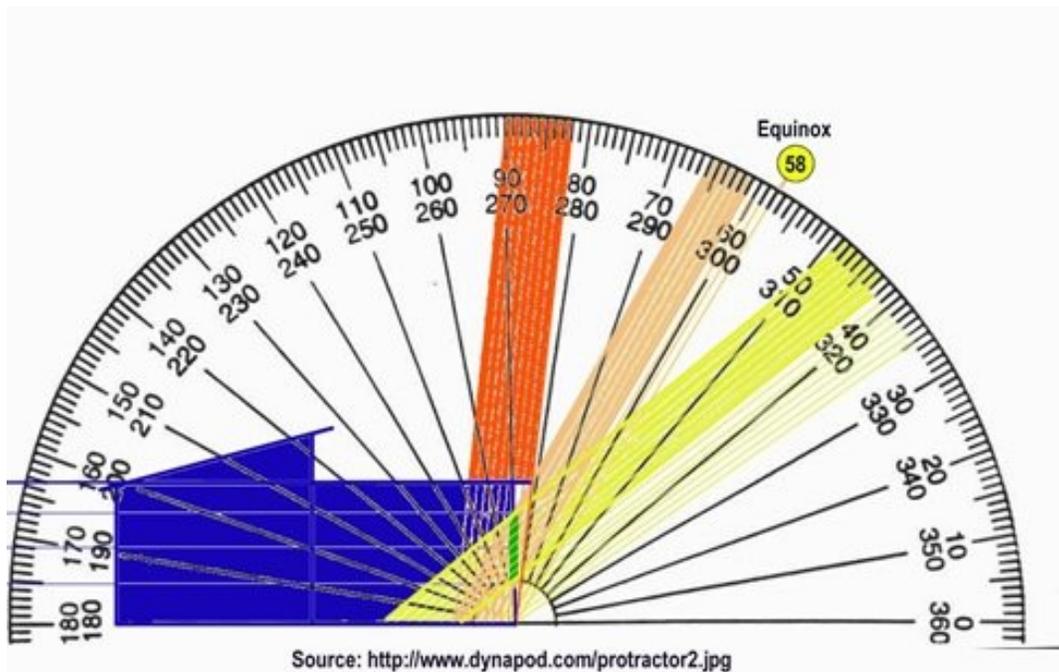
Note: The way I drew this was simply convenient at the time. You may find that another way is better.

I kept ALL lines parallel since the sun shines in parallel rays.

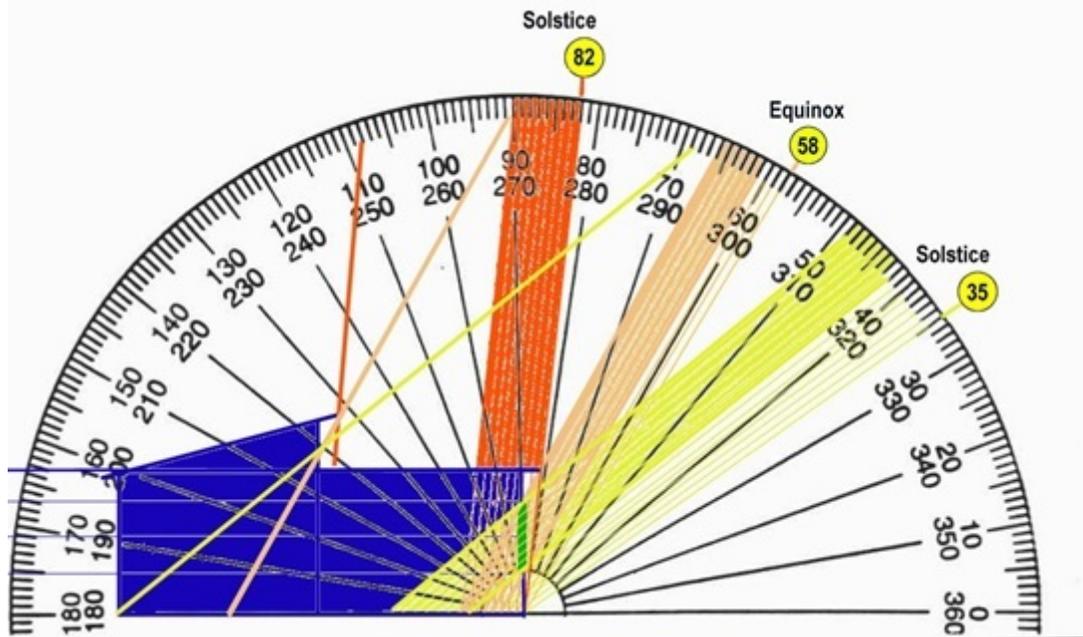


Next I filled in the colors to make it easy (since this book is in black and white you will only see shades of grey-black) and added a shed-style roof on the back half of the house, with clerestory windows at the top so sunlight could enter that portion of the house. You will need to draw your own house design. Again, the height was arbitrary,

and if I had wanted I could have made the pitch of the roof higher, or lower, depending on preference.



As you can see below, the exactly determined overhang length shuts out ALL of the summer (top) sun's rays, while letting in some of the middle (fall / spring) and all lower (winter) rays. I used the graph paper to align the same angled rays for the clerestory window (upper level window in rear section of house).

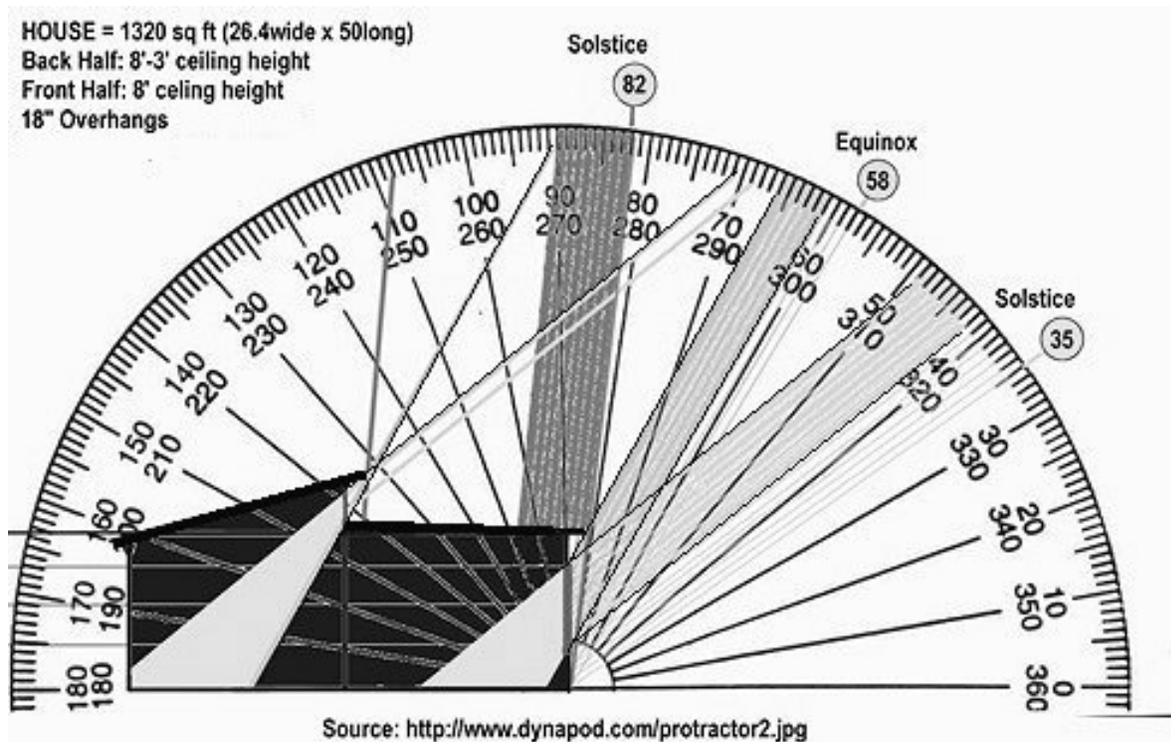


Source: <http://www.dynapod.com/protractor2.jpg>

Below is my final product (minus fixing the FLAT roof to have a small pitch of $\frac{1}{2}$ "-1' (a half inch drop for each foot of length) minimum so rain would not puddle and cause leaks), showing exactly how much sunlight will enter the house over the period of 6 months (solstice to solstice) and back again.

You can take the square feet of sunlit area (perhaps 1' wide strips) and work backwards to obtain the 7% NET amount of sunlight needed, or you can determine how much window area you need based on the square footage of your house, and figure out how many windows, and of what size, you will need to obtain the 7% NET.

Remember that if you want to add more windows you must also add more thermal mass (interior walls are best) or you risk overheating.



Do not be surprised if you have to do this more than one time as you get better and better and seeing the “little things” that need to be changed, or that you want to add on, or take away. Overall it is pretty easy though.

In the meantime, you now have the tools and greater understanding for designing our overhangs so that you can design your own home’s eaves to the right length to accommodate the sun’s angles between the season extremes.

There is one other way to create a general overhang calculation using Edward Mazria’s overhang calculation from his book: *The Passive Solar Energy Book*. He wrote it back in 1979, and he provided a formula to calculate for overhang distance based on latitude. However, I do not suggest spending any extra time to seeking it out as the formula is vague and does not provide enough information on measurements or details to adequately use the formula. Chuck Reel and I both have found it confusing to use, as well as others I have asked. Visual aids typically help me most, and so it is with a lot of other people; hence, the old fashioned paper and protractor method.

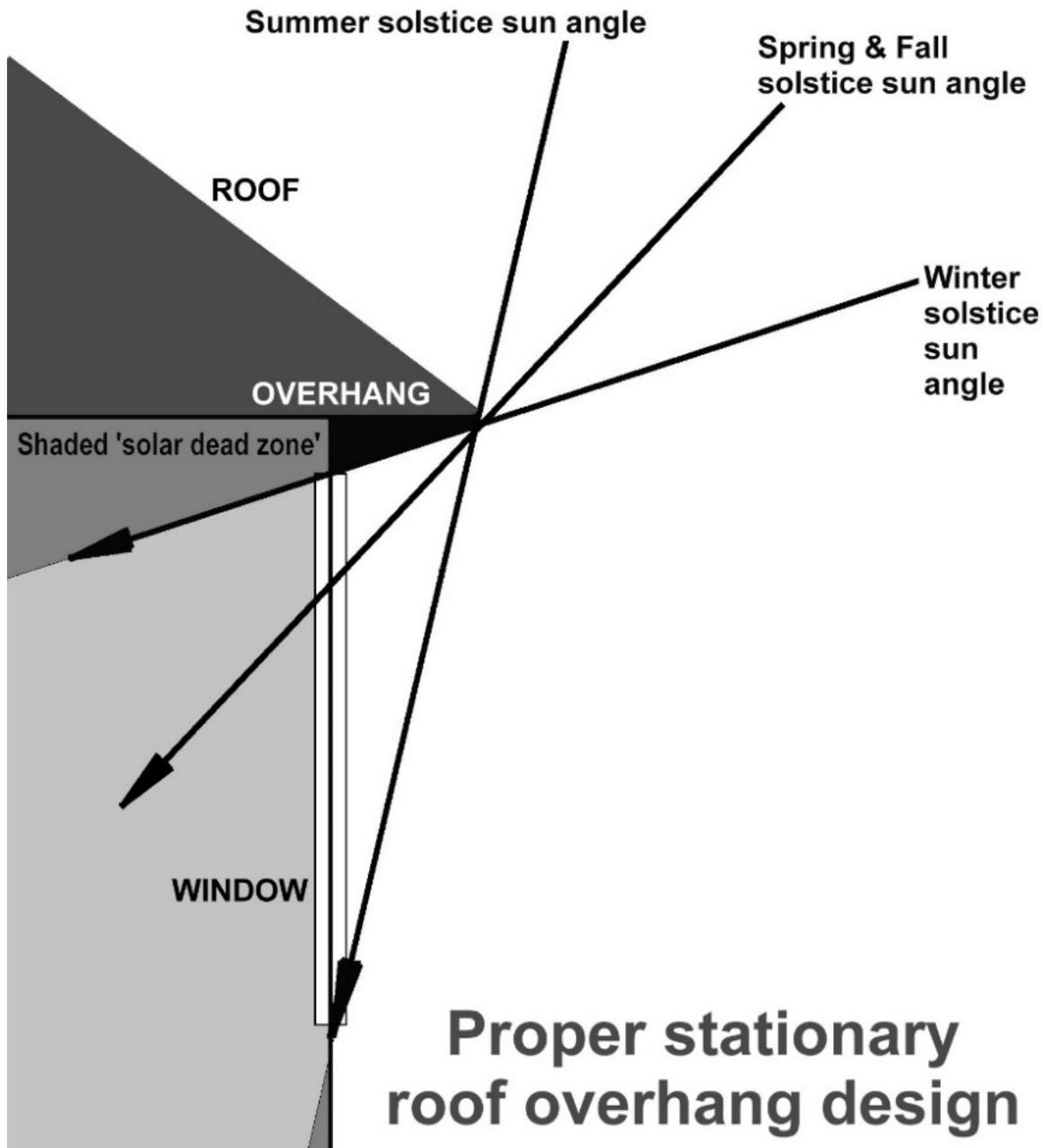


**South facing windows in
relation**

to the overhang:

**Winter solstice sunlight
should reach the top of the
(highest) window, and
summer solstice sun should
stay outside of the very
bottom of the (lowest)
window.**

A properly designed overhang should determine exactly where to place the tops of the south windows (usually a foot or two below the soffit edge) so as to avoid the shaded 'solar dead zone' mentioned earlier. Otherwise, you may get unwanted shading or sunlight on the glass at inappropriate times (and a cold house in spring / autumn, or other times), so be careful. Drawing the image and sun angles on graph paper as I described previously would solve this problem.

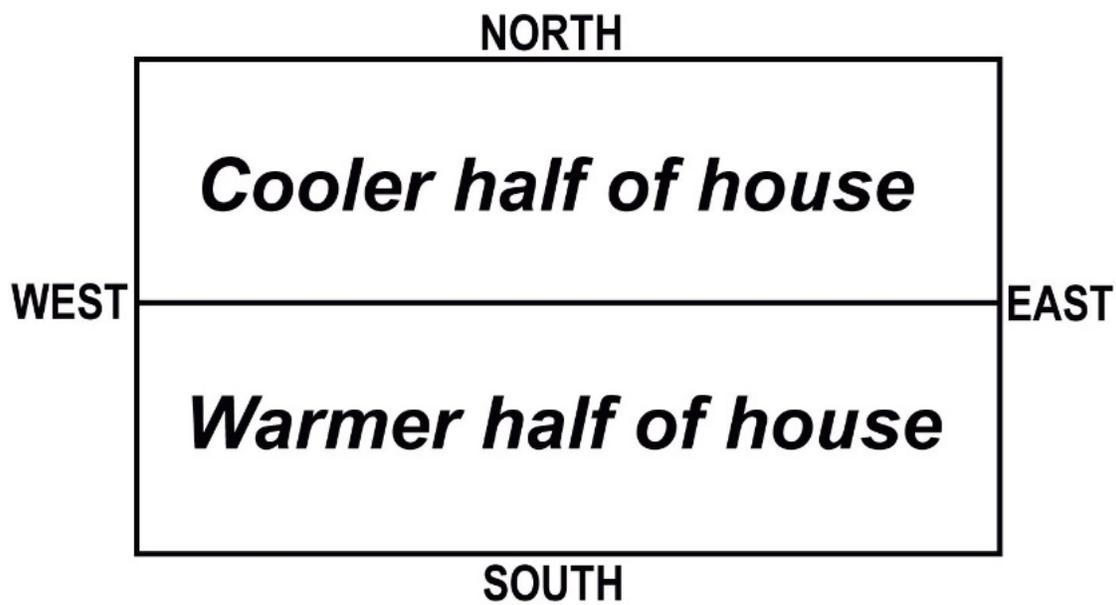


If you are not sure about designing the overhang yourself you can always go to plan B and hire an architect or draftsman / draftsman with AutoCAD software can help you with this calculation. If nothing else, they can double check your numbers.

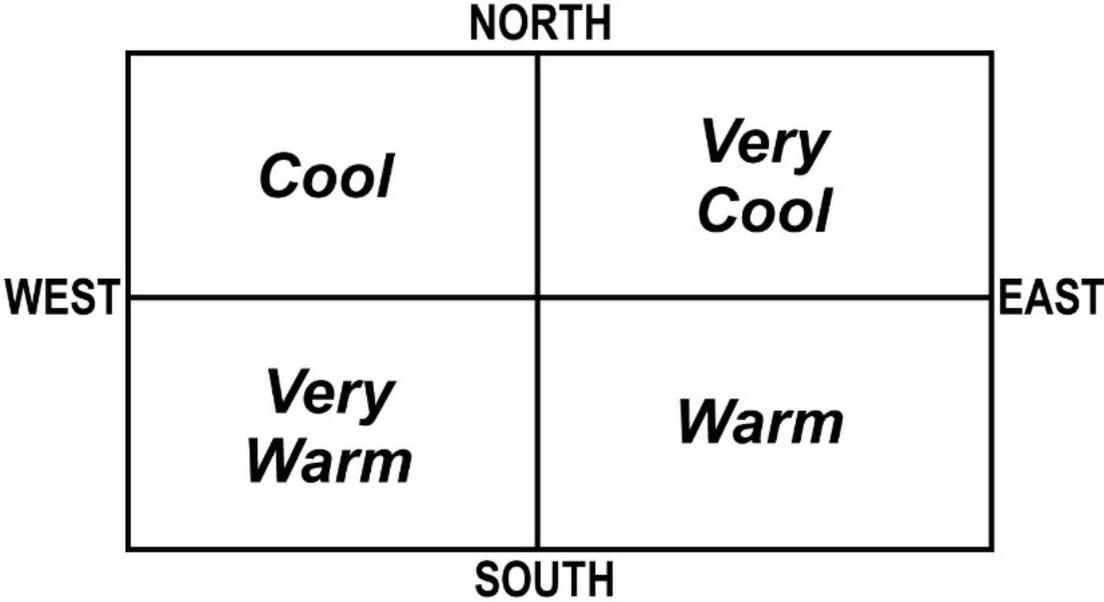
FLOOR PLAN DESIGN

This chapter covers details for how to design your own floor plans (it does not provide floor plans as most people prefer to find their own) for the home you might like to build / have built. Sometimes you can take a pre-chosen floor plan (example: standard home that has more windows one side) and just flip-flop it, or turn it 90 or 180 degrees or so and find that it works fairly well for solar orientation. Sometimes you can make adjustments too; an architect or draftsman may be able to help you. There are also a ton of passive solar floor plans online, and some are even free! Everything from contemporary to modern to round houses, and even tiny house plans are available.

If you are starting from scratch and want to draw up your own floor plan, however, just remember that the warmest side of the house is the south side (thanks to the sun); the coldest is the north (thanks to the shade from the house itself). You can use these features—and others I will explain below—to design your own home/floor plan.



It is time to think about the sun for a minute. Which is warmer, the early morning on a summer day, or just as the sun is setting? In the evening, of course. This is because the sun's energy has been captured by the planet's atmosphere, bodies of water, the earth, and even your house. Where a summer day might start out comfortable, by evening it is typically HOT outside, and so not only with the southern side of the house be hotter than the north (due to solar energy hitting the southern wall), but the western side of the house (unless shaded extremely well) will also be hotter than the east (which will be in shade by evening). Therefore, we can extrapolate that the warmest corner of the house at any time of year will be the southwest (SW) corner, so placing main living areas here would be wise. The coolest corner would be in the northeast (NE)—kitchens generate their own heat due to appliances (refrigerators stay warm on top) and use of those appliances (ovens, stoves, etc.) so placing kitchens here is best.

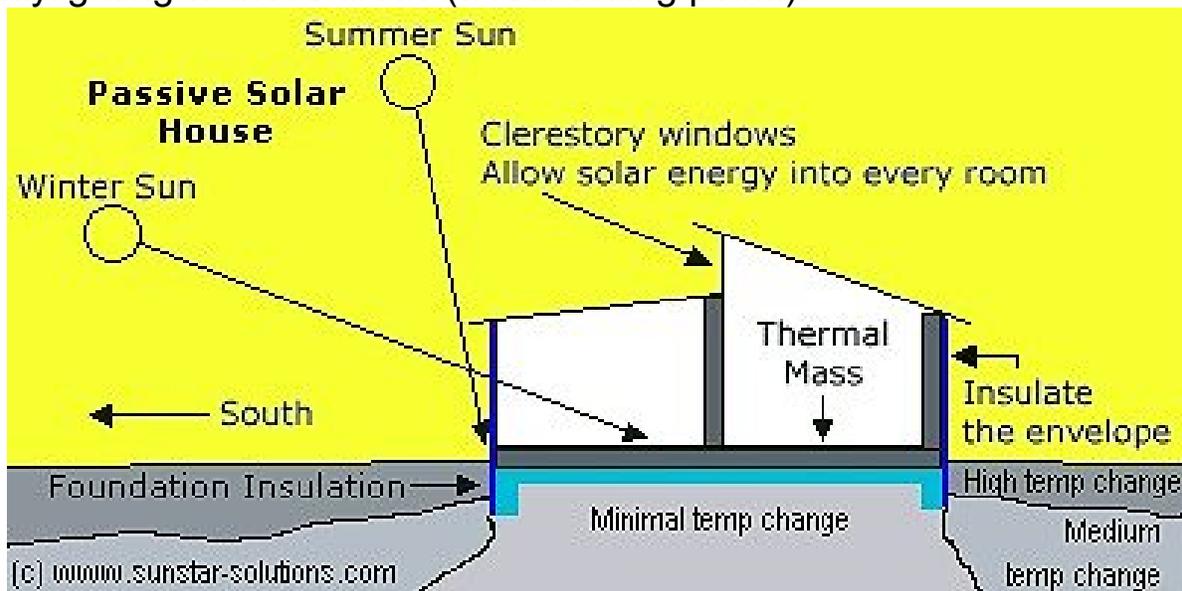


Closets and bathrooms, entryways, utility rooms, pantries, laundry rooms, and storage areas are excellent for the north half of the house. This is because they each serve as a type of “buffer area” and do not always need to be heated, or else are not “lived in” spaces, so placing them on a north or west exterior wall can be a good idea. Bedrooms

also go well against north walls because people tend to sleep better in cooler rooms.

Communal living spaces, such as the living room, dining room, or family room are better for the southern half of the house. Some people also like to put their master bedroom here.

You may add in some clerestory windows (these are very high—above viewing range—short but very wide windows) to the north half of the house; doing this will bring additional sunlight as well as natural daylighting to these areas (a real selling point!).



Clerestory windows allow sunlight in north half of the home

BEST ROOMS FOR SOUTH HALF OF HOUSE:

(places where people gather / live)

- Living room
- Great room
- Dining room
- Master bedroom
- Den
- Home office (if used a lot)

BEST ROOMS FOR NORTH HALF OF HOUSE:

(places that are not “lived” in)

- Kitchen
- Bedrooms
- Utility room

- **Walk-in pantry**
- **Laundry room**
- **Entryway**
- **Mud room**
- **Storage room**

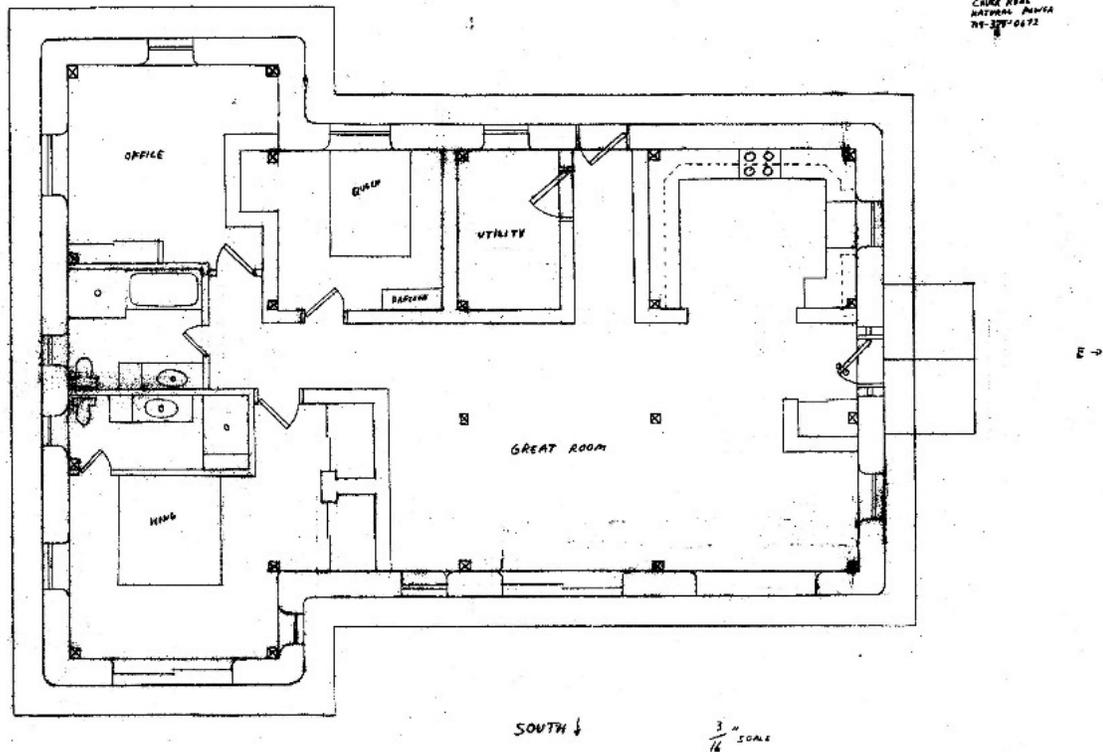
It is very simple really. Living and dining areas (or bedrooms) go on the south side, and bedrooms, kitchens, and buffer areas go on the north side. You now have some basic concepts in your solar home design toolbox that can help you design a floor plan of your own. Now, when you fish through a book full of sample floor plans, or create your own floor plan using graph paper, you will be able to quickly spot which ones will work best for you for solar gain, or which ones will be disastrous when it comes to your heating / cooling bills! Remember, you can rotate or flip flop or mirror many floor plans to make them suit your needs. Energy efficiency and thermal mass and other solar features can be applied to many (if not most) floor plans as long as there are the proper amount of windows (glass-to-mass ratio) and the home is oriented correctly.

There are many, many websites available these days that have passive solar floor plan designs, or that can be adapted for such, and some of these sites are even free or inexpensive to purchase the floor plan of your choice. Look, look, look! Once you know what your site can accommodate, you will know what your house needs, as well as what you want.

There are even plans that use alternative construction methods and materials, such as for hempcrete houses, adobe, rammed earth, papercrete, fidobe, earthbags, earthships, and more. Green home construction design (which I cover in my other book, which is intended to go along with this book on passive solar home design) means building ecologically sound homes that reduce the impact on the environment. The great thing about green materials is that sometimes it means you are not buying new or expensive materials, but instead are buying used materials, which are a fraction of the cost of new. Plus some used materials can be gotten free!

Floor plans that account for the extra thick walls of adobe homes, or straw bale houses, can be found online as well. One of the most

energy efficient and simply-made passive solar homes (that is also 90% energy efficient) that I know about is the one designed by Chuck Reel with extra thick walls, which you have learned about in this book.



Because of the vast amount of architect services, residential drafting (technical drawing) experts, companies that specialize in providing floor plans, and websites that sell downloadable floor plans, and so on, I am hesitant to recommend any particular companies with floor plans or service providers. The advice I can give is to ask around—word of mouth will usually find you reliable deals, professional companies, and trustworthy sources. Check on google and watch company ratings (including Yelp)—many people obtain great floor plans from online sources these days, and some of them can provide the blue print as well (for a fee). Really, you just need to find that ONE floor plan that will work for you, will suit your site, and will fit your personal style and desires, and especially supply your needs. Floor plan design or shopping is a very personal endeavor, so go about it carefully and with enthusiasm, and try not to lose steam by the time

you have looked at 100 or even 1,000+ floor plan designs! You might find the one you like right away, or maybe you already have it in hand.

Really, even if you are drawing up your own basic floor plan, you can borrow ideas from professional versions. Then you can take your own ideas as a simple drawing on graph paper and pay a professional residential draftsman to draw it up, or ask the drafting teacher at the local community college if he can recommend a student or someone who can draw your floor plan as a full-size blueprint at a discounted rate. Either way, in the end, you will have a blueprint of a floor plan of your choosing that you can take to the planning department of any city / county so the building permit process can begin.

Passive Solar Floor Plan Design Features

Here are some tips and design features to consider when choosing or creating a floor plan for your passive solar house. Recall that the longest elevation of the home should face as close to solar south as possible, which provides more area for window placement, and therefore improves solar gain. Facing the main wall of your house in a southerly direction also aids in controlling or optimizing gains as your overhang and shading mechanisms can be put to use.

A slab on grade type of construction (versus a basement) allows absorption of solar gain directly into the slab for easier passive heating. The best part of a slab on grade house is that you do not need to add as much additional thermal mass when the slab (which is already there anyway) acts as your main thermal mass source. This feature alone can improve the heating and energy storage capacity of the home without additional cost, and it can save on energy use for heating the home, especially when the slab is properly insulated (such as with a raft foundation or Shallow Frost-Protected Foundation). The slab will absorb the sun's energy in winter when you need it most, and release that heat at night. During summer the same thermal mass slab will help keep the home cool.

Waste pipes are placed in the slab, otherwise all domestic hot water (DHW) heating pipes should be above the slab, inside the home's interior. This makes it easy to repair or alter later on, and the

pipes and hot water tank should be insulated. According to Don Roscoe, you can also place all electric and plumbing lines through 2" conduit to route it through walls or in the slab (also, tech cable can be run through 3" conduit).

Be sure to allow the sunlight to shine directly onto your thermal mass floors. If you cover up a thermal mass floor (such as a slab on grade) with insulating materials such as a wood floor, laminate flooring, carpeting, linoleum, vinyl flooring, or other insulating floor coverings, then you have just defeated the very purpose of having a thermal mass floor! Do not cover your thermal mass with these insulating materials (the same could be said of interior thermal mass walls—placing sheetrock over a brick / rock / block wall reduces its ability to work for you). Consider, at least for sunlit areas, using a dark (dark absorbs, light reflects) matte finish (shiny reflects) style of tile, brick (herringbone patterns are particularly nice), colored and/or stamped cement / concrete, rock or slate, or a host of other thermal mass flooring types. If you do not want your feet on a hard surface, then put down a few throw rugs here and there, or wear slippers, but do not destroy the thermal mass qualities of your floor as that would defeat the purpose of the energy efficient design.

Mass walls should be PERPENDICULAR to insulated walls to keep that heated mass as far away from the exterior insulated walls as possible (thus losing the minimum amount of heat to that wall). Chuck Reel did this: "We ran 2 barb wires down the mortar joint of every 4th course of the adobe walls and then up the straw bale walls and attached them with Robert's pins to have a secure connection between the 2 different types of walls so they wouldn't crack. To this day 12 years later we have never had a single crack where adobe walls meet straw bale walls."

Use the 7% glass-to-mass ratio rule for windows to floor area for the south side, with an additional 1 sq. ft. of south glass for every: 5.5 sq. ft. of sunlit thermal mass floor, 40 sq. ft. of floor not in direct sunshine, or 8.3 sq. ft. of thermal mass wall. The maximum amount of sunlit floor is 1.5 times the south window area. The recommended maximum amount of south glass for direct gain is 12-15%.

For people who wish to grow old in the house they build, there is a concept of “aging in place” as a design goal, which means that your main floor of your home is one level (flat) and should be handicap accessible. When held to the legal / federal requirements for accessibility, it also offers your home an improved value and selling point should you ever need to sell the home later by implementing the proper width of doors, safety bars in the shower and by the toilet, height of sinks, etc. The goal of this ‘aging in place’ design is so that living on the first floor of the home becomes possible whether you are (or someone you love is) in a wheelchair, cannot climb stairs, or needs aid.

Design the home with four bedrooms (and utilize zone heating) to accommodate visits by family and friends, and use an open floor plan for the great room, which consists of a combined kitchen / dining / living area for gatherings, entertaining, kitchen parties, watching movies, eating meals together, playing games, or just sharing space. Many people tend to spend the majority of their time in the main living space and preparing and eating food—with three meals a day, this makes the kitchen and main living space the most frequented (and for the longest duration) areas in the home.

Consider implementing the Passive House standard for your home design, which costs more, but also saves money for the lifetime of the house in heating and cooling bills. Additionally, Passive Houses might cost more, but they do not need a HVAC ductwork system or furnace, which can save \$10,000-40,000 off the top (so the money can go into making the home energy efficient instead). Instead of furnaces, these superinsulated homes rely on ductless mini split heat pumps to aid in heating the already energy efficient space. I would also suggest that if you do not use a slab on grade, that you incorporate more thermal mass (interior walls are fantastic for this) into the home to ensure a more even temperature, which is especially important if you live in extreme climates (very hot deserts, or very cold places). Thermal mass is your temperature stability.

In a Passive House or very well designed passive solar home, point source heating may be used, meaning a 9,000 Btu/hr ductless mini-split heat pump for the first floor space (heating and cooling). A

second unit should be placed above the stairs landing of the first-to-second floor for conditioning the air on the second story. If two ductless units are not desired in a two-story home, then a single ductless unit may be installed (perhaps in a utility room) that provides conditioning to both floors. Make sure that it is installed centrally in the house.

North facing walls should include rooms that are only used part of the time, such as bathrooms, additional bedrooms, walk-in closets, utility rooms, mud rooms, entryways, pantries, or similar rooms. Keep windows on north walls at a minimum as they do not gain heat in winter, but do lose it; this will reduce heat loss and save energy.

The main living space should be on the south wall. This area will be warmer than back bedrooms because of the direct solar gain.

Bedrooms should have two windows, preferably on different walls, which allows for cross ventilation when the windows are open (the exception might be in a Passive House design, which is intended to keep windows shut the majority of the year).

If bedrooms are on the second floor, you can place the laundry room there (reduces accidents in carrying a laundry basket downstairs) or you can make a laundry chute from the upstairs bathroom drop directly into the laundry room below, if designed that way. Otherwise, a first floor laundry / bath may have a clothes washer and dryer placed in a 'drying closet', which is a space with louvered doors that facilitates drying of hanging wet laundry. Generally this room should be ventilated using a heat recovery ventilation (HRV) exhaust. This reduces the cost of drying clothes in an electric or gas dryer. Any conventional clothes dryer acts as a thermal bridge since it produces heat loss to the outside (alternatively, venting into the interior can cause moisture build up, overheating, or cause VOCs (volatile organic compounds) air toxicity from dryer sheets, which is not healthy to breathe (source: INDOOR AIR QUALITY: Scented Products Emit a Bouquet of VOCs, by Carol Potera (2011), <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3018511/>). Ventilating naturally and free via a 'drying closet' and passive HRV (which provides 70-92% heat recovery compared to a venting exhaust fan) is a gentle way of drying

clothes by hanging them inside the home, out of the weather. Or you can also use a 'solar clothes dryer' (a clothesline) in summertime.

Although a fireplace is 90% inefficient (a woodstove or insert unit is far more energy efficient), all combustion devices should have a combustion air tube that provides fresh air to service the flame. This way your indoor air temperature is not compromised since fire feeds off the air around it in order to burn; allow a fresh air tube to supply what it needs to combust rather than your already-heated indoor air.

In some areas of the country (whether the US or Canada) radon mitigation is required, as is the issue of proper air ventilation for indoor air quality; consequently, their requirements can be combined and used with an HRV or MVHR (mechanical ventilation heat recovery) unit to ensure that radon does not build up inside the house, while reducing heat loss at the same time.

Unless radon and/or HRV or MVHR systems are required for ventilation in your area, you can also use vents in the bathrooms (can empty into the attic that has continuous ridge vents and continuous soffit vents). Also, place a vent over the stove (in Chuck Reel's house design this "goes up about 3ft and then sideways for about 7ft to go out under the back 10 ft porch's ceiling of rough sawn lumber"). The vents are used when taking showers or cooking, otherwise there is no venting happening unless a window is open. A woodstove (or pellet stove / wood-burning fireplace) also acts as a vent whenever a fire is burning (less so when you bring in fresh air through a combustion air tube to the front of the woodstove).

Place floor drains in all rooms that use water—this means kitchens, laundry rooms, bathrooms, or utility rooms with sinks, etc.

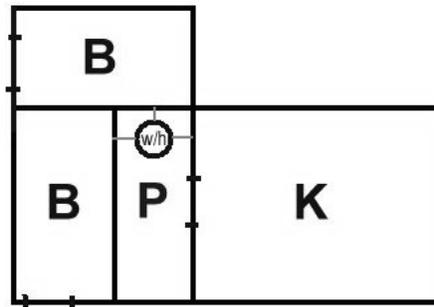
Keep Plumbing Close Together

If you enjoy drawing floor plans (or shopping for them) try to keep your plumbing for sinks and drains close together (between kitchens, utility / laundry, and bathrooms) to save space and money. Ideally, you would place plumbing fixtures on adjacent walls so you do not have to pay to run extra plumbing pipes half way across the house in order to get water to the other side.

Additionally, put your water heater (w/h) near the kitchen / bathroom area as well so you do not have to waste water down the

drain while you wait for the hot water to show up at the tub or sink faucets. Water waste because of poor design is one of the most easily remedied parts of designing floor plans.

Below is an image of an example of how you can cluster your rooms that utilize hot water so as to save on plumbing costs and water heating bills and reduce “stranded water” issues.



**Plumbing-centric design by clustering rooms
(bathrooms, pantry with w/h, & kitchen)**
(plumbing core shown only, not entire house)

In this case, the water heater is placed in the pantry and is central to both bathrooms and the kitchen. You can also use tankless (on demand) hot water heaters that heat water using electricity or gas at the point of use. When the tap is turned on, the hot water is made instantaneously on location and stops heating the water as soon as the tap is turned off. This saves about 24-34% on energy for heating water according to ENERGY STAR® estimates because 40+ gallons of water are not being heated 24/7 just so you can have a hot shower once a day or turn on the hot water faucet occasionally. However, these point of use water heaters are small and generally will only supply hot water to a single sink or device / plumbing fixture at a time (hence, point-of-use). The larger ones can be fairly pricey.

Another option is to use a solar pre-heater for your water, or tie in a backup system such as a woodstove for aiding hot water heating. You will need to think about these designs as it relates to your floor plan ahead of time so you can incorporate these features into your plan. Also, if you choose to have any solar water pre-heating done via

the roof of a shed or outbuilding for other purposes, then designing your site for these additions becomes imperative.

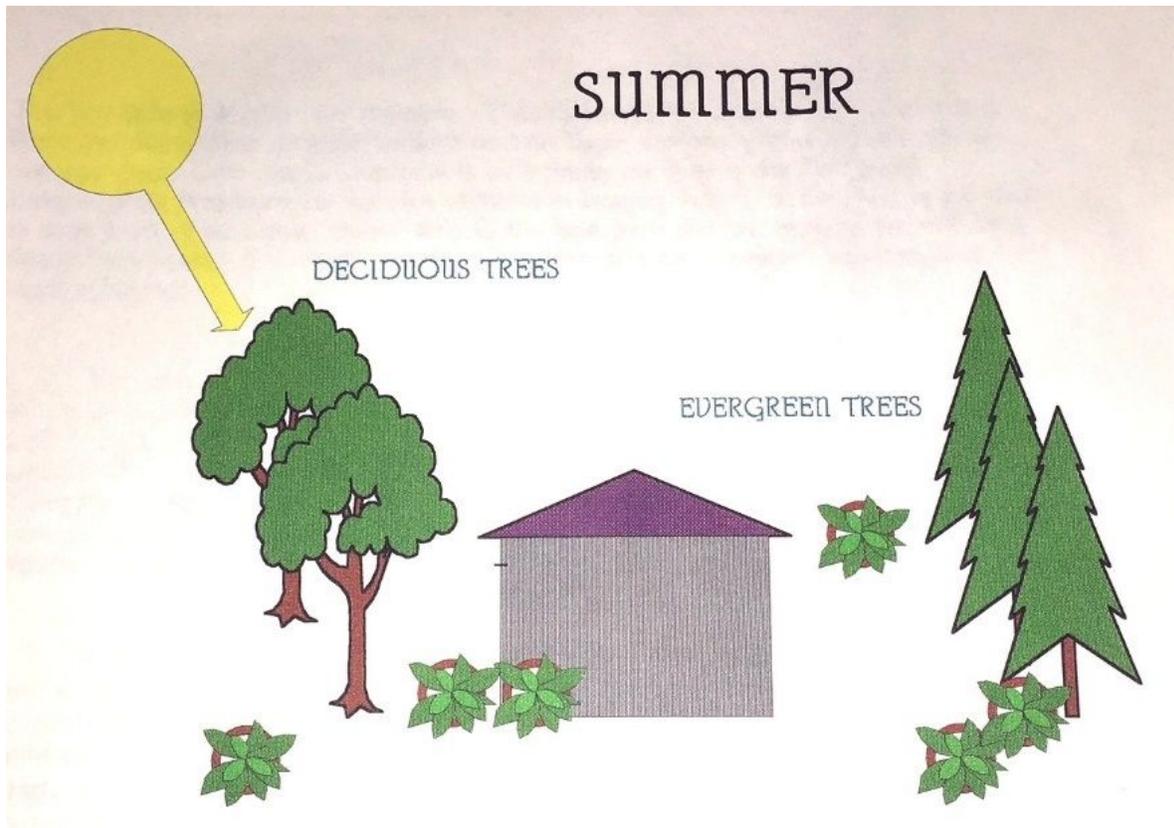
LANDSCAPING

Landscaping can help you with your passive solar design. Solar gain means heat energy, which is absorbed through your exterior walls, the roof, and especially through windows in summer (if they are not shaded by a properly designed overhang) as well as skylights. Incorporating shading methods for these areas in summer can help reduce your cooling load. Plants and trees have leaves that participate in cooling due to evapotranspiration (how a plant moves / releases water vapor), which can lower the surrounding air temperature by up to 6°F (3°C). Recall that since cool air falls and hot air rises, the cooler air will be found nearest to the ground in the shade. The air can be cooled further by the use of water (ponds, fountains, or other water features).

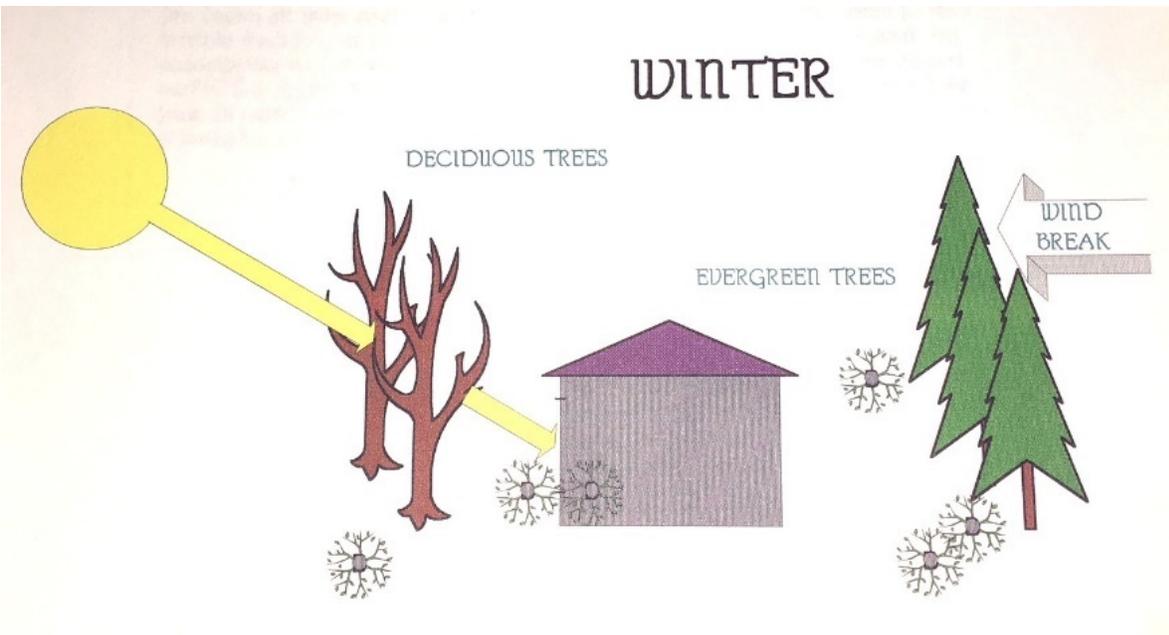
The hottest air will be above the roof (especially dark-colored roofs) and the blacktop, over rock beds (again, darker will be hotter than lighter colors), which means you can purposefully arrange a “sun trap” for desert-loving cacti and other dry-climate loving plants by utilizing local materials and arrangements. For instance, in a non-arid climate a south-facing light-colored wall facing full sun, with a v- or u-shaped area (open end of the “V” or “U” facing solar south) made with rocks and bricks, or well-drained sandy soil, or such would make a good heat-producing microclimate for growing your favorite cactus or asparagus.

Shading your home is dependent upon the types and size of your trees, as well as the size, shape, and height of your home. The shadows of trees also move throughout the day, and elongate at sunrise and sunset (albeit briefly). Cool regions in full shade from trees, hills, or mountains will be difficult to warm in winter if the sun is below their tops. The only plus to homes in these areas is that they

will probably never overheat if they remain shaded throughout the summer. Pay attention to landscaping, and what you might need to alter to produce the effect you want or need, based on your local climate and microclimate.



Trees can be planted as 12” high saplings as a relatively inexpensive investment, but they take time to grow if you get them that young (yet still worth it in the ends). If you can choose trees that will still function for the purposes you need then you may wish to choose fruit trees over non-bearing trees, because... fruit! Cherries, apples, citrus (in hot-humid climates), pears, peaches, plums, and even nut trees can provide not only summer shade, but free food that can be eaten raw, traded / bartered, given as gifts, sold at your local farmer’s market for extra income, baked into delicious desserts, or canned or frozen for later use. Alternatively, staggered rows of evergreen trees produce a wonderfully effective wind break during winter when the winds blow hard.



Grow deciduous trees (trees that lose their leaves in the fall/winter) on the south side of your home if desired, but not too closely to the house. Deciduous trees also do well on the east side of the house.

Grow evergreen trees (usually in three alternating rows) no less than 25' from the west and north sides of your home. This will shade that horribly hot west sun from overheating your house during summer, and will cut down the winds that will rob your house of its heat during winter. If your particular area has winds from a certain direction, then you'll want to plant evergreens on that side of the house too, to form a wind break, but not too close or you might ruin your direct solar gain!

For summer-only shading purposes, choose deciduous trees that have high, spreading tops and plant them on the south side of the home to help shade the roof and south wall. Trees that have lower crowns are more suited for the west side of the home to block the lower angles of the hot late afternoon sun. Typically trees are not planted on the south side in colder climates as the tree trunks and branches (even without foliage) can cause a reduction in solar gain.

Slower growing trees take a long time before they shade your roof, but they also live longer, so will provide shade for many more years in the long run, plus their roots and branches tend to be deeper and

stronger—less breakage, less potential for damage during storms. Slow-growing trees are also more resistant to drought than their fast-growing cousins. You will want to plant the trees away from the house so the roots do not cause damage to the home's foundation. A 6'-9' (2-3 metre) tree will be able to start providing shade as early as the first year, and within 5-10 years should be able to shade the roof, depending on the house and the tree species.

A combination of groundcover plants, shrubs / bushes, and a variety of trees will be able to shade the pavement area and ground around your house, which cools the air and reduces the radiating heat before it enters your home through the windows and walls. To shade your driveway, create a line of low shrubs or a large bush. Hedges help shade sidewalks, whereas vines on a trellis / lattice or planter box will climb and help shade and cool a patio or exterior walls their first year. Whether it is vines or shrubs, be sure that they do not grow too close or densely against the home as higher humidity and dampness (especially after rain) could cause issues, so keep your yard landscaped and trim around the house. Wind should be able to pass around and through these areas, and ensure that the soil near the house stays relatively dry.

Proper landscaping saves energy and makes your home more comfortable. It is a great way to let nature work for you as you adapt to the local climate. Using native species is the ideal situation as they are already adapted to that climate and require less upkeep once they are established. Watch out for invasive species such as Japanese knotweed (despite their amazing medicinal uses) they can take over an area and even cause damage to the home and foundation.

Windbreaks

Nothing can rob your home of its heat faster than a bitter winter wind! It literally sucks the heat right out of the house, and then you have to crank up the heat to compensate, eating more fuel just to stay comfortable. A windbreak can help reduce the wind from stealing your warmth (and money) and pay for itself many times over in the long run. The landscaping for a windbreak must be carefully selected trees, bushes and shrubs, placed in a particular arrangement to break the wind at low, medium, and high levels. The value of these plants increases as they grow and protect your home. Heating costs are reduced through the process of the windbreak lowering the wind chill. The wind chill is what it “feels” like, based on temperature and wind speed and the resulting heat loss on exposed surfaces (your skin, or the “skin” of the house).

A properly designed windbreak will lessen the wind speed for as far as 30x (distance) as the height of the windbreak; however, you will need to place the windbreak away from your house about 2-5x as far as the height of the trees (at full growth). So a row of 100' tall trees should be placed 200-500' away from the home. Tree types and heights can be staggered as well as positioning their rows. Winds should break first closest to the ground, so a row of shrubs, should be followed by a row of bushes, and then at least a couple rows of dense evergreen trees. Berms made with earth can also help deflect the wind. Placing windbreaks on the north or northwest sides of the home is most common, but be aware of your local climate and terrain as to where windbreaks should be planted. Do not place windbreaks too close to your home on the south side if your plan is to have solar access as it could block the sun to your home.

Snow drifts can be slowed by planting small shrubs on the windward side of the windbreak. They will trap the snow before it has a chance to blow close to your house. This serves the same purpose as a snow fence, but is natural rather than manmade, and potentially will last longer.

Where windbreaks are placed at a distance from your home, vines, bushes, and shrubs planted near our home can create a dead

air space that will help insulate the house through every season (however, deciduous plants lose their leaves, so may lose much of their insulating value as well). Plant these so that—once grown—there will be about a 1' (30 cm) space between the plants and the wall. During the summertime, particularly at night, these plants can aid in cooling if you are opening windows for natural ventilation and the cooling effect. Many people will open windows for a cross-breeze at night, which cools the thermal mass inside the house, and then close everything up (including shading any direct gain windows) once morning comes. This works well in summer to keep the house cooler once it warms up outside, and also on too-warm days in spring and fall.

CHECKLIST: DESIGN BEFORE BUILDING

Once you have ideas about what kind of building style and materials you have in mind, it is time to think about constructing your home. You will need a written plan, including a floor plan. Here is a list of things to consider, which you could use as a type of checklist or way to organize your thoughts and plans.

Professional Help

If you are an owner-builder, it is highly recommended that you have at least some basic construction skills by volunteering, working, or doing smaller practice projects such as building a shed as a miniature concept of your house, or even better... take courses or go to a building school to learn the trade. Although it will benefit you, it is not required—we did it all by sheer will and lots of preparation and learning but without a school since we used alternative construction methods, which are not taught at most schools. There are plenty of weekend workshops and alternative schools, however, usually for specific types of building (hempcrete, earthbags, straw bale construction, etc.), plus tons of online resources (free videos, in particular—one guy I heard about built a tiny house by watching videos on YouTube—I am not suggesting you do this, but it has been done). Even if you are an owner builder who is capable of doing most or all the work yourself, there are sometimes occasions that arise where the help of a professional is needed. This is true in regular life circumstances, emergencies, as well as when constructing your house. Also, ensure you have the time to devote to your project—it can take a year or two of your time, or much more if you do it part-time or on-and-off.

I have seen some owner-builders start out building, and then something happens (illness or accident, etc.) and they have to hire a GC (general contractor) to do the rest—the GC will oversee the project from beginning to end, including hiring sub-contractors (electricians, plumbers, framers, drywall installers, tilers, etc.). There have also been the opposite cases, where the GC was hired to build and something happened to the company, leaving the homeowner / land owner high and dry and with a house that was started but not finished—in these cases sometimes the owner takes over and does the rest of the work themselves wholly or in part. Always make a Plan A, B, and C, just in case of unforeseen events. These are usually “what if” scenarios, but make sure to write them down as a back-up plan.

When we built our passive solar straw bale house we did most of the work ourselves, plus occasionally had volunteers, neighbors, and friends and family that helped, but we were required by law to have the electrician inspect and then sign off on the work my husband did to run the electric wiring in the house. Also, after we had a workshop—and attendees who wanted the hands-on experience helped us build half our walls in one day—the weather turned sour soon after we got the rest of the walls, the trusses up and the roof on, so we had to hire a professional plastering company to come in and finish plastering the exterior of the exposed bales. They were able to finish the last coat just as the snow started falling! So plan ahead and set aside a certain percentage of your money for emergencies or certain situations like these. Examples could include contracting companies, sub-contractors, independent contractors, or professionals for:

- Building permits—talk with the local planning department to see how many you need for your project, and how much it will cost. Apply for them (sometimes a form and / or map or floor plan is required) before you start construction. This process can take a few hours, days, or even weeks, so be sure to ask how long it will take
- Excavation company, tractor, bobcat, or other heavy equipment for digging trenches or foundation work
- Concrete mixing and pouring for pads or walkways, footings, foundation work or other projects
- Plumber for underground or in-house plumbing
- Electrician for running electricity, panels, etc.—some laws require they do all the work, or part of the work, or sometimes you can do the work and they can do an official inspection and sign off on the work if it is correct (or they will tell you how to fix it before they come re-inspect it)
- Tiler for floors, walls, showers, countertops, etc.
- Flooring installers for special flooring that is outside of your expertise or ability (carpeting, wood floors, etc.)
- Landscape architect
- Any other professional work that is needed, which you need to hire out for

Floor Plan & Features

As mentioned previously, you can get a drafter / draftsman / draftsperson / drafting technician to help draw up your floor plan into blueprints, and if you are on a budget sometimes drafting students at a university or community college can do them fairly inexpensively (the professor can double check the work and you save a few bucks while the student gets the extra practice and real-world experience). You can also hire an architect, but they can actually do the house designing for you, including the floor plan blueprint and the finite details for construction (loads, strength of materials, etc.), including providing a materials list, but it is more costly than doing it yourself.

There are a ton of websites and magazines and other sources for obtaining floor plans that you can look at (literally many thousands can be viewed free online), which your draftsperson or architect can use to make the drawings for you. Owner-builders do not always need blueprints, however, but some contractors require them, or the city or codes might require them for permitting (sometimes hand drawn pictures or drawings on graph paper are enough, as long as the measurements are accurately portrayed). Here are some things to consider...

Floor Plan Considerations

- How many **bedrooms** do you need?
- How many **bathrooms** do you need?
- Do you want a **garage or workshop or carport**?
- Do you want an **eat-in kitchen or formal dining** area?
- Will the **living area** be a great room or will the kitchen be a separate room?
- Do you need a **pantry or walk-in closets**?
- **Patios, covered porches**?
- **Tub or walk-in shower**?
- Are the bathroom and kitchen **plumbing** close together?
- Tanked or on-demand **water heater**? (compare life cycle costs and operating costs)
- **Back-up water heating** system, such as a solar or woodstove or rocket stove hot water heater?

- **Furnace, heat pump, or alternative heating** source?
- **Back-up heating source(s)**?
- **Cooling system(s)**? (air conditioner, heat pump, earth tubes, earth berming, etc.)
- Whole-house or other **water filtration** system?
- List **kitchen and bathroom** preferences (cabinets, counters, islands, sinks and faucets, colors and styles, tiling, appliances, lighting, etc.).
- **List anything else** you may want or need in your home, including preferred materials (make a list), foundation type, wall types, roof type and look, roofing material, flooring and wall and ceiling textures and types and materials, and so on.

Design Features

- **Eco-friendly materials** used in all parts of the home, including energy efficient appliances, water saving devices, and kitchens and baths placed to reduce waste of materials or water.
- **Window placement**—are there fewer windows on the north and—especially—the west sides of the house to reduce heat loss in winter or unwanted summer heat gain? Do the majority of your windows (double- or triple-pane) face south (and maybe a few on the east) so the home can benefit from passive solar gain?
- Is there an adequate amount of **thermal mass** (4” insulated slab, dark tile or slate, etc.) on the interior floors in front of south-facing windows to absorb and act as a sink for the solar heat, or thermal mass interior walls or mass materials like tile or rock added to the surfaces of insulated walls (even more efficient than floors in areas where there is no direct solar gain) throughout the home?
- Is the **envelope insulated** and built above and beyond code (preferably)?
- Is your house designed for **accessibility**? (handicap access—this means wider doors, ramps, grasping bars in bathrooms, etc. *A universal design* allows you to grow old and still use its features without further alteration later, or the home to be sold and not need those upgrades if elders buy the home)

- Is the home **designed for adaptability**? (can it be added onto easily later, or the design altered, is it a “core house”—the core of the house is the kitchen / bath / living area... it is designed small and for bedrooms to be added on later)
- **Home configuration** (main living area in the solar gain area (longest southern wall), maybe master bedroom too, kitchen nearest northeast corner (they generate their own heat and this is the coldest corner of the house), bathrooms and closets and mud rooms or entryways on north side as “buffer” areas since the north side is cooler than the south and has more wall space and less windows)
- **Energy efficient lighting** such as LED lighting (more costly but lasts longer and does not have the mercury hazards of CFL (compact fluorescent lights) if they break)
- **Renewable energy** considerations (will you have energy systems or design features? Where will they go?)
- **Energy efficient design** (thermal mass, plus what are the R-values of the walls, attic / roof, under the floors, foundation perimeter, empty cavities within or around windows and wall sockets? Airtightness of the envelope, no thermal bridges (get rid of areas between sections that allow thermal transference of energy or heat loss / gain by insulating them with thermal breaks, energy efficient windows, etc.)
- **Moisture control, air ventilation** (including a HRV / MVHR – mechanical ventilation heat recovery), and **radon mitigation**
- **Passive solar heating** via design features such as floor plan considerations, south-facing glazing, thermal mass interior, superinsulating the envelope, proper overhang configuration (this allows natural daylighting plus saves energy and can reduce utility bills by up to 80-90% if designed well)
- **Water conservation** features (low-flow toilets and showerheads and faucet aerators, greywater system, composting toilet, rain barrels)
- **Construction waste** reduction plan
- **Green landscaping** (protection and soil building like composting, worm farm, chop-and-drop (permaculture method of chopping weeds or dead annuals and dropping them in place for on-site mulch), energy conservation during

construction on the site, supporting biodiversity, reducing lawns (big water wasters, high maintenance, usually requiring fertilizer and chemicals—consider a garden instead, or edible landscaping), allow local prairie grasses and native plants, capitalize on weeds (example: dandelions are entirely edible—leaves for salad and soup, flowers in salad, roasted dandelion root tea is a tonic for the liver and tastes delicious), water conservation methods, planting woodlands and fruit and nut trees, etc.)

- **Construction cost analysis** (find ways to reduce cost of construction as well as life cycle and energy expenses)
- **Operation cost analysis** (design the house to reduce operating costs in daily use (energy bills, appliances initial cost vs efficiency and energy cost over life cycle, etc.), maintenance or repair, upgrades or additions)
- **Deconstruction** features of the home designed into the floor plan so it can be dismantled properly and its parts reused or recycled, upcycled so waste does not wind up in the landfill.

By now you should have a very good idea about your ultimate plan, and you can take the design features and have them put into your drawing (floor plan). Start with your site plan for land you acquire, finish your floor plan, gain any necessary permits or professional help, then break ground (install infrastructure), and begin building your house. You will surely find your way—consider it an adventure! A journey worth your time and effort, because you will wind up with a beautiful, energy efficient, green, and possibly passive solar house that can reward you with peace of mind and lower energy bills, and a lower carbon footprint for the rest of your life, or your home's life.

Planning Steps for Passive Solar Home Design

Once you have done the site analysis and other steps above for your property, including figuring out where solar south is and marking it (perhaps with a permanent marker) on your property, then you will need to focus completely on your floor plan and design features for the home itself.

- Longest wall facing south (orientation) for maximum solar gain (stay within 20% of solar south)
- Calculate the area of glass on south facing windows:
 - 7% NET is only “sun tempered”
 - 9-15% is ideal
 - up to 20% is allowed, but beyond that the house is at risk for overheating unless extra thermal mass is incorporated into the home
 - *See chapter on Window Glazing for more details*
- What kind of windows (styles, double-pane or triple pane, solar heat-gain coefficient (SHGC), UV films, IR films (good for west windows, NOT good for south facing windows), low-E windows, etc.
- Determine overhang length for your latitude
- Include thermal mass—how much do you need? (too much is overkill and a waste, and not enough reduces thermal stability)
- Insulation—will you superinsulate? What materials will you use? What R-factors will you use in your ceiling, walls, floor, foundation?
- Landscaping preferences, living fences, wind blocks, sun shades, etc.
- Air conditioning—electric (standard) or ductless mini-split heat pump? Earth tubes? Thermal mass with earth berming? Other?
- Green building materials desired for your home
- Free, used, or bartered materials you want to include in the home’s construction
- Is your home a core house (home core)?
- Appliances and water heater options

As I close this last chapter, do not forget other resources I have available... your passive solar home can include features from this book as well as other books I have written on built-in solar ovens, solar water distillers, earth tubes, and green building design, etc. Most of my writings on these subjects are DIY (do it yourself) topics for people who want to save money and build things that are practical / useful and will last for years to come while saving them money.

I hope that you find success in your passive solar house designing (and building) endeavors, and that you can tell others about it... share more, teach more. Everything we say and do influences our children (and others) who inherit this planet, and affects the planet both directly and indirectly.

“Studies have shown that schools incorporating passive solar features, such as daylighting, use less energy, student grades have improved, and attendance is higher.”

~ EnergySmart Schools

HOW TO MAKE AIR CONDITIONING EARTH TUBES

DEDICATION

Dedicated to my late son Jeremiah, who was always a breath of fresh air to my soul, and who the thought of still brings life and light to all who knew him. Thank you for being your bright self while you were here on this earth. I love you more than you will ever know!

INTRODUCTION

Earth tubes, or simply “earthtubes” (I will use these terms interchangeably throughout this book) are an efficient way to cool your house during the hot summer using natural cooling principles. Alternatively, they can be used to warm up the air inside your home as well, at least in part, plus they can feed heat-tempered air to a fireplace or woodstove and reduce cold drafts around doors and windows.

These in-ground PVC cooling tubes are also known as air tubes, earth air tubes, a sub-soil heat exchanger, ground-coupled heat exchanger, an earth-air heat exchanger, a air-ground heat exchanger, cool tubes, thermal labyrinth, heat recovery ventilation, or a number of other terms. The kind you will learn about here require no pumps or fans, and are completely passive (no moving parts). They are an example of natural cooling, or passive cooling.

Earth tubes are cheap/inexpensive to build, and can supplement or completely replace your air conditioner(s). The cost to build them is around \$100-150 USD per tube, and you will need several of them to cool your house.

Who Invented Air Conditioning?

Natural cooling methods have been utilized since Paleolithic times, especially for cave dwellers who understood that caves not only provided shelter, but also stable temperatures whether during a cold winter or a hot summer. However, natural cooling is not necessarily the same thing as air conditioning, which requires a cooling of the air not just by sheer mass (rock or earth) but also by removing moisture, or dehumidifying the air.

Different types of air conditioning methods have been employed since ancient Egypt where reeds in the windows were wet so the air could pass through and reduce the temperature (much like misters are used at restaurants and public functions today). Similarly, in desertous climates moisture is actually added to the air to cool it, rather than removing moisture from the air.

In desert areas today many people add moisture by using swamp coolers (also called evaporative coolers), which tend to use or waste water, so many cities have outlawed their use (except for certain brands that are more efficient). Plus evaporative coolers do not tend to work in hot moist areas or when a thunderstorm arrives on a hot summer day (again, being hot and *moist*) as they only work best on hot *dry* days.

Ancient Rome used aqueducts (artificial channel) to carry water that went through the walls of some of the houses, which cooled them down. In Persia during medieval times cisterns or qanats (underground tunnels that had water flowing through them) were utilized along with wind towers, so could cool buildings from underneath the earth or by evaporating the moisture. I will go into this concept more later.

Modern electric-based air conditioning was invented in in the early 20th century by Willis Carrier for a printing company in Buffalo, New York. This was the first large-scale air conditioner ever built and it started working on July 17, 1902. It helped control not only the temperature within the printing plant (to help manufacturing process control) but it also controlled humidity. Carrier basically used the reverse process of heating with steam by cooling (using cold water

coils) to remove moisture from the air, therefore cooling it. By controlling temperature and humidity levels it aided the paper and ink for uniformity in printing. Later on these systems were used to increase workplace productivity, and the demand grew to the point that the inventor created The Carrier Air Conditioning Company of America. After a while it extended to use in homes and finally vehicles.

Today we have complete air conditioning units or HVAC (heating, ventilation, and air conditioning) systems in most modern homes. The electricity that is used to power these air conditioners sometimes runs in the hundreds of dollars (USD) per month, depending on the dwelling size and energy efficiency levels. Older homes suffer the most, or should I say, the owners suffer the most... either because they cannot afford the bills so deal with the temperature extremes, or because they have to work harder to pay the bills so they can live in comfort.

Overall, air conditioning has been a boon to society in developed countries and especially to the medical community (including pharmaceuticals) where temperature control is crucial in some circumstances.

For regular households, however, people are simply looking for comfort. So why should anyone have to pay through the nose for comfort when it can be gotten by natural means? Why pay a huge bill to force the rules against nature when one can utilize what happens by itself in nature simply by changing the design? Earth tubes are not only natural cooling (geothermal) but they are passive, so simply sit there and do their job without any electricity or moving parts.

By now, you may be asking questions like: So how do earth tubes work? Are there different designs? How do I build them? Are they safe? Can I really do this myself?

Well, the tubes themselves take up more space than a window air conditioning unit (they are long tubes rather than a big box), but they are unseen because they are placed underground; however, they are actually very similar to a regular air conditioner in how they work. Let me explain...

How Earth Tubes Work Like an Air Conditioner

Have you ever noticed one of those small window air conditioning (A/C) units that was dripping water into a puddle onto the ground outside? That puddle was made from excess condensation that was collecting and dripping out of the A/C unit. This excess water was removed from the air inside the house, and expelled as wastewater. By the way, it is NOT safe to drink the water (perhaps in an emergency only) because the units are filthy inside and have metal surfaces that are not potable and may make the water not only unsafe to drink, but could be contaminated with bacteria or heavy metals, etc., as well.

The A/C works by removing moisture from the air, and therefore cools it off and then recirculates it through the house. Similarly, the air that flows through an earth tube is cooled by the ground surrounding the tube—since it is buried several feet below ground—and the lower temperature causes the water vapor in the air to condense inside the tube. This water exits out of the earth tube. The air that enters the house, then, is not only cooler, but drier.

The process of cooling the air and drying it out via removal of the moisture as condensed water is how both air conditioners and earth tubes work. However, there is a significant difference between earthtubes and an A/C unit (whether a full sized unit or a window unit) ... where air conditioners require the use of electricity, earth tubes do not.

The Cost of Earth Tubes vs Air Conditioning

The fact that no electricity is needed to “run” earth tubes means a natural consequence of having no electricity bill either, saving you on the cost to run them each month. Continued on in time this monthly savings can last for up to as long as the lifetime of the tubes (or the building), depending on how they are made, the climate, how they are maintained, and environmental conditions/factors. This saves money by putting it back in your pocket, plus keeps your carbon footprint down.

This is both *natural cooling*, and *green cooling*, simultaneously, and the principles take advantage of what nature already knows how to do (in tune with the earth and physics), and is not polluting. I prefer to call it *passive cooling* since no moving parts or mechanical parts or electricity is needed.

Running an A/C (air conditioning) unit in a standard electric HVAC-based house can cost up to hundreds of dollars per month, especially in homes that are:

- Not insulated well
- Have black roofs (which gain heat in summer when it is hot, and lose it when it is cold outside)
- Leak air because it is not a “tight” house (lots of small gaps or holes or spots where hot air from the outside may infiltrate the interior of the house)
- Have a lot of windows on the south or west side that are not shaded in summer
- Are designed wrong (standard designs are terribly inefficient, including for overhang and window placement, whereas passive solar design helps *prevent* solar gain in summer and *promotes* solar gain during winter for passive heating).

The tubes work by harnessing what nature provides us already, but just utilize simple principles and allow us to cool the ambient air temperature by usually at least 10 or up to 20 degrees F (5-11 degrees C), depending on your home’s energy efficiency values.

These earthtubes (also referred to as *air tubes* by some people) work well in humid climates, although they work in arid climates also.

The cost for making these earthtubes is minimal, perhaps several hundred dollars at the most for the entire average-sized house (approx. 1500 - 2000 sq. ft.). Larger houses just utilize more earthtubes. You will need about one earth tube per 250 square feet, but there are many options you will learn about as we proceed in this book.

Be sure to read through all the ideas first and choose what you want to do before attempting to build the tubes. After I cover the background of where earthtubes come from, and what you can do to use them—whether in a new house you build, or retrofitting an existing house—I will explain step-by-step how you can build them.

Since these tubes can last for the lifetime of the house, and use no electricity, they can replace, or nearly replace any evaporative cooler (swamp cooler or Mastercool) or air conditioning unit, depending on the house, location, and efficiency of the home.

BACKGROUND AND HISTORY OF EARTH TUBES

I want to give you a little background on how I came to learn about, build, and use earth tubes, as well as cover a little bit of the history of where the idea of earth tubes came from. Modern uses are simply variations on older ideas that have been used for not just decades, but centuries, and even longer.

How I Learned About Earth Tubes

We built our first house in the mid-1990's. It was a passive solar straw bale house and we learned about earthtubes like many other people do—word of mouth—and in this case, from a man named Dave Carter.

At the time, Dave was both a building contractor and instructor who taught different classes such as “*Handmade Solar*” and “*Owner Built Homes Under \$20,000*” at Southeast Community College in Lincoln, NE. I first took Dave's classes on owner built homes after we moved to Lincoln.

We bought two acres on land contract out in the country west of Valparaiso, which was very close to the little speck of a town called Loma, although technically we had a Dwight address. Interestingly (or maybe not?), this was the same cornfield-laced area of Nebraska that shows up in some Stephen King novels, including the horror movie *Children of the Corn*. Strangeness aside, our little dot on the map was basically placed between a few rural towns in what was locally known (to many in the surrounding Czech community) as the “Bohemian hills” because it was so hilly, unlike most of the rest of the state. Glaciers once scraped across these lands before the end of the last Ice Age, but all that mattered to us was that we had a plot of land with a water well and a septic tank and planned to build a house, and our goal was to build earth tubes to cool it. Dave Carter aided us in the design and construction of our house and earth tubes there on that property.

Dave, along with a few of the semi-local homeowners he introduced us to, taught us the principles that you are about to read here in this book about earthtubes. We once went on a tour of houses and at least two of them had earth tubes so we were able to ask plenty of questions and pick their brains for details at our leisure. One of the homes had been using their earth tubes for at least a decade, and the owners loved them!

I have picked up a lot of other information on earthtubes since then, as well, which I am including in this book. Now others (like you) can benefit from this effective knowledge on how to cool a home

using simple methods that are based on ideas and practices that have been used around the world for millennia, especially in the Middle East.

Qanats – 3,000 Year Old “Earth Tubes”

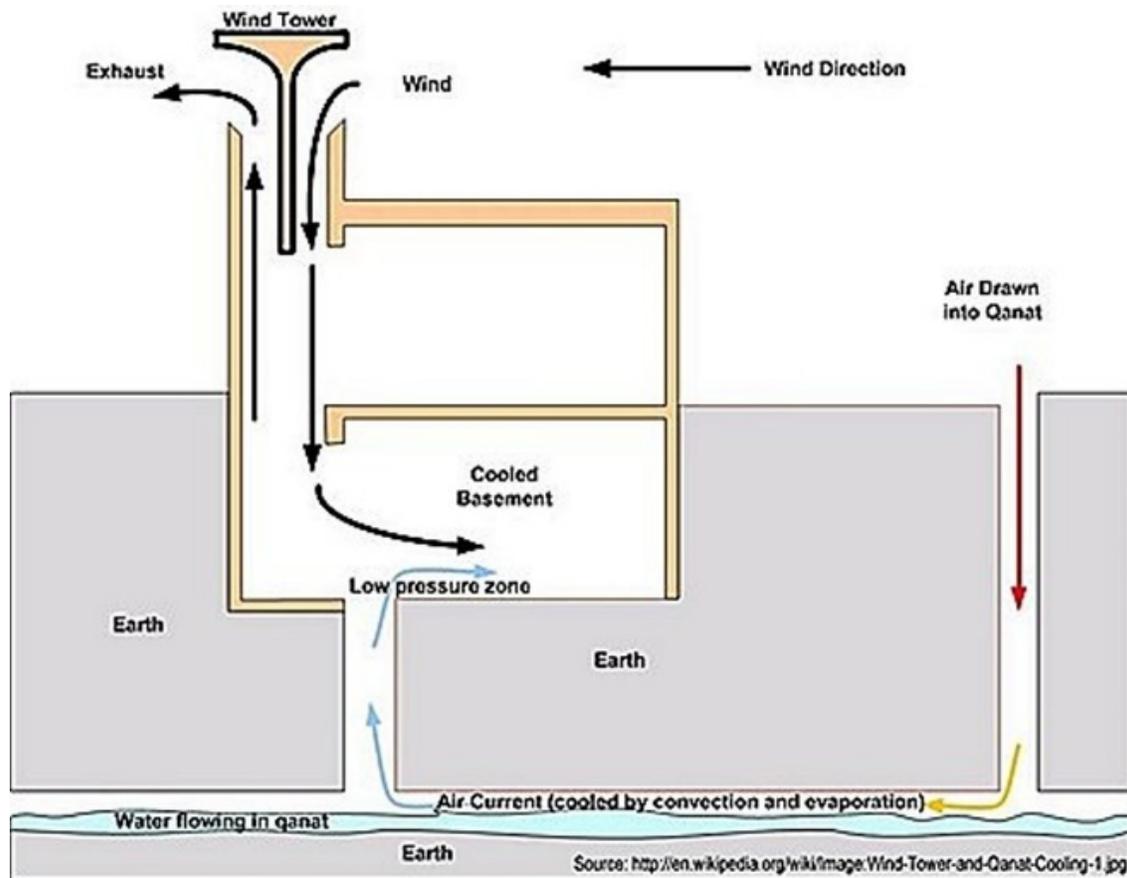
The history of where the ideas of things like earth tubes come from is a fascinating subject, and puts our limited knowledge about modern style earth tubes to shame. So many of the old ways have been forgotten because of technological advances, but not advances are necessarily more superior. For instance, I would rather sit and watch a fire, smell the smoke particles in the air, and hear the popping and crackling of the logs any day than to have to stand in front of an ugly, boring electric heater to warm my hands or my body on a cold winter day. Earth tubes, by the way, can feed tempered air to a woodstove during winter, which prevents drafts.

Earth tubes are typically used in summer (at least ours were). Cooling the house on a hot HUMID day was the goal. Nebraska summers were stifling! Yet, earth tubes can be used in hot DRY climates as well.

It is in the arid regions like Iran where hot deserts provide 100+ degree Fahrenheit (38+ degrees Celsius) days, but nights that are quite cool. Old Iranian cities have tall buildings constructed close together, with narrow alleys, which provide more shade during the daytime; but during the night the cool air falls.

This cooler air is taken advantage of within underground reservoirs (*Ab anbars*, similar to a cistern, but with a dome on top, and keeps the water inside cold); however, the water is also cooled because the ab anbars are tied into *Qanats*, which are water management/irrigation systems—some built prior to Alexander the Great, and others still being used today.

Qanats are similar to—and older than—the aqueducts that were used in Rome, except they run underground. One of the uses of the qanat was to help “air condition” some of the homes of the royals who could afford it.



Qanat and Wind Tower
(source: Wikipedia)

I have a friend, Parivash Anvari, from Iran whose father had a qanat running to his ab anbar when she was a little girl. Also, her grandfather was one of the people who ran the village, so he had enough money to dig down to the qanat tunnel at his home. The vertical shafts can be very deep to reach the water at the bottom of the qanat, which runs at a slight angle (slightly downhill) through the tunnel.

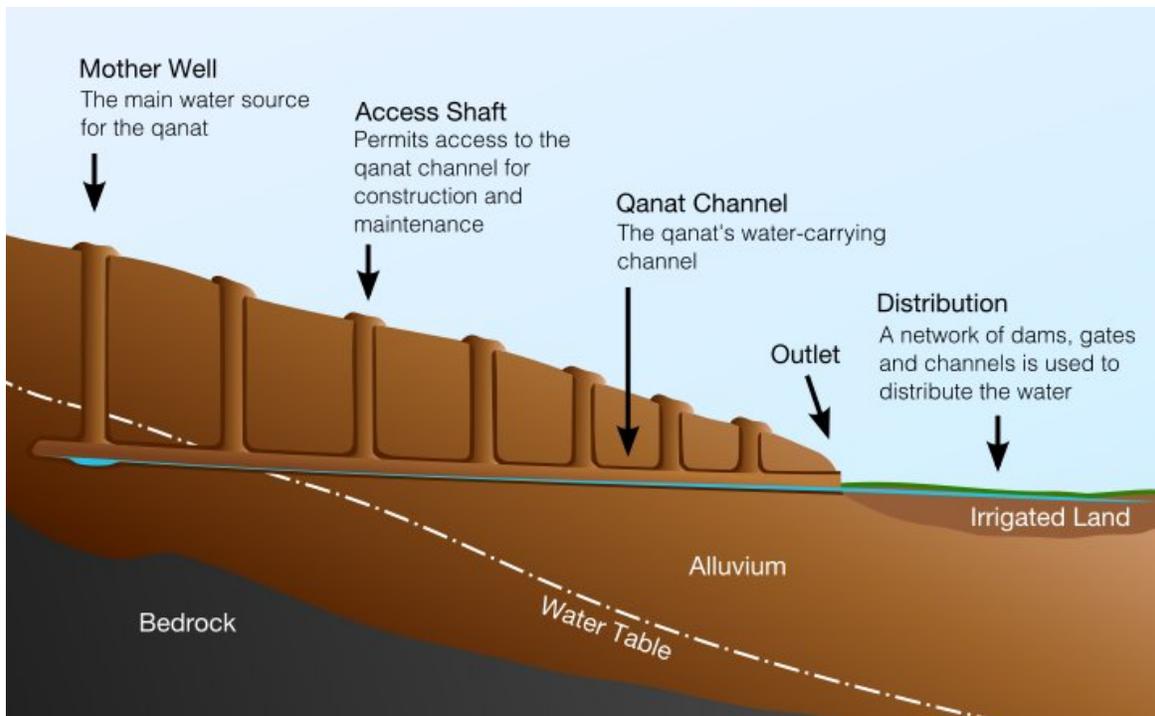
According to my friend Parivash, some qanats feeding water to the ab anbars are very old and out of use, or run very low on water, or are kept only for travelers who are passing through and need emergency water. Her father had to move from their home because their own ab anbar was too low on water for their large family, so they moved away and her aunt moved into the house instead.



Ab anbar (domed cistern) with badgir (windcatcher)
(source: Wikipedia)

INTERESTING FACT: The qanat originated from Persia about 3,000 years ago and spread to at least 36 countries from there.

A qanat is basically a water well that is skillfully dug with a series of vertical shafts to access one very long horizontal shaft, which keeps the water running through the channel underground for up to many miles before being exposed for irrigation and other uses. Oftentimes many wells can be connected together through this underground tunnel system, as well. Containment within the earth through the tunnels or underground canals prevents contamination of the water from the elements, land animals, birds, and people.

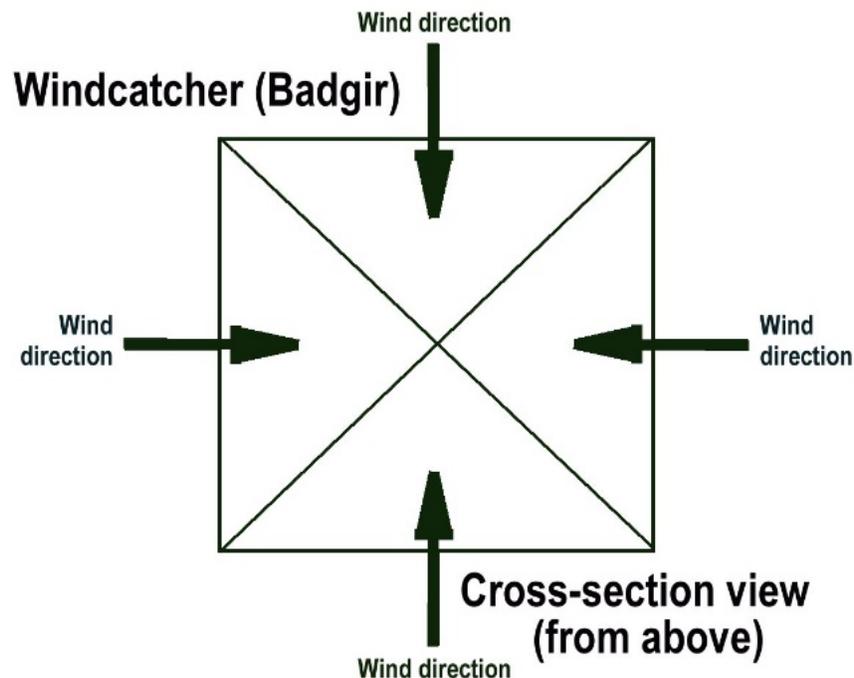


How a qanat is dug

(source: "Qanat cross section" by Samuel Bailey (sam.bailus@gmail.com) - Own work. Licensed under CC BY 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Qanat_cross_section.svg#/media/File:Qanat_cross_section.svg)

Buildings with lower rooms similar to basements are constructed over the qanats and in some areas a Persian badgir (i.e. “windcatcher” tower) is built that acts as a single or multi-directional wind scoop drawing air down and cooling it in the room/ab anbar due to the cool water and air already going through the qanat. This keeps the building very cool.

I spoke with my friend Shery’s father, Mohammad Khanlari, who is a retired engineer who lives in Tehran, Iran, and he explained these systems to me in detail. Look back at two of the previous pictures (showing wind towers/badgir) above and take a peek at the tower itself—it is square, but channels air in one side, where it falls into the cooler rooms below, and then circulates back up and out the other side of the tower. The tower is internally divided into four sections, so an overhead view would look like this.



He explained to me that the lower room (i.e., basement) actually has a pool of water in the middle of it, because like evaporative coolers in the desert, these rooms help cool the air by adding moisture. The wind blows and pushes the air through the tower and down into the lower room, cools it, and then any warmer air moves up and out the tower on the side that is facing away from the direction of the wind. A simple but effective process.

The windcatcher (badgir) or wind tower, then, acts as a ventilation shaft for air exchange, and work basically as the air conditioner for the buildings they are attached to. Sometimes there are a number of badgir/windcatchers for each building. Just like earth tubes, the bigger the room, the more the tubes... the bigger the room, the more the cooling towers. Yet, they work on opposite principles—earthtubes use air and water (REMOVING MOISTURE) to cool hot moist air, while qanats and windcatchers use air and water (ADDING MOISTURE) to cool hot dry air.



Qanat tunnel in Isfahan, Iran
(source: Wikipedia)

The water running through the qanats to each of these buildings in the town can also be what cools the air down as it enters the building through the windcatcher/badgir. To add an additional element, this same engineer said that there are huge dome buildings (yakhchal) that are basically giant ice pits 10-30 metres deep (30-100 ft). These deep holes with a dome top and a wide north wall to shade it from the sun, are where ice and snow are kept in winter, which stays cold year around and provides refrigerator-like temperatures to for the use of ice and food storage during the hot months.

In the 1990's I witnessed a similar design by the Platte river in Nebraska from the times of the pioneers that was utilized the same way, minus the shape of the building (basically a hole in the ground, covered over by a roof covered in sod, with steps down into it—they would hang beef and store food year around).

Although this was an example of a way to utilize the earth's stable temperatures, it does not use flowing water or qanats, which represent amazing versatility in desert climates. A qanat, along with the ab anbar (dome for water storage), can be pumped out by a hand pump (tolombeh) from above ground. There is a design for spiral earth tubes that I will cover later that you can use to store the condensate in a cistern, which can similarly be pumped out by hand, but I will cover that later. In the meantime, qanats have proven themselves as the original "earth tube" that cools buildings in hot climates, plus they provide water in places that would otherwise be uninhabitable.

There are currently over 37,000 qanats in use in Iran today, with over 7 billion cubic metres (1.85 trillion US gallons) of water flowing through them. One such qanat is over 1,500 years old and still in use. The deepest qanat is over 300 metres (almost 1,000 feet) deep. The water is used to run grain mills and other necessities. The source of this information can be viewed on an excellent 6-minute video by the *Iran Program Presstv* on [YouTube.com](https://www.youtube.com/watch?v=...).

One old qanat in Yazd, Iran, is 17 miles (28 km) long and runs from the mountain (that provides the source of the water) all the way through the dry desert to the city. The water flowing through qanats like this often turn mills for grinding grain for local townspeople, or other things. Qanats are a sustainable practice that helps from having to build more power plants. You can also find out more by searching online for qanats in Yazd—there is one 17-minute video on the UNESCO (United Nations Educational, Scientific, and Cultural Organization) website.

So how do qanats tie in with earth tubes? Because they are tunnels through the earth that allow water and air through the earth, and sometimes they are used to cool buildings (homes, ab anbars, etc.). The difference is that the water in the qanats, which is "piped" down to the cities and farms, bring cool air and water as resources that can be utilized in whatever ways the people need; whereas, the earth tubes do not have running water in them, but do drain out the condensation and provide cool dry air to enter the building.

Qanats also have constantly flowing water moving through them, which is fresh and is not as likely to grow bacteria or mold, whereas earth tubes only have condensate (which is basically pure distilled water), but the condensed droplets need to drain out of the tubes so the water does not collect in the bottom and become stagnant. Stagnant water is a big no-no for health purposes, especially over time. Catching the water and removing it in some fashion is necessary and what earth tubes are designed to do. Clean fresh and cooled air (or warmed air in winter) can then enter the home.

EFFECTIVE USE OF EARTHTUBES

There are a number of things that make earth tubes function, and also to make them more efficient in their use. I will cover the principles on how the tubes work (convection (the “mechanics” or force that drives it), evaporation (which is not too relevant), and condensation (which is very relevant)), the best materials to build them from, and why having/adding thermal mass in your house can help your tubes work more efficiently.

How Earthtubes Work

How earthtubes work is simple, and quite similar to the air cooled in a qanat, except that water will not be flowing in the tube (it will collect and drain out instead).

What we use is a long PVC tube (4" diameter THIN-WALLED PVC), which runs underground and spans about 100 feet (30m). One end has an extension that comes up out of the ground at a 45-degree angle to bring in fresh air from the outside. The opposite end also rises up at a 45-degree angle to feed freshly cooled air into the house. A floor vent or wall grate typically covers the air tube's entry into the room.

Air escapes from the house through a single window up higher in the house, which is cracked open. Examples of high windows could include: *clerestory windows*—long narrow horizontal windows higher than your head on the wall—or vertical windows that open at the top, or a *cupola* (a raised dome or area shaped like a square, hexagon, or octagon, with windows all the way around its sides, slightly higher than the roof). Basically, any standard *upstairs window* can be opened; that is what makes the earthtubes “work” because it begins the process of natural CONVECTION. As air escapes the window, air is drawn up through the earth tubes.

Note that *any window* will work, even in single story buildings. The idea is to open a window that is at/near the highest part of the house so that naturally-rising WARM air will escape, creating a pressure difference to suck in the cooler air from the earthtubes. This works because hot air naturally rises, so you are simply letting it out.

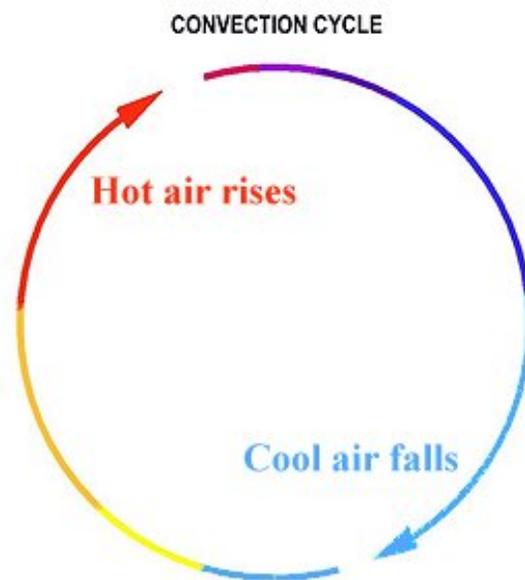
IMPORTANT: DO NOT open too many windows or you will get a cross-breeze and it will cause hot air to come INTO the house from the outside, instead of drawing the cooler air from the tubes.



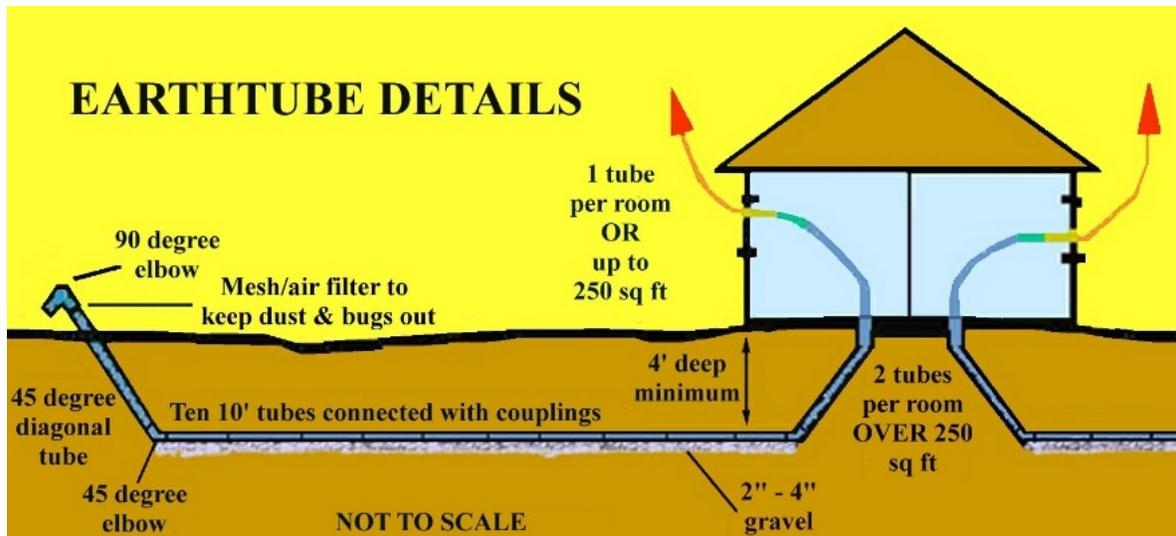
Cupola with windows on housetop

Convection Brings Cooler Air Inside the House

Convection occurs in nature and is most often seen in weather patterns. Warm fronts and cold fronts are masses of air that rise and fall and move across the landscape, all generated by the sun's energy (wind is, in effect, a by-product of solar energy). Warm air rises, cools off in the upper atmosphere, and then falls back down again, creating a cycle—a convection cycle.



Convection in your house and through the earth tubes works similarly. Warm outside air enters the tube at the far end of your yard, descends and cools off while it passes through the tube, and then exits into your home. Over time it will slowly warm back up (due to factors such as body heat, outside air infiltration or sunlight through windows during the heat of the day, etc.) so rises and then leaves the house through the open window.



How an earth tube works

In a qanat there is cold water in the earth that flows steadily and helps cool buildings down (with the help of a wind scoop tower to aid the convection process). So what exactly makes earthtubes' air cooler, especially since the air outside the house during summer is usually hotter than the inside air, and there is no flowing water? It is actually simple physics...

First physics lesson: Heat seeks out cold.

It would first appear that, since “heat seeks out cold”, the hot air outside would want to naturally enter the house because it is cooler due to having a roof that shades it inside—and this is actually what happens and is why your air conditioner has to work so hard to KEEP your house cool during the summer! It is not as much that the cold escapes the house (although that happens too), but the sun’s heat radiates through windows, and even through insulated walls.

Realize, though, that heat also rises, and that the hot air outside would want to rise, rather than go down into a tube, but any cool air (especially air under trees/bushes since foliage cools the air naturally) would automatically be more inclined to go down into the earthtube. A fan could potentially blow this air into the tube, or suck it from the

other end, but this is not recommended... instead we use natural convection to make this air flow happen.

Convection occurs due to a natural pressure difference and is what makes it work. The open window lets out the warmer air and creates the pressure difference that literally sucks in the air from the tube(s), which is the only real inlet(s). This is a natural siphon, and is more powerful than just hot air rising outside, so will overcome that and suck hot air into the tube, then the cooling process takes over from there, feeding the process further.

I could also add... it is not just convection, but also evaporation and condensation that make earth tubes work; although, evaporation is a small part of the picture, whereas condensation is a huge factor in why the temperature of the air cools down.

Evaporation and Condensation

Condensation is a physical process of air moving from one state (vapor) into another (liquid) so the phase change (based on the laws of thermodynamics) causes thermal loss (exothermic process), hence, the lower temperature of the air is the result once the water droplets are condensed out of it. This is not ignoring the fact that the earth is also already at a cool temperature and has an influencing effect, and in fact drives the process.

When the hot outside air enters the earth tube at the end farthest from the house, the cooler temperature of the earth itself, which surrounds the tube, begins to cool the air, causing a natural downward flow.

CONDENSATION EXAMPLES: When air passes through the tube and is cooled, the water vapor leaves the air itself and condenses on the inside of the tube, much like water that condenses in an air conditioning system (remember those old window A/C units that constantly drip?). Similarly, water vapor condenses out of the air and forms droplets of water on the outside of a tall, icy-cool glass that has your favorite drink in it. This is why the glass gets wet on the outside and drips down and makes a circle-stain on your table. It is the temperature difference between the cooler glass and the warmer air, which causes this condensation to occur.

This is the bottom line of how an earth tube works:

The hot air rising inside the house carries any moisture (*evaporated* from cooking, people breathing, taking showers, making tea/coffee, etc.) with it to the outside by escaping out of a high window. This exiting of warm air causes a pressure difference inside the house, which pulls—literally sucks the—air in from the only other open places it can get it... the earthtubes. The air inside the tubes drops in temperature from the cool temperature under the ground, condenses out the moisture droplets and lets it go back to the earth, so the air that comes into the house is then cooler and dryer. Viola! Air conditioning!

Does it make sense? This is what cools the inside of your home, in a continual passive-flowing process that “runs” all day long without you ever having to flip a switch or pay a penny for its use (outside of building them initially). The payback period for these tubes, at around \$150 each or so, is incredibly fast, sometimes within the first year of use.

The temperature difference between outside air, let’s say, 98 degrees F (36.6°C), is cooled off to as much as 20 degrees less (to 25.5°C) so that the air entering the house is around 78 degrees or so. Generally a 10 – 20 degree (F) drop like this in temperature is average and normal for standard homes.

Some weather conditions may change this number as well as how energy efficient the house itself is. If the house is very old and hard to heat and cool with a standard heater or air conditioner, respectively, then it is safe to say that earthtubes might not help that much (so just add more of them). However, in a modern or energy efficient home, the tubes can make an unbearably *hot* day become a cooler, more *comfortable* day inside your house!

Here is another trick to making the tubes work best—energy efficiency. We built a passive solar straw bale house when we lived in Nebraska in the late 1990’s, and when it was 99 degrees F (37°C) outside, with 99% humidity, it was 70 degrees F (21°C) inside. That is almost a 30 degree Fahrenheit difference, but our house was especially designed well to keep the sun out during summer, plus was super energy efficient with R-50 insulation values in the walls and

ceiling. The better the design of the house, the more efficiently your earthtubes will work. If you build a house, consider this aspect, or you can also do things to make your current house more energy efficient such as by adding insulation, caulking all joints, and so on.

It is important to note that earthtubes work best when they are used in humid climates as the principle behind them is to REMOVE the humidity from the air. In super-humid climates it is recommended add extra earthtubes (perhaps even double the amount of tubes) to ensure enough of the humidity is removed to make a difference.

In arid climates it is common to see the evaporative coolers/swamp coolers on rooftops of homes because the already dry air needs moisture ADDED back in to the air in order to cool it, as I mentioned earlier. However, standard air conditioning units are also found in homes and businesses in arid climates so earthtubes will also work in these areas, especially on those hot humid “rainy season” days in summer, when a swamp cooler just adds to the already hot humidity, rather than cooling it. Earthtubes would be ideal during monsoon season in the desert! Never try to use earth tubes and an evaporative cooler at the same time because they work on opposite principles.

Best Material for Earth Tubes

Throughout this book I will cover different materials that could be used for earthtubes, but I will just briefly cover a few here... I was taught to use *smooth* and *solid* (non-perforated) thin-walled NEW (never used) sewer PVC pipe (4" diameter/10 cm) because it is rot resistant, bacteria and mold resistant, and repels moisture.

Some earth-air tube builders have utilized corrugated pipe, but the problem with this is evident in the puddling that can occur in the bottom of the ridges once the pipe is laid flat, which can stagnate and promote mold and bacteria growth. The last thing you need is health problems due to breathing contaminated air.

Another material you will want to avoid is concrete pipe because it absorbs water so can become saturated and will likely grow algae, mold, and bacteria.

Clay tiles or other earthen tiles are also similar to concrete because they absorb liquid so their saturation point can not only cause health and breathing problems due to mold/bacteria, but the tiles themselves break down or disintegrate over time.

Other pipe types that can give you problems are iron pipe or galvanized piping—the eventual rust or oxidation related problems can cause health problems, including the clogging of the exit holes due to buildup of rust debris around the drilled holes that would be exposed to moisture. Remember the tubes will be very wet as the moisture from the air condenses on the inside of the tubes.

Weeping tiles are corrugated flexible plastic pipe that have slits all the way around their exterior. Weeping tiles are used near the foundations of houses to leach away water in the soil so it exits away from the foundation and prevents potential problems with the structure. Usually they direct water to the sump pump area, which takes the excess water and pumps it out and away from the home. It is not recommended by most people I have talked to, to use weeping tiles for earth tubes, mostly because the soil can come through the slits and contaminate the air in a similar way as concrete or clay tiles can, plus organisms such as earthworms or insects and such may be able to enter the tubes through the slits, and could be a source of

potential problems. Also, because there are so many slits in the tube, radon gas can accumulate and enter the home.

Big-O pipe (high-density polyethylene (HDPE), which is basically weeping tile material, but can be bought without the slits) could potentially be used for earth tubes, and has been used by some, but typically those are systems that require a fan to force the air through. Corrugated material will act as a hindrance to natural air flow, so it often takes a fan to force the air through, which basically defeats the purpose of having passive earth tubes that cool without assistance. Again, there is the problem of water collecting in the bottom and becoming stagnant.

USE THIN-WALL PVC PIPE: Another consideration with your earth tubes is to ensure they are smooth, solid, thin-wall PVC pipe. Thicker walled pipe, such as standard PVC pipe (whether schedule 40 or schedule 80) simply will not allow the heat or cooling effects required for proper thermal transference between the air passing through the tube, and the ground on the other side of the tube. The idea is to allow the stable temperature of the earth to either cool or warm the air (depending on the season) that is passing through the tube—if the tube is too thick the necessary thermal exchange is not going to happen very well at all, thus reducing the effectiveness of your earth tubes. Stick with the thin-wall tubing material so you will have success.

Interior Thermal Mass Enhances Earthtubes

Did you know that a way to enhance the comfort levels in your house is by utilizing a principle of thermal mass inside the building? Buildings that are constructed with materials that have a lot of thermal mass (able to hold heat or cold), such as adobe (earth) brick, slate, rock, or other heavy conductive materials hold or keep temperatures longer than do insulating materials. For example, the Middle East qanat brings in cool air, but this type of “thermal mass” construction of adobe, tile, or stone walls and roofs is actually an important part of KEEPING it cool for long periods of time.

Similarly, you will want to make sure to have plenty of thermal mass (tile, brick, rock, slate, cement, etc.) exposed inside your dwelling/building, if possible. Thermal mass materials are *conductive*, which means they conduct or transfer heat and cold, and also store it. This is what you want plenty of in your house. Realize that it is not a requirement, but it will keep your house cooler in summer, and warmer in winter, if you include thermal mass materials inside your home or building.

It is important that you DO NOT cover thermal mass materials with laminate flooring, wood, wall-to-wall carpeting, or any other type of *insulating* material or you will lose efficiency. Thermal mass inside the house helps keep the house cooler by holding the temperature stable, and as I said, although it is not mandatory, it helps greatly in the long term.

If you have carpeting, considering removing it and replacing it with tile, slate, or similar mass floor covering, or treat/color the concrete as is found in many newer homes these days. The occasional throw rug is okay to use, however.

Other—and sometimes better—options are to have thermal mass walls inside the house, if the floor is not an option. Stone hearths, half-walls of stone or adobe or tile-covered concrete, or other mass materials, are ideal. I mention this mostly for people who are planning on building a house, or for people who would like to add some design features to their existing house, but it is not a must, just something to enhance their use and keep your home more comfortable using

natural principles. Interior thermal mass walls are more efficient in absorbing and releasing heat/cold than are thermal mass floors.

Passive solar home designs are typically perfect for using earth-cooling tubes because thermal mass is typically designed and built into the structure (you can see my free information on passive solar house design for details at sunstar-solutions.com). Passive solar homes (in the northern hemisphere) have 'solar south' facing windows with a specific glass-to-mass ratio so as to prevent overheating or under-heating.

In ancient Persia, and even today, earthen brick is often the building material of choice because it has "thermal lag" – the sun's heat is absorbed on the outside of thick walls and slowly re-radiated to the night air, while inside the temperature stays semi-constant. This works for both holding heat stable during winter, and to hold and release cooler temperatures during summer. Insulating the envelope makes it far more efficient, however, since wall thickness is not nearly as wide as earthtubes are deep.

An interesting specialized-use building in Iran called a yakhchal (deep ice pit) has a cone-shaped dome, very thick walls (3' at the base) and a specially made heat-resistant exterior. It can be used with the subterranean qanat to help keep ice (brought down from the mountains in winter) frozen all summer long, and food cold, which is a real treat in the hot desert.

Earth-air tubes are not designed to be that cold, since they just move air through about 100 feet (about 30 metres) of PVC tubing, but they will drop the outside air temperature to about 10 or 20 degrees F (5-11 degrees C) cooler by the time it enters the house. In an energy efficient house it will cool it even more.

Earthtubes are very simple in their design, and not nearly as labor intensive as qanats or yakhchals, but where you live and what kind of soil you have, how deep your frost line is, what type of weather you have, etc., will determine just how hard (or easy) installing your earthtubes will actually be. Another consideration is whether you have a house you live in already that you want to add earthtubes to, or if you are planning on building a new house and would like to

incorporate these into the infrastructure of the house prior to building. I will show you ways to do either/both.

We learned the hard way, from toil and sweat and digging by hand through HARD-pan ground that was about 70% clay, and even renting the WRONG type of trencher, in making our first earthtubes. Now, due to our mistakes, you can utilize the information so that your own attempts to make earthtubes can be via a lighter load, and easier work.

Either way, I know you will enjoy your earthtubes, and the coolness it brings on a hot summer day, for many, many years to come!

HOW MANY EARTHTUBES DO I NEED?

In order to determine how many earthtubes you need, you must first figure out how many rooms you have in your house, or in the floor plan of the house you intend to build. It is much easier to make earthtubes for a house before the foundation is built (before any slabs are poured or basements are formed) than it is to make them and retrofit them into an existing house, but it can be done either way.

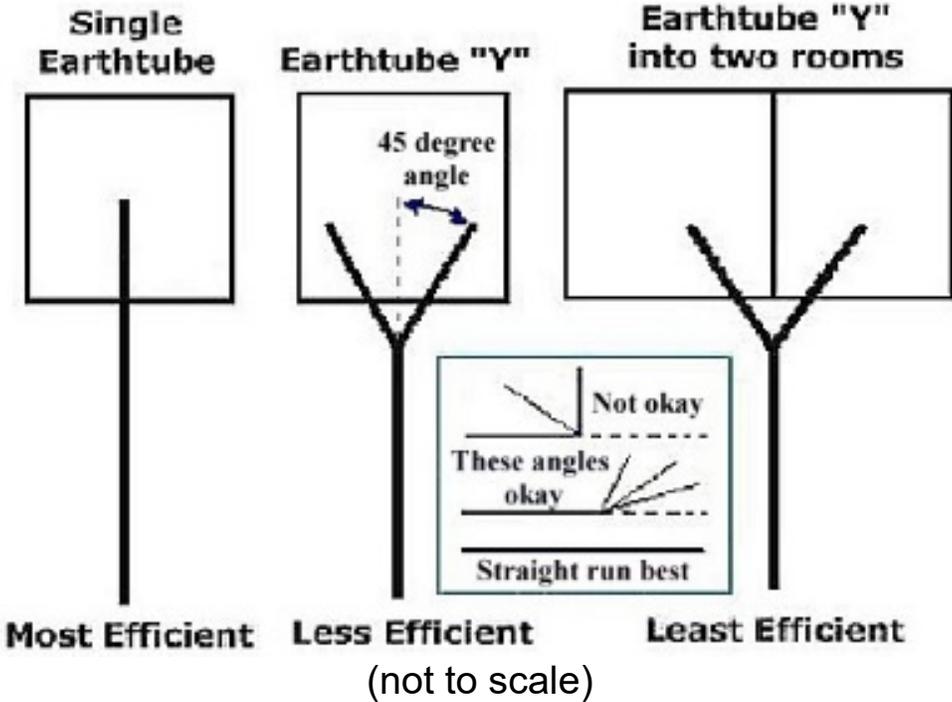
Plan on having one 4" (10 cm) wide and 100' (30 m) minimum-length earthtube per standard sized bedroom (do not include closets or utility rooms, pantries, or bathrooms). For larger rooms such as a Great Room it is recommended to put in two earthtubes to cool it effectively. Upstairs rooms do not usually require earthtubes although they may be run through the walls up to vents in rooms that are particularly hot (such as a south or west wall).

NOTE: Remember to open only one window, or crack two windows only (in the whole house) so proper draw can occur through the tubes. If too many windows are open then you'll get a cross-draft and no air will be pulled through the tubes into the house, hence the house will remain as hot as the air outside. Make sure the window you choose to *crack open* is one of the highest ones in the house.

The earthtubes can be made 100' (30 m) long at the bottom of the run, plus the 45-degree elbows coming up off each end, but if you need to save on costs, you can make them 100' from end to end (which would include the 45 degree bends). If you really need to scrimp on costs then you can also make one earth tube for two rooms, splitting them off with a Y under the ground at 45 degree (up to 75 degree) angles, but you will lose a little bit of efficiency in the cooling effect.

Typically, the more earthtubes the better when it comes to cooling down your house! If there are not enough to be effective, then they are basically a waste of your time, energy, and money to make them at all, so do it right the first time (plus it is not like they cost much). Please keep this in mind when designing your earthtubes for your home.

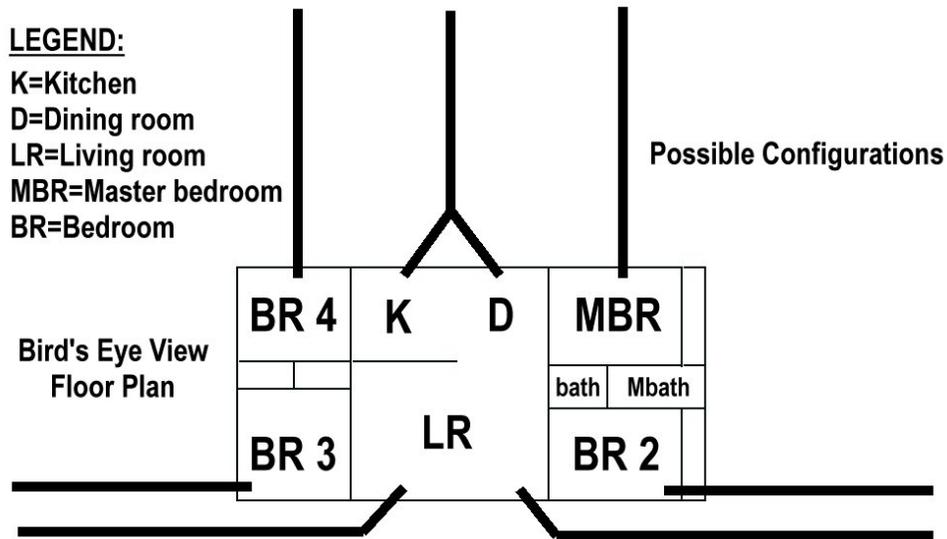
Diagram showing the “Y” option



Normally you will see one earthtube for each of these rooms (this example is a single level home):

Living room, Kitchen, Dining, Bedrooms (3). Bedrooms can be split off into the Y-type earthtubes unless you spend a lot of time in there during the daytime. Sometimes the kitchen and dining rooms are also on a shared earthtube, especially if they are not separated by a wall.

APPROXIMATELY 1 TUBE PER ROOM



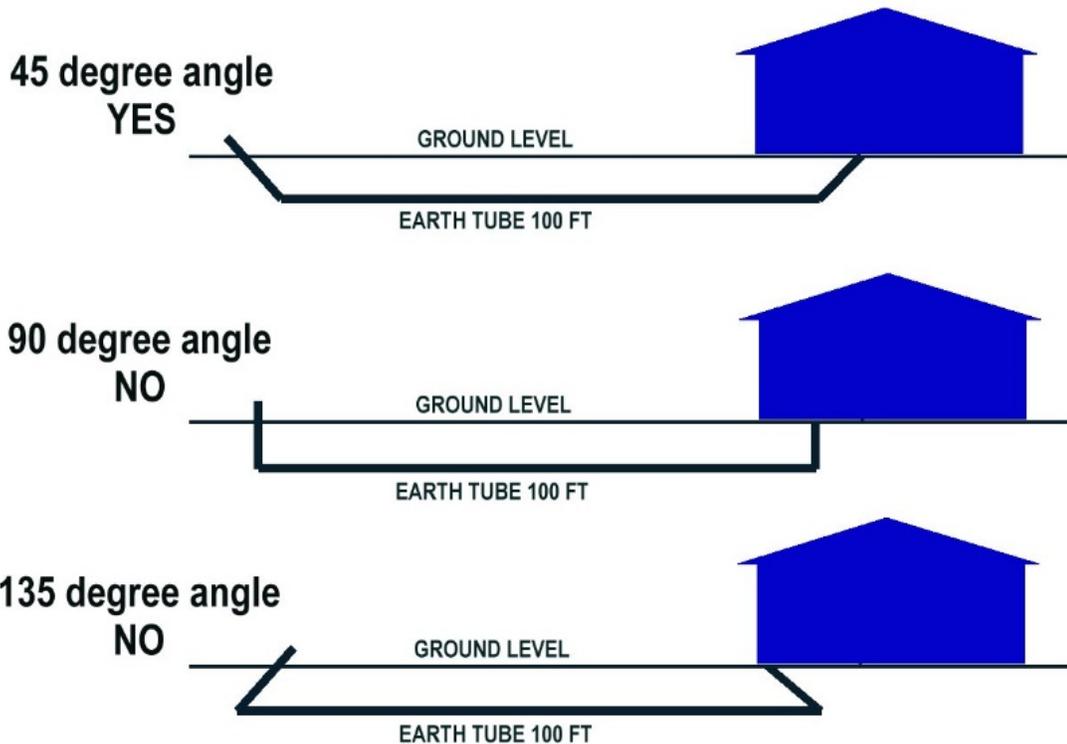
Earth tubes can come in from different angles, depending on room in the yard to dig the trenches

Living rooms, if small, can have one earthtube, but really large ones are recommended to have at least 2 earthtubes. All in all, the typical house will probably utilize a total of about 4-7+ earthtubes (the more the better). Remember that kitchens generate their own heat, so you may want to have at least one earthtube for that room alone.

Remember not to use more than one “Y” off of any earth tube as too many branches could cause the flow to favor one or two branches, and cease to flow through the others, plus there is not enough surface area inside the tube length to support cooling that much space. Having at least one designated tube per room is always preferable.

NOTE: It is best if earthtubes are run in straight lines. For every 45 degree bend (up to 75 degrees – NEVER use angles at 90+ degrees or air flow can be almost completely stifled!) you lose efficiency because the air is not able to move through the tube as quickly. Too many bends and it will nearly stop the natural flow altogether. Try to only have two bends per tube and no more, and these two bends—

although they can shoot off in a different direction (e.g., at a diagonal to enter the house)—should technically be where the tube goes up out of the ground at each end (see image below).



**BENDS IN THE TUBE SHOULD ALLOW FOR MAXIMUM AIR FLOW.
ANYTHING GREATER THAN 45 DEGREES IS RESTRICTIVE.**

The cost for each earthtube can run about \$100-150 each including the length of all the 4" (10 cm) PVC pipe (schedule 40 or schedule 80 is generally too thick—the best is thin-wall BRAND NEW sewer pipe), and all connectors (couplings), and elbows. Price depends a lot on if you have any leftover *unused* PVC on hand, or what the cost is for the pipe in your area. If you already have a good source for inexpensive PVC pipe then go for it, but do NOT use USED PVC pipe for your earthtubes unless you KNOW it was not previously used by something that could have tainted it (typically clean water only, and you should still scrub it well with a bleach-and-

water solution before use). You do not want to risk Legionnaires' disease or other respiratory diseases.

Some types of tubing have an anti-microbial coating on the inside, which should be a good choice ensuring the air that will be transported through the tubes is free from contamination. The inside of the tubes need to be perfectly clean and sanitary so as not to cause respiratory problems later on during use.

As I mentioned before, when we first learned about making these air tubes, we were told to NOT use corrugated tubing material because it could collect water in the corrugated areas, pool, stagnate, grow mold or bacteria or microorganisms, and possibly make you sick. I will cover more about this later when I discuss air quality. One gentleman has used that type of tubing successfully, but we were told not to, so we did not risk it. We never had any problems either, so am content with the decision to listen to the advice we were given from experienced earth tube users.

NOTE ON EARTH TUBE LENGTH: One last word on the earth tubes. You will want to be sure they are at least 100 feet (30 metres) in their main length that runs underground, preferably not including the rising sections that go up to the outside/above ground. If the tubes are too short the air will not have gone through them long enough to have cooled off enough (or warmed up enough in winter), or to have dehumidified properly, so they will be ineffective. Too long and it becomes a waste of money because the efficiency does not really improve much after the 100-130 foot standard length (30-40 metres).

MAKING THE EARTH TUBES

First things first... make a plan before doing anything else; this could save you a lot of wasted physical work later on. Always make sure to pre-measure the land and make a written plan (on paper) where you are to place the earthtubes, and to double-check your floor plans as compared to where your land boundaries are actually located in real space. There is no sense in putting 100' (30 m) long earthtubes in a yard that is only the size of a small city lot that cannot accommodate their lengths! Also, read this book in its entirety as there are options further along in the book that could influence you to change your original plan. For this first step, just measure the land and plot it out on paper.

Instead of measuring the land (and exterior dimensions of the house/building, if applicable) with a measuring tape is to get a copy of the Plat Map from the Zoning/Planning department with the city or county or province for your area. Also, if you have a larger plot of land you can print out a bird's-eye-view of your property from Google Maps online, or the Google Earth program, or similar program or online source—be sure to know the measurements and to scale it accordingly. Double-check it by measuring or pacing the yard, if necessary.

Alternatively, you can also use graph paper and draw the plan by hand, but be careful to measure properly and assign each “block” on the graph paper a designated size, such as 2 feet per square (61 cm) in length, or whatever works best. If you need help with this just ask an instructor in the drafting department of any community college as they are used to teaching newbies to the subject and are usually willing to offer free advice, at least within reason. I have heard of people hiring their students to help with simple drawings as well, for the cost of a few bucks.

Whichever way you choose to plot out the tubes on your drawing plan, you need to ensure that your property can accommodate the earth tubes. Remember, without the proper tube length accounted for, the efficiency of the earth tubes will be cut way down and you will wonder if even making them will have been worth your time. Do not waste your time and money and effort on something that may not work because you did not have the foresight to plan well.

IMPORTANT: Note that the earth tubes will have their intakes at the farthest end away from the house/building. Keep these clear of any source of pollutants as the air you draw into them needs to be fresh and breathable. Keep them away from vehicle or generator emissions, exhaust from fans or vents (dryers, bathroom or kitchen vents), sources of combustion (fire pits, BBQ's, furnaces, etc.), or other odors (dog runs, garbage or compost piles, sewer cleanouts) and so on.

Once your plan is set, then you are ready to get the parts together for making your tubes. Eventually you will need to get the 10' (3 m) lengths of 4" (10 cm) PVC tube glued together, but not before the trenches are made. Trenches will be covered in the next section. For now, just concentrate on how the tubes are made. Here is a simple parts list and what tools will be needed:

Parts Needed to Make One Earthtube:

11-12 – 10-foot (3 m) sections of thin-walled 4" (10 cm) diameter PVC tubing (non-perforated sewer pipe is good)

2 – 45-degree elbows

1 – 90 degree elbow

10-11 – couplings (to attach tubes to each other)

10"x10" window screen (25x25 cm)

PVC primer

PVC cement/glue

Tools Needed

Drill

½"-1" (1-3 cm) paddle bit (for drilling holes in bottom 100' (30 m) run of pipe)

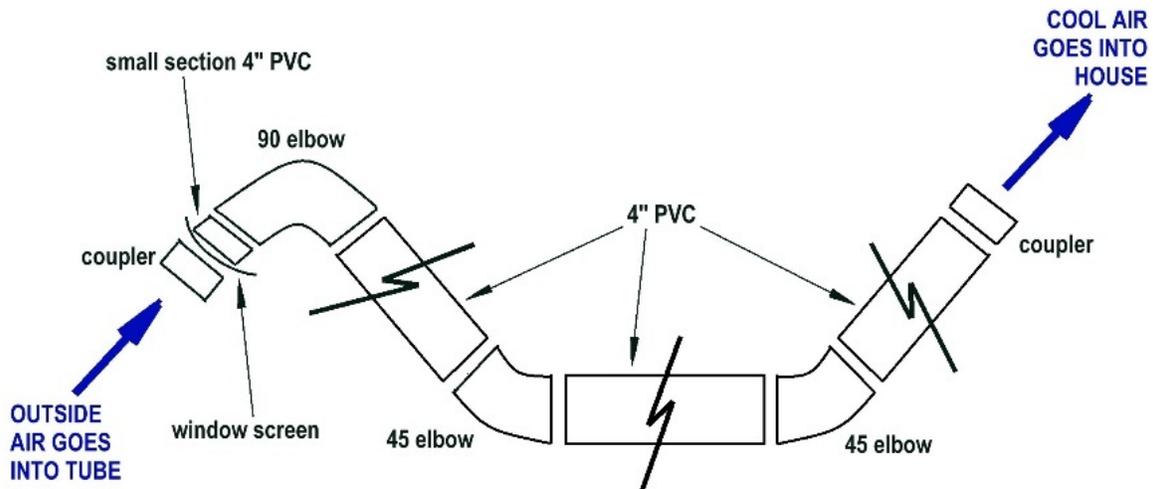
Measuring tape (measure where to make pipe cuts/holes)

Marker/pen (to mark pipe cuts)

Jigsaw (to cut pipe)

Jigsaw blade (any that can cut PVC)

Exploded View of Earthtube



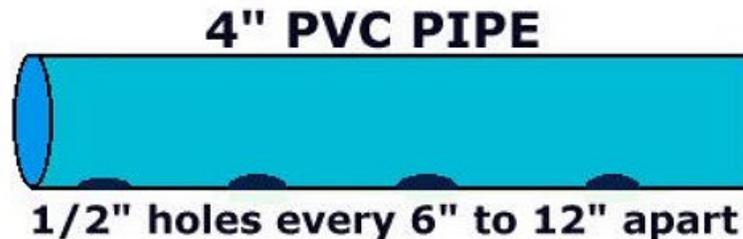
Each 10' length (3 m) of the flat bottom (only) section will need to have holes drilled in them with a drill, using a paddle-type drill bit (1/2-1 inch (1.27-2.5 cm)) works fine, but any similar size will do). Depending on the tube thickness you use there *might* be a need to purchase 2 or so of these drill bits in case they break or go dull. They are fairly cheap at only \$2-\$5 per bit.

You will need to drill holes all along the length of the tube **ON ONE SIDE ONLY** so that they run in a straight line, all about 6" to 12"

(15-30 cm) apart depending on the size of the holes. These will serve as the exit holes (when turned to face down) for condensed water to escape when the tubes are “working.” If solid tubes are used (without drilled holes) then be sure the *entire trench* is sloped so the tube, once installed, is also sloped—in this case it *must* slope away from the house (so as not to flood it with condensate) and the condensation drips should empty into a gravel pit or sump. For now, I will stick with discussing solid pipe with drilled holes in it for solidarity in design throughout the book.

If the water is not allowed to run out into the ground then they will eventually fill up with stagnant water and cause problems (health concerns as well as plugging up the tube with a pond inside the tubes themselves). Do not put in more holes than is necessary as you do not want radon to infiltrate the tubes, either.

Drilled homes for condensation escape



(not to scale)

Make sure you have the right number of couplings and elbows on hand, as well as PVC primer and glue for when the time comes to put the earthtubes together. Before you put the earthtubes together, you will need to dig the trenches.

Earth Tube Checklist

Here is a checklist of what you need to do to prepare for making the earthtubes:

Drawing plan:

Bird's-eye view of land on paper with measurements and placement of building and number of tubes, how far the tubes extend and which direction(s).

Potential places to call:

Trencher rental companies, utility company(ies), zoning/planning department for maps/permits, radon specialist, geotechnical engineer, tree and root removal services, hardware stores for earth tube materials.

Earth tube parts list:

List type and how many tube lengths, # of couplings, # of elbows (45 & 90 degree types), PVC primer and PVC glue, screen, hardware cloth, vent covers, box materials (inside house at tube outlet), or potential vented outbuildings that might cover the tube inlets, PER EARTH TUBE.

Tools needed:

List any possible tools (see tools list from earlier in this chapter)

By now you should have a good idea of what you will need to make the earth tubes for your house or building, what it will take, and hopefully a cost estimate in place (including any necessary permits, if needed) before you ever break ground. Doing this is important so you do not waste your time and effort in building earth tubes that may not be feasible in your area.

If earth tubes are something you want to incorporate into your next house, and you have not yet purchased your land, then you may want to consider the local codes and rules and other topographical and geological limitations that could prohibit or support your choice to build earth tubes, before you buy the land.

When we bought land and built a passive solar straw bale house with a greywater system, earth tubes for cooling, and composting

toilet, we purchased property in a no-codes area (which is harder to find, but certainly not impossible). Most of these areas without codes are rural, and certainly not typically found within city limits of anywhere I am aware of. However, do be aware that just because some counties may have no building codes or permits required, some state or provincial codes may still apply (for instance, greywater systems are sometimes not allowed unless they meet certain specifications). Most codes do not have rules for earth tube construction, but may not prohibit them either. If in the case of the latter, then you may not even need to mention that you are building them, but at least find out first.

TRENCHES

There are different ways to make the trenches for the earthtubes. One is to dig them by hand, but with a number of earthtubes, all being 100 or more feet (30 metres) in length, this can be a very laborious task! We tried this method at first, but the high clay content in our soil at the time prohibited us from doing it very long. Our backs just simply couldn't take it since the earth was like digging through hard rock.

In cases like ours I highly recommend renting or borrowing a trencher for the task. If you know someone with a tractor or other equipment that can also help you with this task, then all the better.

Here, you can learn from our mistakes... We were trying to save money when we rented a small trencher and we were sorely disappointed in the way it "behaved" for us. It was hard to manage as you had to walk behind it instead of riding it. Perhaps we got a moody trencher, but it loved to just take off on its own and make a curved trench going all directions. We fought and fought with it and I do not know if it was the trencher itself or the people running it (even me!). That was...

Mistake #1: Make SURE to get a riding (vs. walk-behind) trencher as you have much better control, plus it will make much wider and deeper trenches (easier to work with).

The little trencher we used barely made a trench just wide enough for the 4" (10 cm) diameter tube to be stuffed down into the hole. It was a tight fit! We constantly had to trim the insides of the trench down using a flat shovel (more digging!) and a posthole digger, which made for a LOT of extra work!

Using a small trencher also made the trench only two feet (61 cm) deep and we should have placed the tubes at a minimum of four to

six feet (1.2-1.8 metres) deep due to the frost line (6'-10' (1.8-3 m) is typical for homes in Europe that utilize earthtubes). Although, 10 feet (3 metres), they say, is best. Anything below this might be a waste, and gets costly. A foot or two (.3-.6 m) or more below the frost line would be crucial for earth tubes being used during the cold months.

We had no plans to use these earthtubes in winter though (except one to feed the air to our woodstove) so we thought we could deal with the fact that they were only set down a mere 2 feet. This was...

Mistake #2. DO make sure to go *at least* the 4' (1.2 m) depth to set the earthtubes as the temperature of the earth is far more stable at that depth. If you live in a northern latitude, then you'll have to go even deeper (definitely below the frost line – so you'll have to find out from a builder, planning department, or the Internet as to how deep it is in your area).

For our purposes, feeding air to the woodstove through one single tube (winter only), while blocking off the others with chunks of Styrofoam and plastic in the “box” (build as an intermediate spot where the tube enters the house, but before the floor register/wall grate cover) keeps drafts from occurring around doors and windows to feed air to the fire, and therefore keeps the house warmer. I will cover more about how this works later.



Walk-behind trencher typically only makes a 2-foot (.6 m) deep trench, so a larger riding trencher is recommended.

With all that I said about deep trenches, do know that our earthtubes worked perfectly, even at a mere 2' (.6 m) depth. However, earthtubes should help temper the air in winter to bring in fresh and ground-warmed air in sub-zero weather. Ours did NOT work for that at all. It fed air through one tube for the woodstove, but the air was not tempered because it was located in frozen rock solid ground. It did, however, stop the draw of air across the floor or from windows by feeding outside air to the woodstove directly, but it was not tempered (warmed) air, heated naturally by the ground. By far, the best choice is to use earthtubes year around, not just in the summer to cool the house, like we did.

Possible layouts for the trenches will vary with your house, and whether the house is preexisting or whether it is new construction and you are barely breaking ground. Either way, fitting in 100'+ long (30+ metres) trenches into the yard may prove the biggest obstacle in some circumstances. Why?

Possible Limitations to Digging Trenches

Limitations for digging trenches are important reasons why you need a written plan before you attempt making earthtubes. There could be reasons that you should know up front that might prohibit your ability to even use earth tubes at your property. If you have raw land and are developing it from scratch, then you may have a much easier path to making the tubes for your building/dwelling. However, if you already have a house, and it is in the city limits, then other factors come into play, such as codes/permits.

If you have bedrock or a high water table (Florida has this issue since water can be found 12-18" below the surface, in some cases) then digging trenches for earth tubes simply may not work without a closed-loop geothermal system that is completely different than open-air earth tubes like we are talking about here.

Here are a few things to consider before running out and renting a trencher to dig:

- The yard is (land boundaries are) too small in either width and/or length
- Bedrock or soil type or layers of caliche or other rock may prohibit digging—know your local geology
- Trees or roots or other vegetation may be in the way or may need removal
- Buried pipes or wire or other underground obstacles may prohibit digging trenches—call your local utilities to make sure you are not liable for cutting into one of their lines, plus for safety's sake
- Outbuildings or patios/decks may need to be temporarily moved or destroyed/rebuilt entirely or in part, or you may need to re-plan where your trenches are placed
- Property easements may be in the way, or disallow digging, or may need special permission
- Permits or permission may be required by the city/county/province before digging can occur

- Zoning or codes or even HOA (Home Owner Association) rules may apply to whether you can dig or not, or if you can install earth tubes at all since they are not usually covered by codes/rules

Many urban planners have not even heard of earth tubes, let alone dealt with them, so if you find yourself in the position of needing a permit, then be aware that you may have to do some research to show others in the area, or in a nearby region, who have already dealt with this issue head on. If you can find someone who has had it approved before you, then the likelihood of you getting it approved improves substantially.

Some areas are code-free (especially if rural) and in those cases no one may need to be notified at all of your digging intentions, but it is your responsibility to find out and do what is legally required in your area.

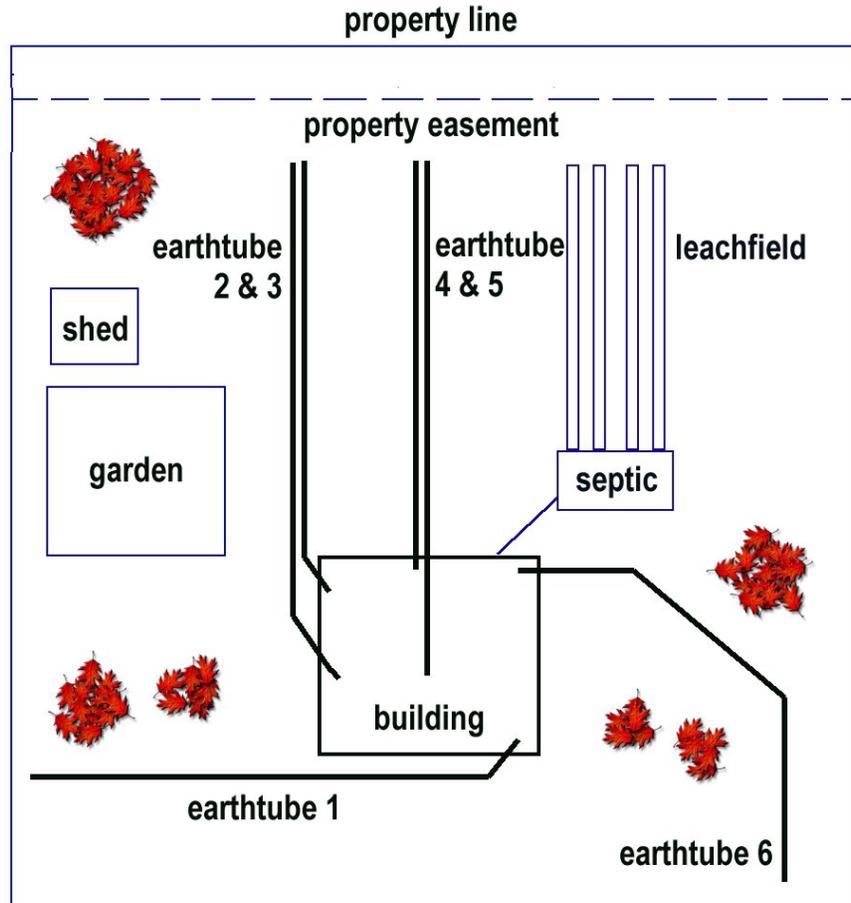
A good place to start besides the planning department in the city center is also the utility companies (especially regarding easements or underground wires or pipes, including gas lines or water lines).

Placement of Trenches

There are many different configurations of placing trenches on your property. I cannot assume that you either have a house already and are needing to retrofit it for adding earthtubes, or whether you have raw land or are tearing down an old house and starting with fresh construction, so I will simply use a basic square or rectangle in the diagrams below to represent the “building.”

Buildings could be your house, a cabin, micro-home (as in the tiny house movement), a workshop or barn, a commercial building, or even a small apartment complex. Whatever your building is, it can benefit from the use of earthtubes to cool it and aid in warming the air inside during winter.

Having a plan in writing is the key to your success in building and utilizing earthtubes. Do not dig until you have a full picture (plot plan) of what you want to accomplish and any necessary permission.



Example of possible configuration of earthtube trenches drawn as a plot plan (not to scale)

In the example above is a plot plan of where your building/house might be compared to the land boundaries and any obstacles, trees, septic tanks or septic field, electric lines, or other features that are a part of your property.

Notice that the earthtubes do not extend to or over the easement at the back of the property (top). An easement is usually owned by the city or similar entity and is used for utility companies to access the property through an alley or near the back fence, or similar method.

Notice also that the trenches are placed where nothing else will hinder their placement.

Earthtube #1: Left side of the property is not long enough so earthtube comes into the house on the right side of the building (overlapping the front of the building to allow proper length of the tube).

Earthtube #2 & 3: Two tubes in one extra-wide trench, which saves space and trenching work. Tubes should be at least 6" (15 cm) apart MINIMUM (1 ft (30cm) or more is better) between their outer walls. Diagonal sections stretch from bottom of trench up to the inside of the house at the box that holds the floor register/wall grate. This is useful for existing houses where the tube needs to come in through the lowest part of the exterior wall or from underneath the crawlspace.

Earthtube #4 & 5: Two tubes in one extra-wide trench, which saves space and trenching work. Tubes should be at least 6" (15 cm) apart MINIMUM (1 ft (30cm) or more is better). This is the very best configuration of trenches/tubes because it is a straight run without any sideways or other bends except where the tubes are bent up at 45-degree angles to go to the inlet and outlet ends. Ideally one tube per trench is best, but tubes can share a trench as well.

Earthtube #6: Least ideal way to put in a trench and air tube because extra bends can restrict airflow. Use this if there are no other options.

Regarding the drawing of your plot plan, whether you use AutoCAD or a drawing program on the computer, or whether you use graph paper or just a sheet of regular paper, be sure your measurements are precise and that you draw a layout to scale. If permits are needed this will be a necessary step anyway. If you are constructing a new home, your architect or draftsman will need this same information.

LAYING THE EARTH TUBES

Once you have your plan (and permits, if applicable) and your trenches are dug, the next thing to do is to lay about 2" to 4" of clean gravel or small river rock down in the entire length of each trench. This allows the condensate to run out freely from the earthtubes instead of making mud or having a flow problem when exiting the tubes. It also keeps earthworms or other little creatures from tunneling up into the holes of the earthtubes by having this gravel in place.

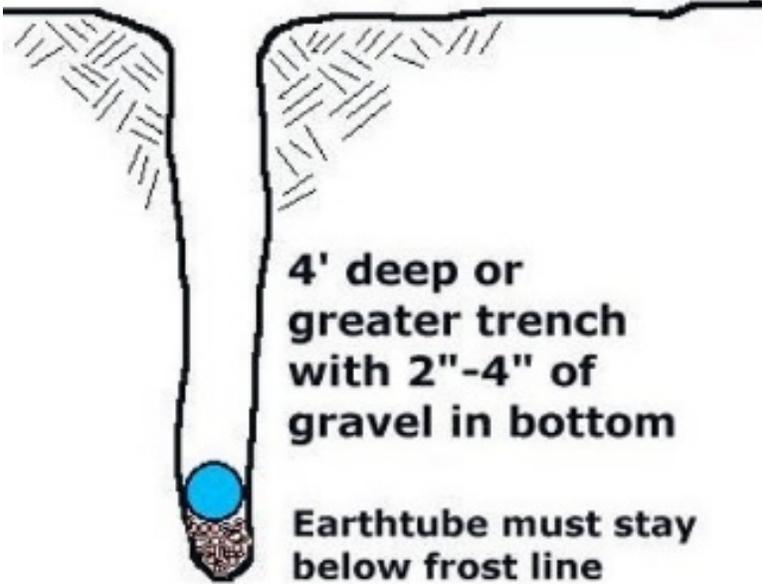
Once your trenches are properly made and "graveled" then you may start placing the tubes (with holes face down) into the trench, using (usually purple) primer quickly and then immediately the PVC glue on each end, then sticking the pieces of tubing together with the couplings. Work fast and press hard so that the pieces stay together all the way, at least for 60 seconds until the glue is "set", otherwise the pieces may slide apart and the coupling will be ruined. *Always double-check so that the holes are faced down!*



**PVC joint
(tube on left, coupler on right)**

Once the glue dries (and it does dry pretty fast!) they are nearly impossible to pull apart as the glue actually melts part of the PVC plastic together to form a bond. After that happens you would have to cut them off with a jigsaw or hacksaw in order to get them apart. If

you bond the two pieces together wrong then you will have to scrap it, cut it off, and the tube will be a few inches shorter. Just start over with a new coupling.



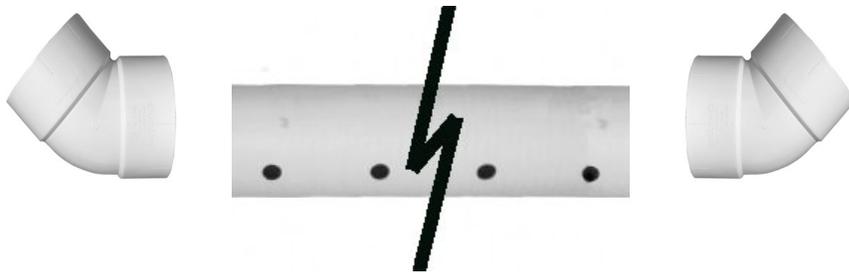
Placing the tubes in the trench

Dealing with Elbows

When you get to the ends of the 100' long (30 metres) stretch, where the 45 degree elbows allow the earthtubes to turn upwards, you'll need to be *extra careful* in gluing on both the elbows themselves as well as the tubes leading up from them.

IMPORTANT: When you set the diagonal piece up from the elbow make sure that this piece does NOT have holes in it as this is the lead pipe up to the surface and will not have water settling in it.

IMPORTANT: Make sure to double-check all angles with a non-glued test before actually gluing them in place!



**45 degree
elbow**

Source:
Lowe's.com

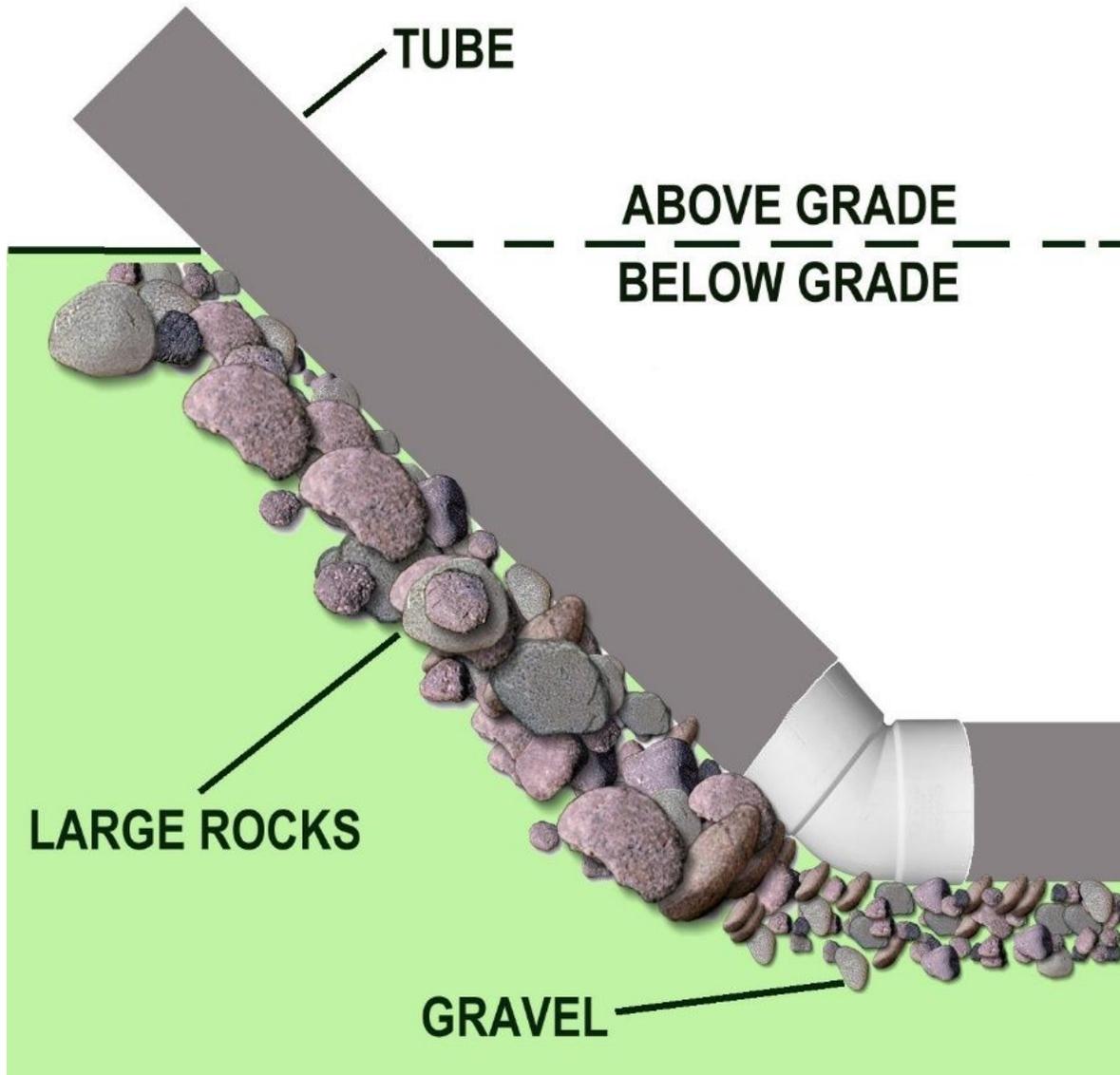
4" x 100' PVC tube

**45 degree
elbow**

Source:
Lowe's.com

PRECAUTION: Once glued, then make sure to put some dirt under the diagonal part of the tube, pack it down, and set plenty of larger rocks in there to help support the tube. This is important because after the tubes are glued, and the dirt is placed back in the trench, then *underneath* the diagonal part of the tube the dirt packs and presses down later on, which causes a gap underneath the tube. A gap could cause your tube to bend down and break off.

How do I know this can happen? Because it happened to us. Please support the diagonals to ensure the stability of your earth tubes! This is especially true near the joints, which are the weakest points.



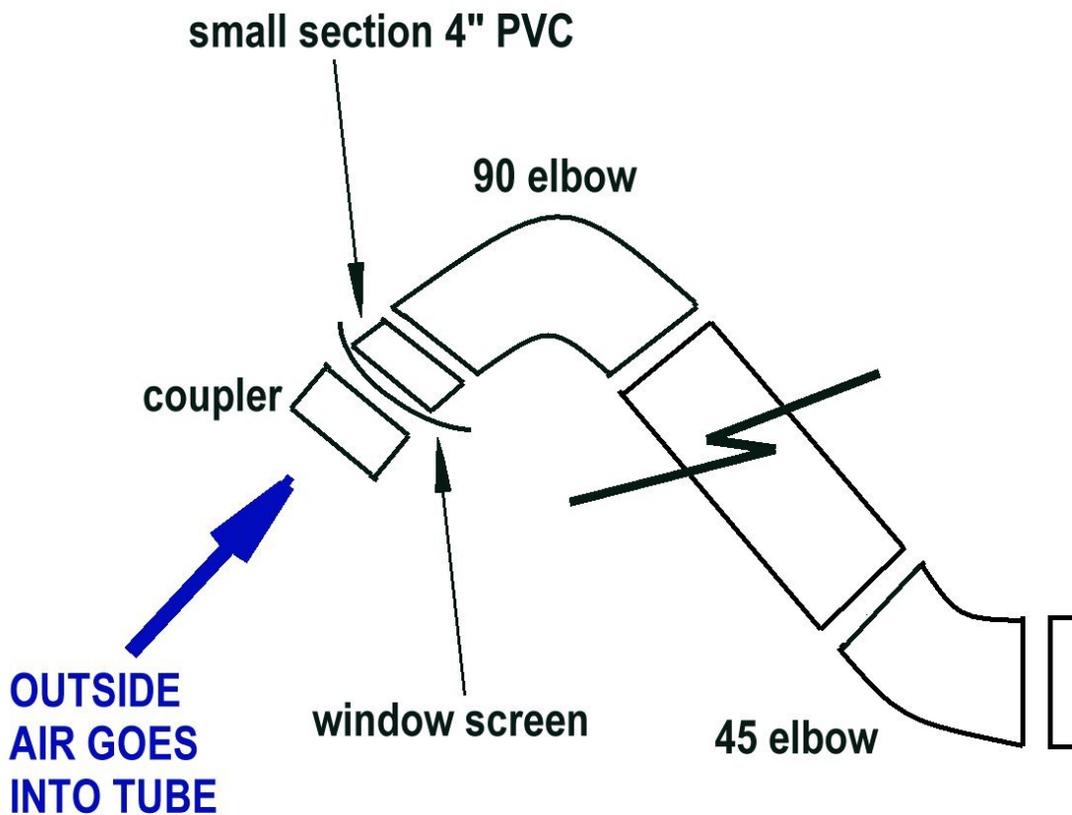
**Protect the diagonal from breaking
by supporting with rocks**

The stresses on the tube after more dirt is placed on top can be overwhelming and it might push the tube downward, causing a break at the elbow. Just to reiterate, make sure to pack the dirt well and/or

use rocks under the diagonal pieces to ensure success and less hassles in the end. Just something to be careful about.

IMPORTANT: It is very important to put a 90-degree elbow and window screen on the inlet tube.

On top of this lead pipe (the diagonal piece) that leads away from the house (this is for the outside section, where the air is drawn in) place a 90 degree elbow, faced down, so that the air can go in, but will keep the rain and debris out.

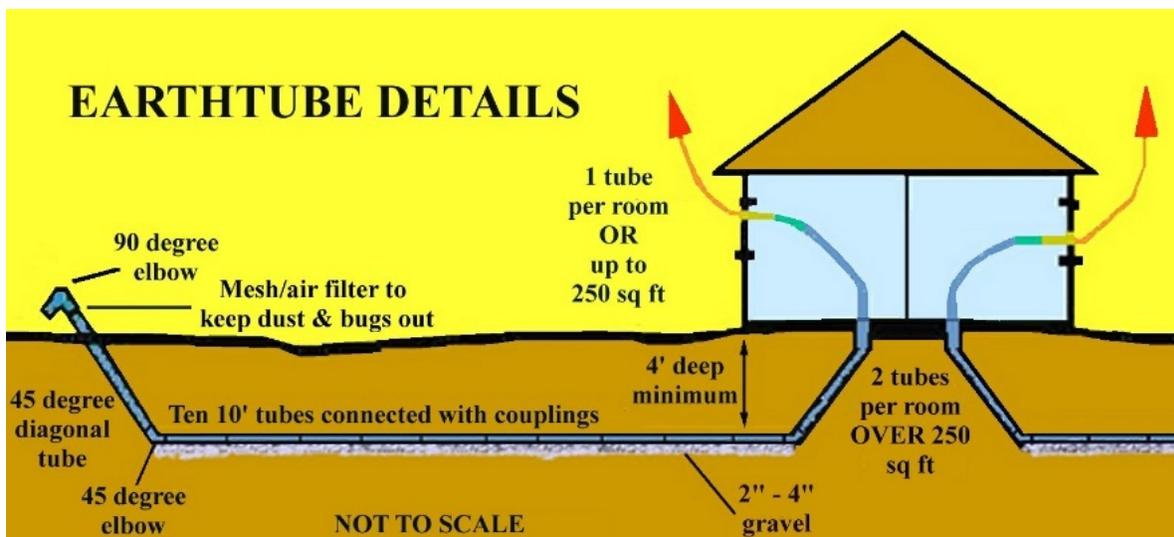


Exploded view of air inlet

Make sure this piece sticks above ground at least 2 feet (.61 m or 61 cm) above ground so small animals or rodents do not scratch

through the window screen (you will place on the opening) and climb—or consequently die—inside the tube. The last thing you need are small rotting corpses fouling up the air that comes inside your house! Speaking of window screen as a cover...

A small 10" x 10" (25 cm x 25 cm) piece of window screen (metal is probably best, but nylon is okay too and does not rust) and/or air filter (a piece of a furnace filter works as long as it does not get wet, although it may restrict air flow) over the end and fasten it with a coupling or band. Another option is to glue a short piece of tube/pipe into the exterior opening of the 90-degree elbow and then cover this over with the screen, and place (it might be tight!) a coupler/coupling over top of that and screw it in place. This keeps rodents, bird nests, dust, and leaves, etc., from entering the tube, plus be aware of children who might like to poke holes and throw objects down the tubes! Hardware cloth might be a significant factor in keeping out mischievous kids or determined animals if you can devise a way to attach it (such as bending it and screwing it down on the sides in several places).



Overview for geothermal cooling/heat tempering tubes

EARTH TUBES—OUTSIDE AND INSIDE

In this chapter I will discuss the air inlet diagonals (outside the building), and the air outlet diagonals (inside the building) and ways to disguise or protect them. What is done on the outside—of the building—is completely different than how the inside diagonal openings are dealt with.

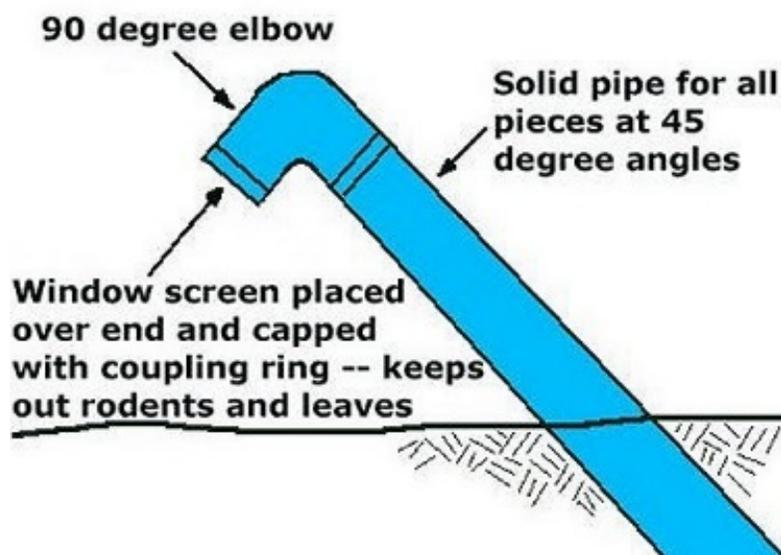
Outside tube ends are for letting air in, so must be protected from weather and other things that could harm the tubes, as well as possibly hiding them from visibility (some people leave them in the open, which is fine as long as you pay attention to them).

Inside the building or house the tubes will typically enter through the floor or a wall, and special care will need to be taken in making the box that surrounds the tube as a transitional piece before the vent/grate, as well as careful placement of these tube ends.

OUTSIDE: Protecting Earth Tubes

When the earth tubes are completely installed, the outer section rising above ground will be the ONLY part of the earth tube that will ever be seen. Because of this the tubes can be vulnerable so will need protecting, and perhaps, even hidden from abuse or breakage by people, downed trees during storms, animals, and so on.

One way to disguise a tube end (if you prefer) is to hide it with brush or bushes around it. This serves a dual purpose in that the leaves of the bushes pre-cool the air and shade the tube from harmful UV (ultra-violet) rays of the sun, which may degrade the PVC over time. Sanding and painting the tube with white paint, or black and then white will also help protect it from UV.



Exposed air inlet tube above ground can be surrounded by bushes/plants to hide it and protect it from sunlight, animals, and people

In addition to using plants to hide an earthtube air inlet, one could disguise a tube as another object by making it a feature item, rather than hiding by concealment... this would be hiding it in plain sight. An example of this could be by using or cover it over with a metal pipe and welding or attaching other pieces to make abstract art as a center

piece in your yard, or to make it look like a palm or other “faux tree” (fake tree) by having the pipe rise vertically and making it into the “trunk” of the tree.

There are probably a million ideas that a creative or artistic mind could think of to disguise earth tubes, by making them taller, or made out of different materials, painted different colors (even a candy cane), metal sculptures, or other ideas.



Metal sculpture ideas to disguise and protect tubes

(Left: http://farm3.static.flickr.com/2158/2107855627_563684c3b7.jpg)

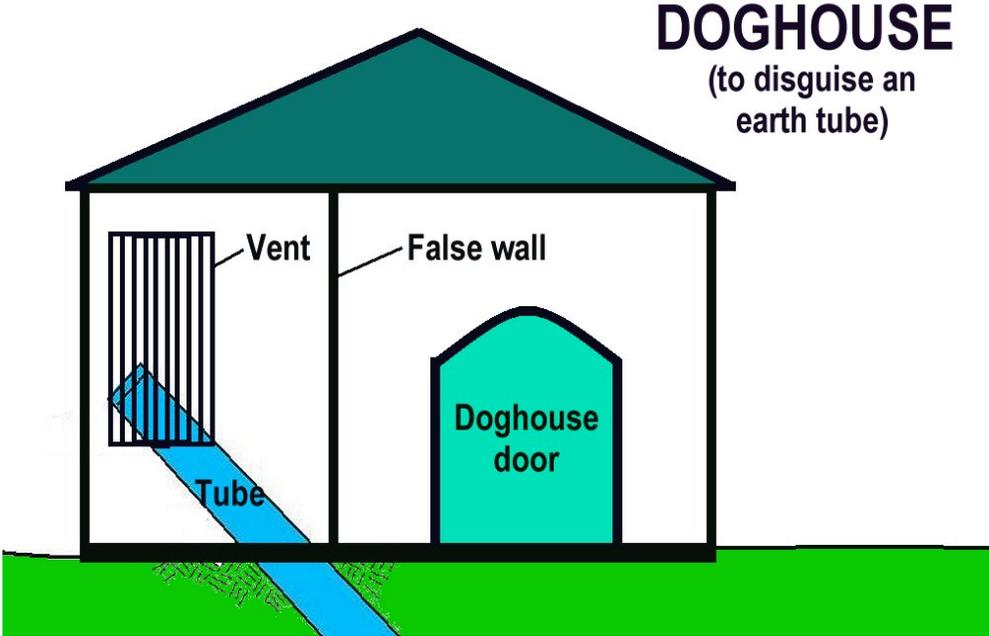
(Right: definatalie.com)

Another option is to build a rainproof box with side vents (use both hardware cloth and window screen) that slip over the tubes where they exit the ground, instead of using the 90-degree elbow. Be sure moles, dogs, or other creatures will not dig underneath the box and sneak up inside and cause damage to the tubes.

One could also use a large doghouse with a false back section that covers the earthtubes (with similar side vent as described above) but still allows a dog to enter and use the completely separate front section.

Whatever you do, be sure to protect the tubes from someone sitting or leaning on them so they do not break, and to keep anything

from entering the opening except for air (no rain, debris, toys, rodents, leaves, etc.).



DOGHOUSE
(to disguise an earth tube)

Doghouse disguises and protects a tube air inlet

Another idea is to have the tubes rise up for use as not only vent intakes, but could be disguised as light posts if some sort of outside lamp is placed on top.



Option: place lamps on top of these vent posts
(source: enob.info)

Next I will cover the opposite end of the earth tubes... the exit/outlet ends where the cooled (or heat tempered in winter) air enters the house.

INSIDE: Floor Registers and Side Vents

The diagonal sections that come up inside the house (exit/outlets for the air) are handled very differently than the inlets. You will have the choice of putting these tubes up through the floor with a floor vent, or at the lower part of a wall so they will have a side vent into the room. Each option has its pros and cons.

Utilizing floor vents are probably the easiest as the tubes come straight up and out of the ground anyway. Sometimes it is hard to tell exactly where these tubes will arrive at even though one “plans” it on paper. We purposefully placed our tubes in a general “off to the side” area of our rooms when we designed our passive solar straw bale house so that it did not matter if they wound up a few inches off of the ideal spot.

That method worked well for us, but the tubes can be placed as specifically as the skill of the builder allows, as well, much like the exact placement of plumbing for toilets and tubs and sinks. Remember also that the extra thickness of the couplings, or an error in calculations can sometimes throw it off by a few inches over the course of the earth tube’s length.

In the following picture you can see at least one diagonal earthtube (center of photo) inside the wood that defines the house perimeter:



Preparing our house foundation



**Diagonal outlet tube (on right) inside
the house perimeter**



You can see three earthtubes sticking out of the ground (leaning to the right) in this photograph



**Good view of the earth tubes exiting the ground.
Notice a coupler is holding on plastic grocery bags
so dirt and debris are kept out of the tubes**



That is me (Sharon) walking next to a tube



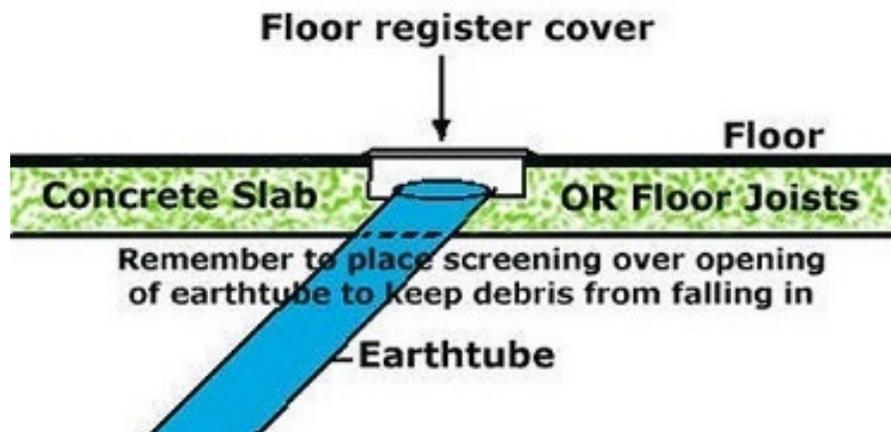
I am standing facing my 2-year old son Jeremy, near me are two tubes that are the “Y” extensions off of a single underground tube, while the one behind Jeremy (right bottom of photo in the shade) is a single tube outlet

If your tube is designed to enter the building so as to have air exit a vertical wall vent then you had better make SURE that your calculations are correct, and that your work is error-free so that you can ensure the wall will be placed at the tube end, or you'll be having to fix it by adding lengths (and hopefully not elbows or you'll stifle the air flow more) or else moving the entire interior wall! You could work backwards and start at the wall vent, and begin gluing the PVC parts together as you work, heading away from the vent and away from the house. However, if you overextend your tube length past where it should enter the wall (for a vertical vent) then you could simply put in a floor vent instead.

When making a floor vent for a house that is being built, it is a rather simple process. Make your earthtubes first, along the lines of when you are doing your plumbing (if underground). Just make sure

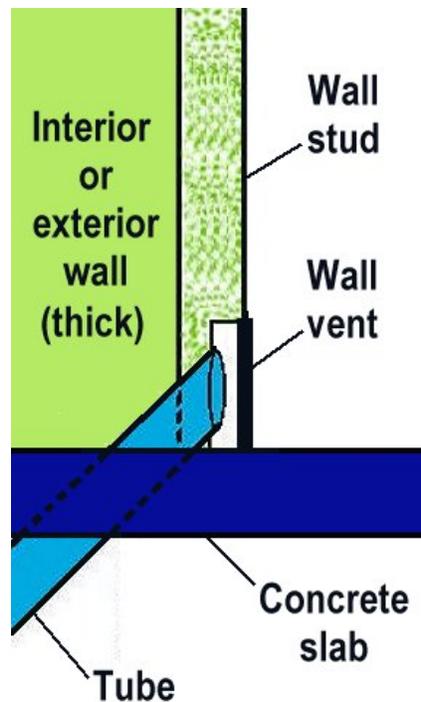
that a *couple of feet* of tube are sticking out *above* the ground and that you cap them with a piece of strong plastic and a coupling temporarily (to keep debris out... this is VERY important).

Once your concrete slab is poured (if you go the route of slab on grade for construction of a rancher style house, or similar) then the tubes will already be there, in place. First, you will have to make sure that there is a small box or some kind of receptacle placed there to create room for the floor vent when it comes time to put in the floor registers (before pouring concrete or else you will have to chip out some of the concrete later on). Once your floor is in, the excess tube (which was sticking out) is cut off, then you build a box (use green treated lumber), if you haven't already, then place the pre-bought and/or pre-measured floor vents on top and you're good to go!



Using a floor register vent for earthtubes

Vertical vent are similar in that you need to build a box to house the tube at its opening, which serves as a transitional piece between the tube itself and the vent cover. Vent covers are usually oblong, and the tube is round, so building a box around them allows for the vent to have something to attach/mount to and so you can screw in the vent plate cover.



Vertical wall vent for air outlet (into building)

Do not forget to paint the wood (optional) and use 100% pure silicone (the kind that comes out of a tube, squeezed out with a caulking gun) to seal around the edges between the slab and the earth-air tube, and all corners/edges of the interior of the wooden box. The silicone seals the box to reduce air infiltration or loss. A metal box can be made instead of wood, depending on preference or skill level.

If you have a house with a crawlspace instead of a slab then you can simply place the tubes up into the floor or walls from underneath in a similar way as the image above (with the slab being the floor joists instead).

Floor registers are easier to make (compared to wall vents) but tend to get debris that fall into them, or dust bunnies that collect inside, which can seriously and adversely affect the air quality over time, so it is important that the boxes are kept clean and that nothing is allowed to fall down into the tube itself, even if that means you place another window screen over the opening at this outlet (into the house/building) at the tube opening. A coupling can be used to hold it on if there is room, and if not you can staple or attach the screen to the interior of the box over the tube opening.

If you make wall vents then the cleaning process would be much less often and less worrisome, although make sure your walls are either thick enough, or that they are designed well so they do not stick out the back side of the wall when they come up through the floor or ground.

NOTE: Having earthtubes designed in on paper (usually in the house plan drawings, by an architect or someone who has taken residential drafting) is always a good idea. Sometimes you can get plans like this drawn by second-year drafting students at your local college/community college for a discount. I took all of my manual drafting (minus AutoCAD) in college so was able to not only design the earth tubes for our straw bale house, but also drew up the house plans myself before we built it all. The more you know how to do, the less you have to pay others to do it.

HOW TO MAKE EARTH TUBES WORK

Once your house/building is constructed, then your earthtubes can be opened up and are ready to be used. Readyng your earthtubes will consist of a few steps...

Ready Your Earth Tubes for Use

Remove any plastic or coverings you have had on your tubes during construction. Next, make sure your screens are clear and not punctured or clogged up with spider webs, debris, or dust (at both ends). Use a vacuum extension to clean the exterior sections, if needed, or if the screens are torn just replace it.

Remember not to let any dust or debris fall inside of the tubes! If this happens you may want to get an extra-long extension for the tube of on your vacuum cleaner, and ensure that it washed first, before you stick it inside the earthtube to suck up anything that might have fall in.

If a small toy or object falls in, then perhaps a pair of those reacher-grabber tools to fish out the object, and if it is metal you can sometimes use a magnet attached to the end of a pole to pull it out. You can use a ground camera (such as a plumber/contractor would use) to check inside the tube for possible obstructions, if needed.

IMPORTANT: It is very important to keep the earth tubes clean! The last thing you need is reduced air flow or lung problems due to bacteria or mold growth.

If you ever have any doubts concerning the use of an earth tube because of lung or respiratory problems, then cap or plug off the tube(s) in question until it can be properly investigated using an air quality specialist/company.

I have not heard of any lung issues from a dirty earth tube happening before from anyone I have known, but I have heard it is possible. Some people are more sensitive than others, as well (for instance, I refuse to use ozone-producing air purifiers in my house because over time they cause lung damage, and I cannot breathe if I am in their presence for more than a couple hours).

Treating Earth Tubes Problems with Ozone

Speaking of ozone-producing air purifiers mentioned in the last section, although the EPA (Environmental Protection Agency) says one should not breathe even small amounts of ozone because of the potential lung damage over time, these machines can be rented (even used car companies use them to get rid of cigarette smells and biological or bacterial issues inside of used cars) to treat potential earth tube problems.

There are some people who have put a bleach-water solution down the tubes to disinfect them, but if mold growth or other issues are growing on the inside walls, then a trickle-stream of solution flowing down the bottom (and exiting out the first hole or two in the bottom) will not even touch it, so I do not recommend this method. If the tubes were the type that had no holes in it (some people use sloped solid tubes that exit into a sump pump area instead of holes in the tube that allow condensate to drip into a gravel base) then perhaps a bleach solution would help the very bottom of the tube, where some debris could collect, but it would still not come in contact with the sides and top of the tube, so would be an inferior way of cleaning the tube overall.

Instead, I would suggest using an ozone generator to clean the tubes of possible contaminants. Do not go suing me because I told you to do this, especially if you have a recurring issue that you have not remedied prior to using the tube(s) that were having the problem(s). When in doubt, be safe! That said, again, bleach water is not my personal best choice, but I would use an ozone generator, but do not breathe it in!

IMPORTANT: Do not use ozone generators in rooms where people are present! Be sure that any ozone generated is tented/sealed off, or directed through the tube from inside to outside, or separated from where people live or breathe.

An ozonator/ozone generator could potentially be placed at one end of the earth tube (from inside the house) so that the ozonated air

is forced directly through the tube to the outside, which over the manufacturer's recommended period of time could easily render any earth tube safe again from any bacteria or molds that may have been present. Ozone kills odors and living organisms such as fungal species, black mold other molds, algae, viruses, and bacteria. These machines are used in houses and commercial buildings that have been tented and are used to treat the building—even permeating the walls themselves—to kill mold and other contaminants. This is a simple and relatively inexpensive solution to any potential problem, if it even occurs at all. Be sure to go by the manufacturer's directions as for how long to run the generator and at what setting.

REMEMBER: If something is contaminating your tubes you need to eliminate/remedy the source of contamination before treating with ozone and especially before using the tubes again.

As I have stated before, the tubes we built in the mid-1990's were used for many years, and they worked very well (until someone damaged them, then they were put out of commission). Others I spoke to and have read about are still in use, even 25 years later since their construction. If the tubes are kept clean, then there are typically no serious threats or problems.

Through time, including as far back as to ancient times with qanats in the Middle East, people have utilized these air-water tubes buried in the earth for cooling with wonderful success. Follow the rules and you should have little to no problems.

Remember that brand new earth tubes should be clean and ready to be used right away and should not need decontaminating at all, via an ozone generator, or anything else. Just be sure you have kept dirt and debris out of them during the construction process. Only older tubes would need cleaning IF they have problems. Fix the problem first, then clean them... this is common sense.

Now that your tubes are clean and ready to go, I will cover how they can be used in the summer for cooling, and then I will go into how they can be used for heat tempering/warming in the winter as

well as for feeding tempered air to a fireplace or woodstove to save on energy costs and reduce otherwise wasted heat.

Summer Use (Air Conditioning)

Summertime use of earth tubes is the reason I wrote this book. These worked so well for us, and were so easy to build, that I would do it again in a heartbeat; in fact, I cannot imagine ever building a house again without them, and have rented in places that I wish they had them (especially after having to pay high energy bills for using air conditioners or even heat pumps. I personally think everyone should utilize earth tubes in their homes, and builders should put larger versions of them into commercial buildings and residential-commercial buildings such as apartments. To not use them is, in my opinion, asinine, unless there is a clear indication in a certain region where it is prohibitive.

Why spend many hundreds of dollars every single month, every single year, for the lifetime of the house to cool it via an air conditioner that is energy-wasteful when you can pay a few hundred dollars ONCE and literally get FREE air conditioning for the rest of your life!

Step 1: Close up the house

Once your tube ends are free of any obstructive materials and the screen(s) are clean, then you will want to close up the house completely. This means keep doors shut and windows shut. Next you will be opening *one* window, but it has to be very specific to make the earth tubes work correctly, which I will cover in the Step 2...

Step 2: Open one or two high windows

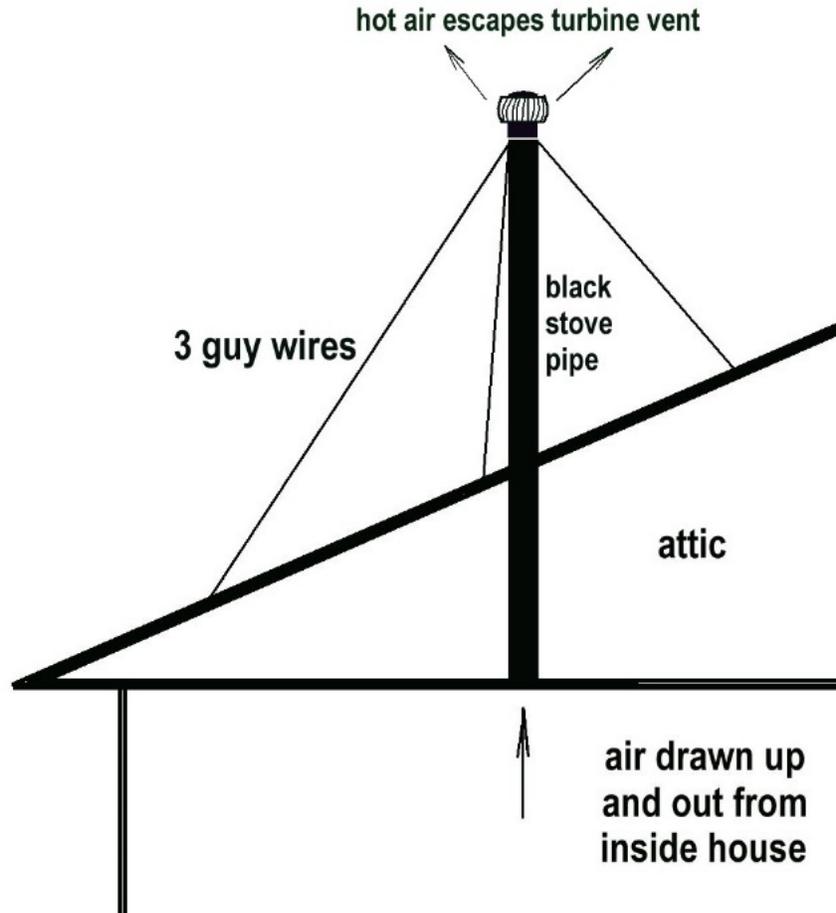
Once everything is shut up tight, then open only ONE window (preferably located as high up in the house as possible, such as an upstairs bedroom, attic room window, or cupola window), which should probably be opened part-way. If your house is long and wide, such as a single story slab-on-grade rancher/ranch-style house then perhaps opening up one window on each end of the house could help draw air through more evenly throughout, but just crack open the windows a little less.

It is good to use a window that is near to where you “live” at or frequent in the house, or else, if you want it to circulate through the entire house then you’ll want to open a window at the far end of the house to pull the cool air through your home.

If you have a two story (or more stories) house you can also install vents in between floors that allow air flow from lower to upper floors (these also help distribute heat more evenly in winter, especially if you have earth tubes for geothermal heat tempering, or a heat source on the bottom level). Another option is to allow the air to naturally flow up the stairwell and through hallways.

Alternatively, besides windows, you can even open the flue in an upstairs fireplace, or use an attic vent fan. Many attics absorb excessive heat, so allowing that hot air out and drawing cool air in will also lessen the load for cooling the house since it does not have to fight against the heat stored up above the ceiling.

Another alternative to using an attic fan or vent is to place a rotary turbine vent on top of a *single-wall* black woodstove pipe vent. The black pipe should rise above the roof at least 6+ feet (1.8 m). Using a 10’ (3 m) section is best, although you will want to use guy wires to tie down the pipe so it does not bend or break in the wind. Single-wall black metal absorbs the sun’s heat quickly (do not use double-walled pipe as this is insulated and will not heat up in the sun!). As the pipe gets hot and heats up the air inside it, it causes the air to rise inside the pipe and will start the suction process from the bottom of the pipe up and out the top. This method can be used on homes that have problems drawing air up and out of the house. Some people also put a clear tube or glass over/around the pipe to heat it up via the sun to create draw.



Black stove pipe with turbine vent

We used this black stove pipe and turbine vent concept on a composting toilet we had, using 4 inches (10 cm) PVC pipe inside the house (from the toilet), and attached the pipe from the roof edge on up. Flashing and tar are necessary at the roof joint where the hole is placed to allow the piping to go through, and guy wires hold everything securely, especially when the winds pick up. Again, this is not usually necessary for earth tubes (we certainly never needed it) but it could be an inexpensive way to draw air out of the house in a corner (lacking a window) that is stagnant and not cooling down properly due to a lack of air flow. Just something to be aware of as an option in unusual cases.

Open 1-2 of these to allow hot air to escape the house:

Single story home

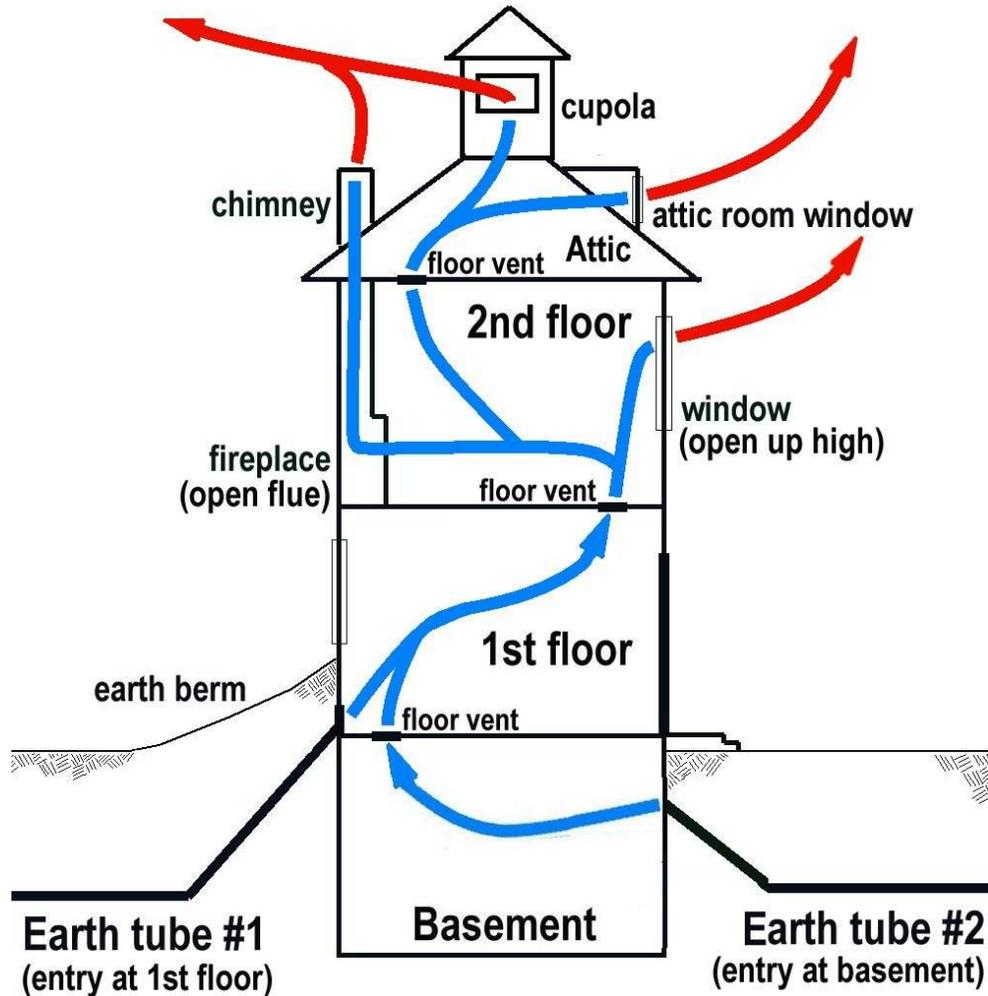
1 window (open at top, if possible)
2 windows on opposite ends of the house (cracked open)
Attic vent/fan (crack open ceiling access to attic also)
Open flue on chimney or woodstove (open woodstove door/vent)
Cupola window
Black stove pipe & turbine vent

2+-story house

1 window on top story
2 high windows (not in same room—cracked open)
Attic vent/fan (crack open ceiling access to attic also)
Top floor only—flue on chimney or woodstove (open woodstove door/vent)
Cupola window
Black stove pipe & turbine vent

Using a window is easiest, but the person that bought our straw bale house near Dwight, Nebraska uses the flue from the woodstove to allow air flow out of the house, which works even better since it does not cause security issues.

Open 1-2 ONLY in Summer



In the figure above numerous options are shown for high windows or openings that you can use for letting out the air that rises through the house. Remember that only one or two (at most) should be open, and no more, or else hot outside air will start coming inside and heat your house up to the same temperature as it is outside. Keeping all doors and all the rest of the windows in the house closed tight will ensure that the proper draw will occur through the earth tubes.

Since hot air rises naturally and cool air falls (convection), an open window will cause a pressure difference inside the house so that the warmest air escapes and the cooler air is drawn through the earth tubes and into the house. The air will naturally warm up a little

once entering the house, and it will want to rise again, keeping the pressure difference going at a nice slow air exchange rate.

Notice in the figure above how the air is made to cross the room before it escapes upwards to the next floor? Hot air rises, so as the cool air exiting the tubes warms up naturally, it will seek out the highest areas to escape. The best windows or openings to use for your exit will be across the room. Knowing this might also help you place where your earth tube vents should go during your house plan designing stage, since you will want to sit between where the vent comes out, and where the air escapes to; this way you ensure you have a “cross breeze” through the room and can stay cool in summertime.

This air movement is basic Feng Shui 101... understanding the movement of energy. Allow the air to move through the space without hindrance, and let the air leave the building in a natural manner. Do not try to block it or impede it by making it round corners as if in a maze. Warm air will naturally rise, so if your earth-air tubes are at the lowest level, it will go up and out wherever it can escape from. This is a simple process—nothing complicated here.

Slow vs Forced Air Flow

I knew a contractor who wanted to put in an air reducer on the pipe/tube (restricts air flow by squeezing it into a smaller space) and attach a fan to the pipe so that it will force-cool the air more quickly. My view is... why? Why add things that are not needed? Why make it more complicated than it needs to be? Why spend more money (which is wasteful, in my opinion)? Why have products that will inevitably break down and need replaced? Why force something when nature already knows how to do it without extra assistance? Why force anything in life when nature already has perfected it? Be in tune with nature.

A pipe in the ground will exchange thermal properties between the ground and the air, but the source of temperature in the earth, although stable throughout the matrix, is not as stable when it is

depleted by too much air drawing from it too quickly along the interior surface of the earthtube. Close-looped systems are not inexhaustible sources either. Just keep this in mind when trying to make the tubes to do something they may not be designed to do. Altering something that already works without any assistance, by forcing things, is unnecessary.

“In a truly successful earth tube design, the pipes are long enough and the flow speed is low enough that the exchange between the earth and the air happens at a rate the earth around the tubes can absorb. ... if your tube is too short or your air flow is too high, or your ΔT is too great, you could quickly exhaust the thermal difference between the air and the soil near the tube.” –
homeintheearth.com

Even a solar-electric fan that runs in the day to assist air flow might help blow air through the tube, but it also might hurt matters by not allowing it to condense the moisture out of the air so may not cool it properly... let nature work as it is supposed to. Why not save the \$\$\$ and have something that will work for the lifetime of the house for FREE! Earth tubes are tried and true, and reliable. Why mess with the design?

SLOW AIR FLOW IS KEY: Earth tubes work because the air flow is slow and natural. They work on natural principles of convection (which causes air flow) and condensation (which cools the air). The slow air exchange rate is constant and works best without wasting money on forced-air fans or electric-sucking

devices. Fast-moving air robs the earth of its stable temperatures before it can replace it, and will reduce efficiency. Slow it down!

All we need to do is harness what is already available by using a design that works. Sure, a forced-air fan would cool the house sooner (if it is already hot), but only initially, and does not really add any benefit past the initial cool-down. This is also only true for standard constructed houses, not energy efficient or *PassiveHaus* (a “Passive House” energy efficient home) designs, which should already remain very cool comparatively.

A properly designed house, which is passive solar in design, insulated well on the exterior walls, with plenty of thermal mass on the interior of the home, will already have features in the overhangs and window placement that will keep the sun out in summer already, so the house will not be too hot to begin with. Earth tubes would simply keep this thermal mass cool and at stable temperatures. There would be no need to *force* anything.

Additionally, with earthtubes you should not have a problem with indoor air pollution caused by smoke or odors as the air will eventually be replaced with newer fresher air from outside, which is drawn through the tubes for a healthy air exchange rate. Earthtubes act as your home’s lungs!

For those with allergies this could pose a problem since it might bring in pollen from outside, but usually the water condensing on the inside of the long tubes, will cause much of the pollen to drop down with it therefore cleaning the air somewhat, at least so I have heard. Air filters also help in this regard (especially HEPA air filters), which are a practical idea in cases like this—just be careful that any air filters do not reduce your air flow to the point that it stops your earth tubes from working (in this case a slow-moving forced air solar-electric fan might be a good idea).

Weatherizing for Fall/Winter

Weatherizing your earth tubes in the fall is only done for tubes that are placed above the frost line, such as mine were. Tubes placed below the frost line can be used to warm the house in winter as a heater-assist feature.

In the meantime, assuming you have tubes that can only be utilized in the summertime for cooling, you will need to know how to close them off in the fall so they will not make your house too cold during winter.

IMPORTANT: For tubes placed above the frost line, you will need to block off the tubes at their openings (inside the building) to keep them sealed during wintertime.

To seal the tube openings is simple enough, I was originally told to just get a block of Styrofoam (I would suggest either recycled polystyrene, or a natural alternative like foam that is made from mushrooms, or some other sustainable alternative) and wrap it in a plastic bag (or recycled plastic/eco-friendly plastic-like bag that can serve as a vapor barrier) and stuff this down fairly tightly (not too tight as you need to pull it back out before summer!) into the box between the tube opening and the floor register/vent. Do NOT put it into the tube itself.

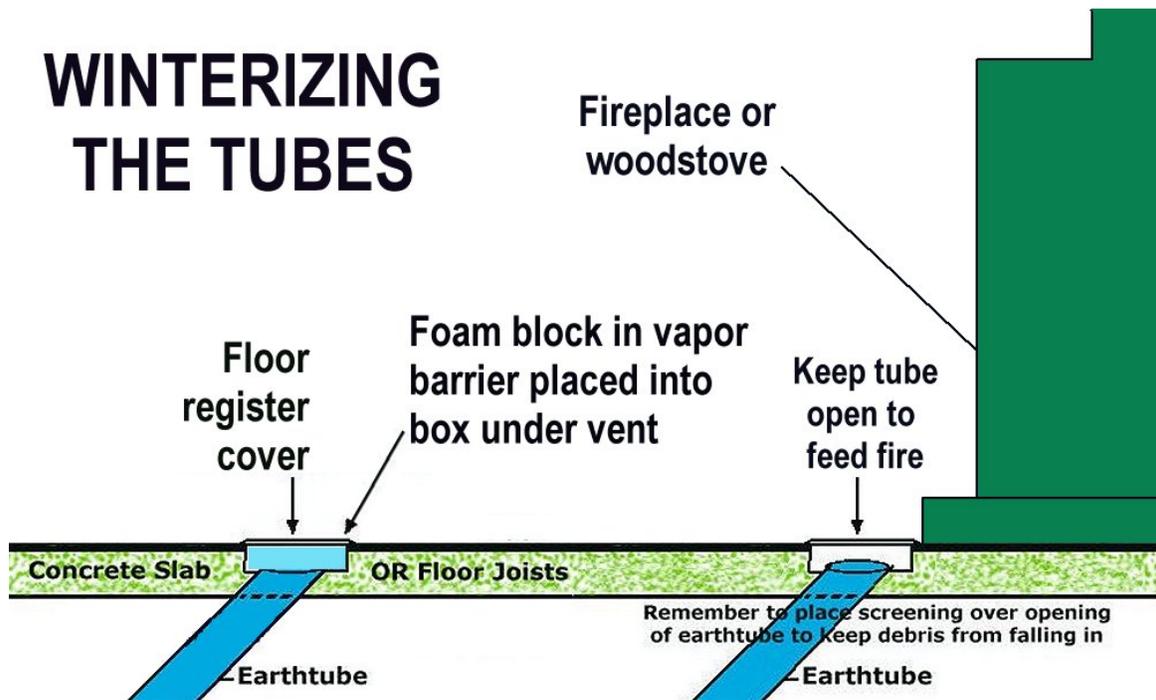
You could also use some edible packing peanuts put into a plastic (or eco-recycled-plastic-like) bag and stuffed down into the box under the floor vent, but be aware they are made out of cornstarch—so you may have to be careful that you do not have rodents attracted to eating them. Also, a block of solid foam block generally fits better and is more insulating than lots of small pieces that have larger air spaces in between them, such as packing peanuts.

On second thought, perhaps recycling newspapers by folding them up inside of a bag to form-fit the hole and block the air is a better idea than peanuts. Also, one could use old clothes stuffed in a bag. There could be numerous alternatives you could use. It is really fairly simple.

You will need to open the floor vent cover by unscrewing the little screws holding it on, and then place the plastic-wrapped block into the cavity to seal off the tube opening. This serves two purposes: 1) It

acts as a vapor barrier to keep air and moisture from infiltrating into the house from the tube during cold weather, and 2) It acts as a thick section of insulation to keep cold temperatures from the tube from affecting the warmer temperatures in the house.

WINTERIZING THE TUBES



Do this with all tubes in the house that are above the frost line, with one exception... if you have a tube that feeds air directly to the front of a woodstove or fireplace, then you may want to keep that one open to bring in fresh outside air (which may be slightly tempered air, depending on how deep your tube is compared to your frost line) to feed the fire. This keeps drafts down in the house and therefore keeps it warmer inside.

Fires eat air; they suck much of the air from the house's interior up and out the chimney to the outside, so the more you can keep already-warmed air inside the house, the better. Let the tube feed the fire colder air from outside instead of robbing your heat from inside the house. To properly feed the fire the air from the earthtube, just make sure that tube's metal vent comes right up to the front edge of your fire/woodstove.

IMPORTANT: If one earth tube feeds a fire, be sure to place a metal screen with very small holes underneath or over the vent opening to keep embers from popping into the tube and melting it or causing a fire in the box. A metal (vs. wooden) box would be a good idea here.

To reiterate, if you have earth tubes that are at least two to four feet (a metre, more or less) down into the earth then you can use them in summer to help cool the house, but you will not be able to use them to temper the air for use in winter unless they are much deeper. That brings me to the topic of using the tubes during wintertime...

Winter Use (Heat Tempering)

Earth tubes can be used year around if they are placed deep enough. Generally, you will want the air-tubes placed 6 or more feet (2 metres) down into the trenches to utilize proper geothermal temperatures that produce temperature stability in winter. You will need to go even deeper if your frost line is below this depth. Anything a bit below the frost line can be used year-around to help warm the house. Anything above the frost line can only be used in summertime to cool the house.

So how can you use the earthtubes during winter to utilize the natural heat from the ground? In the past I would not have recommended for all your earthtubes to be open as it does not really “heat” your house, but only pre-tempers the air instead; however, having tempered air inside your house is better than heating all the air from scratch.

On the Green Building Advisor website, the article *My Earth Tube Story: Buried ventilation ducts represent an absurdly simple and cheap source of limitless free energy* (April 22, 2014), the author, Malcolm Isaacs, wrote about how well his fan-driven earth tubes heated the air going inside his house during winter:

Despite one of the coldest winters for many years, the earth tube has consistently provided a dramatic temperature lift to the incoming ventilation air. On the coldest morning of my monitoring period, at an outdoor temperature of -17°F [-27°C], the supply air was entering the HRV at 36.7°F [2.6°C], for a delta-T of almost 54 F° [30 C°]. That’s consistent with the past month of measurements, during which I’ve seen the supply air temperature entering the HRV fluctuate mostly between 37.4°F and 39.2°F [3°C and 4°C], depending on the outdoor temperature.

The data log plotted below for the 10-day cold weather period starting February 26, 2014, provides more detail. ...

This past month, the houses in my town all had continuous infiltration of -4°F [-20°C] (and colder) air, while I had a flow rate of 60 cfm entering the house at an average temperature of 39.2°F [4°C]. It’s hard not to feel smug.

I can’t wait to see the earth tube performance in hot, humid weather. My guess is that air at, say, 86°F [30°C] and 80% relative humidity will be conditioned down below 68°F [20°C] and 40% RH. And in my installation, the

underground condensation will flow right back down the 45° slope to a drain sump.

In a very high performance house such as this, with good summer shading, this will be all the air conditioning I'll need. And the real surprise is that this system runs off around 50 watts of fan power. Would I do it again? Absolutely.

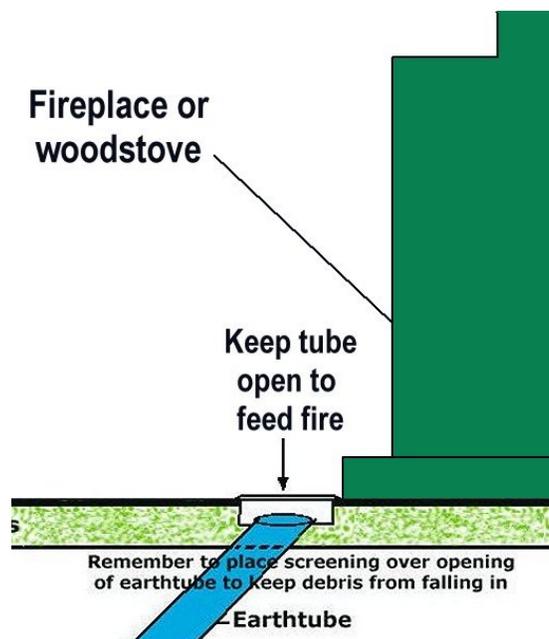
By the way, HRV stands for Heat Recovery Ventilation and is usually a heat exchanger (they have not been found to be helpful when used in conjunction with earth tubes, in fact quite the opposite based on most sources I have read). This example goes to show that even if you do not adhere to strict rules, or have a few challenges in building the earth tubes, it can still be done with great success. Our tubes were not used for wintertime because they were only two feet (61 cm) down they still worked great in summer; so using earth tubes in winter is easy, just bury them deeper! How complex or simple you want your earth tubes to be is up to you. I always prefer simple and elegant to complicated and expensive.

Interestingly, although HRVs (or MHRVs for mechanical units) are not very good at helping out earth tubes, earth tubes are wonderful at helping out HRVs! Andy Swales, who has both at his 168m² (roughly over 1800 sq ft) house, told me, "It's snowing and freezing here today so, of course, the ground tube is earning its keep tempering the air before it goes through the heat recovery ventilation (HRV) unit. Normally, in higher latitudes, HRV has to have a condensate drain and be protected from icing from but used in conjunction with a ground tube these problems all but disappear." A picture of his single earth tube is below, along with what Andy says about it.



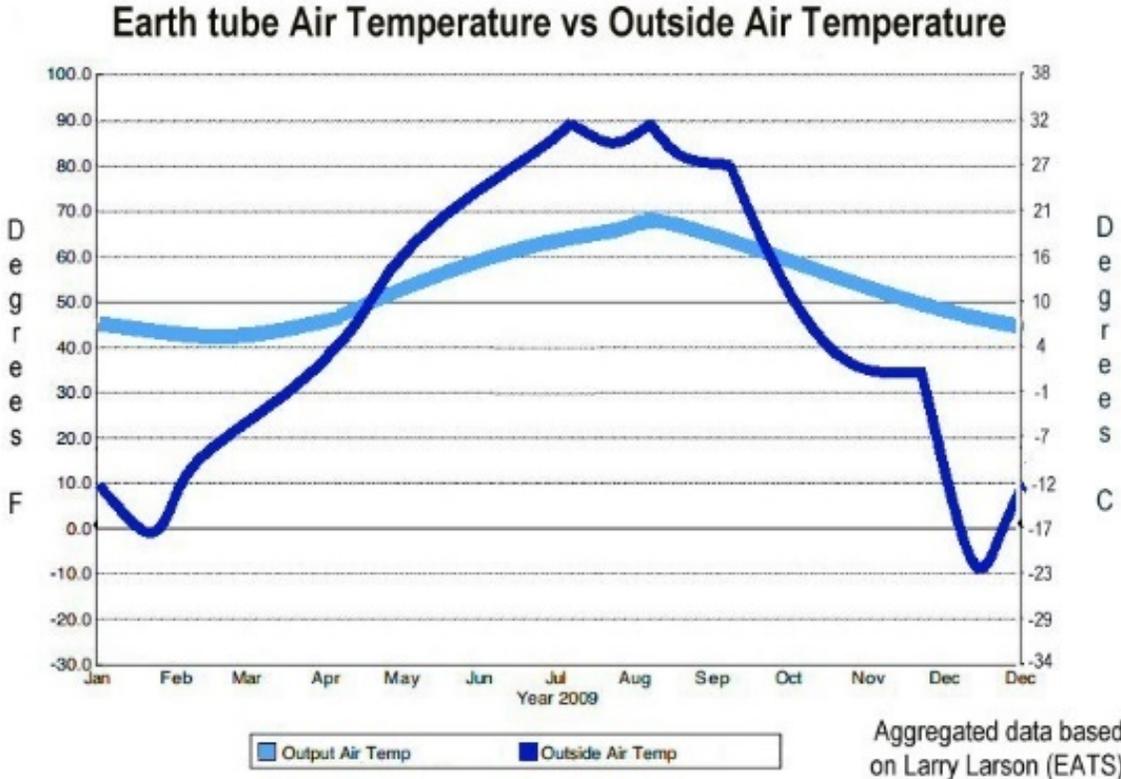
**This is the Provençal well (sub-soil heat exchanger) before being buried. In winter it pre-heats the ventilation air to 12C, conversely in summer it pre-cools it.
- Andy Swales (Selkirk, Scotland)**

Speaking of wintertime, you will want to be sure to feed any air-consuming fires from a woodstove or fireplace (some people even feed their furnace this way) with an earthtube dedicated for this purpose.



This single earthtube is usually only used to draw in tempered air to feed a fireplace or woodstove or furnace. Make sure that earthtube comes right up near the edge (within 3' (1 m), but preferably set as closely as possible, within inches/cm is best) of your heating source, but not so close it will melt anything.

I have stated it before, but will do so again in this section because it is entirely relevant. When you have a live fire burning in your house from one of these heating systems it burns the oxygen that is in the air in your home, therefore causing a draft around windows, doors, and any other leak in the house walls, ceiling, etc. Instead of feeling this cold draft draw across the floor (and your feet!), the earthtube can be set directly in front of, and close to the woodstove/ fireplace to feed that fire with the warmed/tempered air that exits the tube instead. This makes the fire burn far more efficiently and keeps your house much warmer in the long run!



In the figure above, the aggregated data shows the temperature fluctuations as output through the earthtubes compared to outside temperature fluctuations. As you can see, the extremes of the outside temperatures are hotter in summer and colder in winter than the buffered temperatures exiting the “earth air tubes” (much thanks to Larry Larson, one of the earth tube pioneers, who has passed on as of the year prior to this publication).

In Larry Larson's Q&A about earth tubes being used in winter, the question was posed, and I quote:

Q: Do you shut the tubes off in the winter?

A: No. The Earth Air Tube system is designed to operate 24 / 7 / 365. The Earth Air Tube system is part of a whole house ventilation system that provides natural air conditioning in the summer and fresh pre warmed air in the winter. The air inside of the house is maintained at a positive air pressure. Infiltration problems that create cold draft problems in the winter suddenly become points where air can exit the house. This makes room for more pre warmed fresh air to come into the house from the Earth Air Tube system. For fresh air in the winter it is better to heat pre warmed air than to heat the zero degree or below temperature air that leaks through every crack in the house.

Unless your house is extremely air tight most houses will have enough ambient leakage to provide enough positive draft for replacement air to come in through the Earth Air Tube system. This often provides more air exchanges per hour than could ever be achieved with simple makeup air systems using a single 4" - 6" duct run to the outside providing passive makeup air whenever the house experiences a negative air situation (i.e.. exhaust fans, hot water exhaust fans, furnace and stove flues). There is one distinct advantage of maintaining a positive air pressure inside the house. It is safer. Passive flues like those found on most water heaters cannot back draft, which can introduce dangerous levels of carbon monoxide into the home.

As you can see, it is useful to utilize earth tubes during winter. Next I will cover a lesson about air quality based on an analysis of Larry's methods of making and using earth tubes compared to what I know and have experienced.

A Lesson on Air Quality

For his earth air tubes, Larry Larson used a corrugated *flexible* pipe in a serpentine pattern, which was designed to drain well. He felt that *rigid* tubing was not good to use because you could not get proper air flow. Interestingly, I was originally told by earth tube users to not ever buy any corrugated pipes (whether rigid or flexible) to use as the tubes, since these would allow water to puddle in them and cause bacteria and mold growth. Larry decisively had well-drained corrugated tubes, however, and that worked well for him. The tubes in his house were used for over 25 years without any problems. I think, based on this, that *proper drainage* is the key, rather than the type of

pipng used, but I could be wrong. Larry also said this on his website at earthairtubes.com:

The tube material is high-density polyethylene formed into the common black corrugated drainage pipe. This pipe has a corrugated structure, which doubles the surface area of the pipe allowing for more Earth contact and more efficient heat exchange. It is corrosion resistant, easy to handle, non-toxic and readily available. The optimum tube diameter is 8", but tube diameters of up to 12" can be used. The larger diameter tubes require a longer buried run for optimum performance. The tube has a single slit cut into it along the seam. This is the condensate drain for the entire tube.

The tube trench has to be very carefully constructed to assure proper drainage of ground water and air tube condensate. An experienced installer should only attempt this construction, as any mistakes can ruin the installation and possibly threaten the health of those living in the house. There are several trench design details that need to be implemented: trench profile, drainage, tube installation, materials used, as well as depth and dimension of the trench according to the diameter of the tubes.

Note that Larry made his living by installing earth tubes (or whatever else), yet he shared his expertise on his website. His 8" (20 cm) pipe, which resembles—in its description—that similar to weeping tile (corrugated flexible pipe with slits throughout—except his was solid and only had a slit down the length on one side) are supposed to be 2' (.6 m) on center if in the same 10' (3.3 m) deep (and equally wide) trench. The wide trench, which would incorporate numerous runs of the flexible pipe with 4-6" (10-15 cm) of pea gravel or river rock underneath, and covered with a filter cloth so it does not clog. This keeps everything clean and the air fresh.

Larry also said to install the tube with the slit facing down, just like I learned to do with the PVC pipe (then covered with sand before backfilling, which in his instructions he admits sand has poor thermal qualities—in fact it is the worst of all soil types for conductivity). The pipe may be different (he even siliconed any holes or joints), but the basic method is pretty much the same. This should promote proper draining and keep soil from entering the tube, and keep the air fresh without the issue of mold or such.

One of the reasons I was told never to use weeping tile was to keep the dirt out of the tube, because entry of dirt through the slits could potentially grow mold or bacteria. Larry had found a successful way to make earth tubes out of corrugated pipe material without that problem while also avoiding collecting stagnant water, so I am impressed. The air quality of the earth-air-tubes was completely dependent on it draining properly.

Also, Larry's air flow, he admits, "crashes around constantly" inside the tube due to the serpentine laying of the tubes in the trench, but especially the corrugation, which I was told would impede natural air flow, but his fan assist (which runs 24/7) makes it a 'forced' system, and thus would help overcome this issue.

I prefer smooth pipe because it allows a completely passive system without all of these technical issues, use of electricity, plus fans that break down. Air exchange can happen naturally or by force, but both will bring in fresh air on a continual basis. Larry admits, "The best system for air delivery inside each of the rooms is low delivery and high returns. This matches the natural airflow the house will experience if it were allowed to convect on its own," but I ask, why not just let it convect on its own to begin with? The air quality is going to be the same, either way, so why spend more for a system that is less efficient and cannot be used without a fan?

Larry also said that standard PVC would not allow thermal exchange, but I was told this same thing, and was instructed to use THIN-WALL PVC instead, which obviously worked super well in our case. The air coming out was cool and dry (dehumidified) properly in summer, as it should be. It also smelled fresh, never foul, musty, or stagnant.

I cannot say whether what Larry used was right or wrong, or if what I was taught to use was correct or not, but I can say that what we did—separately—worked well for each of us. I typically judge my future success by what I learn worked well for others, through sheer experience. I compare systems, avoid what mistakes they made, and hold fast to what did work. My motto is, in fact, "whatever works." This goes for whatever laws are allowed (if it is against the law then that will not work), as well as what experience and knowledge provides us.

When it comes to air quality we must also practice what works, especially as it lines up with the laws and rules of wherever we live, including natural laws. I have heard both that earth tubes are used all over Europe, and that it is illegal to use them in Europe, yet it likely depends on which country you are talking about, or which specific areas within a country.

Based on what I know of air quality, I typically teach that you would only want to use 4" (10 cm) diameter PVC pipes for the earthtubes in a house, and to stay away from clay tiles or products that could promote mold growth due to the material itself or its design.

The old fashioned clay tiles and other products can become saturated with water and cause mold and mildew to grow. Toxic mold is a serious problem in porous materials (including concrete) that are placed underground where damp conditions are a constant. PVC is made for water, and is non-porous as well as having qualities that do not allow normal mold or mildew growth.

My old college instructor and solar home contractor, Dave Carter, explained this to us back years ago when we first were concerned about this problem that has occurred with others' earthtubes. So please stick to the PVC, especially if there is an anti-microbial surface inside, which could be a boon.

Earthtubes are also a solution to the sick house syndrome issue, at least where breathability is concerned. Vapor barriers keep a house 'tight' (air tight), which is extremely important for energy efficiency; however, some claim allowing breathability is superior to energy efficiency because it stops the issue of radon or air pollutants from building up inside the house. I remember when my kids and I would all get bronchitis every winter, that is, until someone in the family stopped smoking inside the house. If we would have had earth tubes it is doubtful this would have been the case, because the air exchange rate would have remedied the problem of poor indoor air quality.

At the website homeintheearth.com radon is mentioned in regards to earthtubes. One family did have high radon measurements but it is important to know why, as explained here:

Many earth tubes are made from flexible drainage pipe with weep holes along every inch of it. This is great for humidity control as it lets moisture in and out as needed, but it also makes it easy for radon to enter the pipe. Sloping the tubes toward the home also makes it a bit easier for the 8x-denser-than-air radon (and water) to enter the home.

Using sealed solid wall earth tubes (such as HDPE double wall pipe) and sloping down away from the house to daylight, prevent both of these problems.

Even if radon (which only has a radioactive half life of less than 4 days) does enter the home, it is really only a concern if it is trapped in the home and becomes concentrated. Actually, this can even happen in “normal” homes with poorly sealed basements and poor ventilation.

Homes that allow for a proper number of air exchanges each day, should not have Radon problems. In fact, a good earth tube system that provides ample air exchanges can actually be the solution to a radon problem.

Another important thing to remember is to keep intact (unpunctured) screens—like hardware cloth—on the earth tube holes at both ends to prevent rodents, dust bunnies, or debris down into the tubes. Rodents urinating into uncovered tubes can cause growth of bacteria, spores, etc., which cause diseases to proliferate among the households’ inhabitants. Legionnaires disease is a very serious disease that can be caused by rodents (or other bacteria) in this way. It can cause severe sickness, and if left untreated can cause death.

Of course, as long as you keep up with the screens all should be fine. They should stay in place and not have any problems at all under normal use, nor have I ever heard of anyone having any problems with this. I have personally spoken with some people in Nebraska (besides the home we built there, and then later sold to a friend who has lived there since 1999) from several communities who built and have been using their earthtubes for many, many years without incident. In fact, they love them and rave about them anytime you ask them about it!

ADDING EARTH TUBES TO AN EXISTING HOUSE

Ideally, earth tubes should be built underneath a house foundation, for ease in installation and placing them in the best spots in the house according to an overall plan. In the absence of this scenario there is no reason why an existing house cannot have earth tubes retrofitted to the home or building, with the exception of there not being enough yard space to accommodate the length of the tubes underground.

There are other options (see the 'spiral earthtubes for tight spaces' section further on), however, for people who are determined to place these tubes in their home to rid themselves of an eternity of high electric A/C bills.

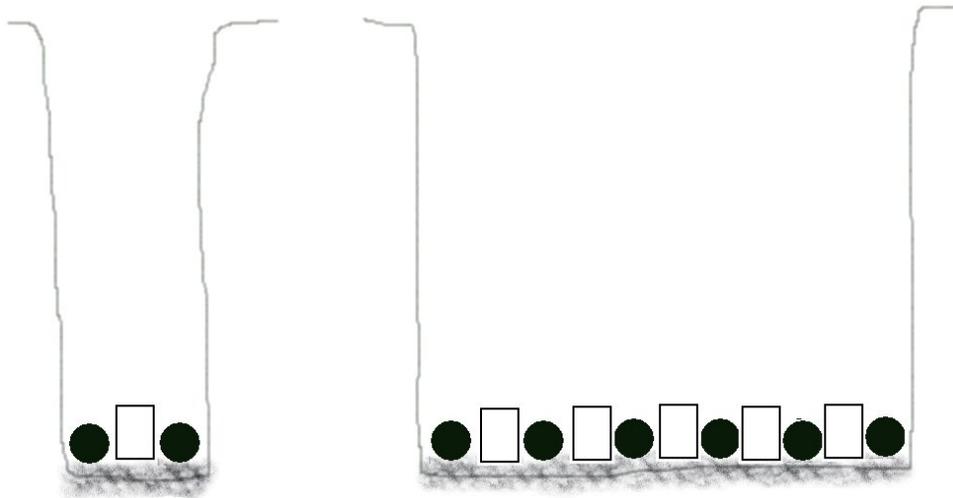
If you have a Large Front or Backyard

Choosing how to lay down your trenches and earth tubes is easier if you have the land to accommodate their length. People in cities, or with small lots are often stuck feeling like they do not have enough space; however, if you have a large enough front yard or backyard then you might be able to build some earth tubes for your use.

Here are a few choices for layout depending on your yard, and this would work even if you have a side yard or extra lot next to your house that you own, to bring in the tubes from the side. Where and how they enter the house is important, but splaying them out underneath the earth in a place where there is room is equally important. You will want to keep the tubes apart by at least a foot (30 cm) on center if they share the same trench, but there is no reason why you cannot excavate a wider trench using heavy machinery rather than using a trencher for a thinner trench.

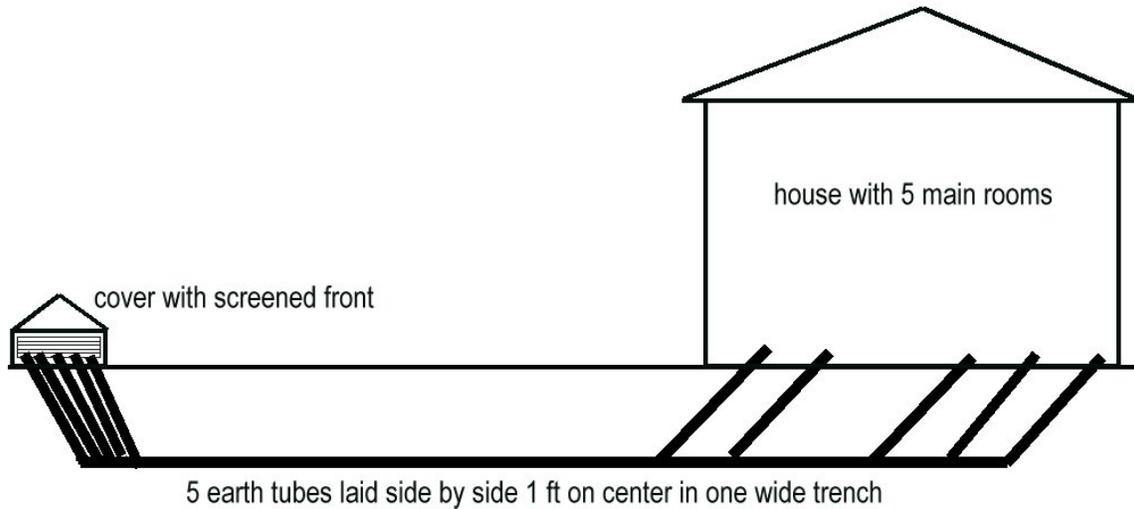
Here are a few choices:

- Two or more tubes in a single trench
- Very wide excavated trench with multiple earth tubes
- Splayed tubes like the sun's rays entering house in one spot (works better with open floor plans)
- C-shaped (half an octagon) trenches/tubes around one side/half of house



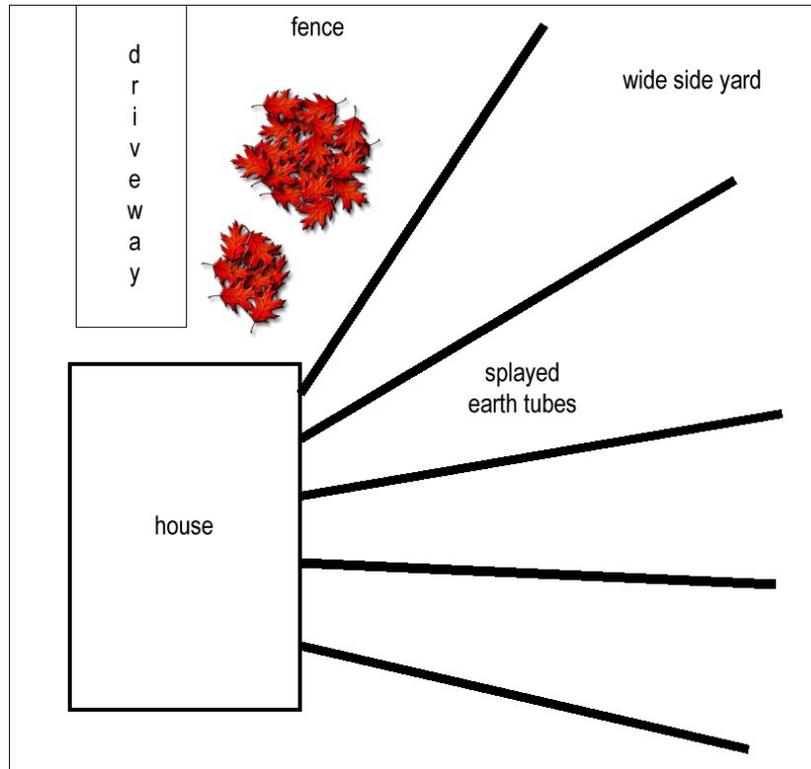
**Multiple earth tubes in wide trenches
with rows of cinder blocks in between them**

The cinder blocks between multiple earth tubes in one extra-wide trench can help protect them from being crushed or from being moved or damaged.



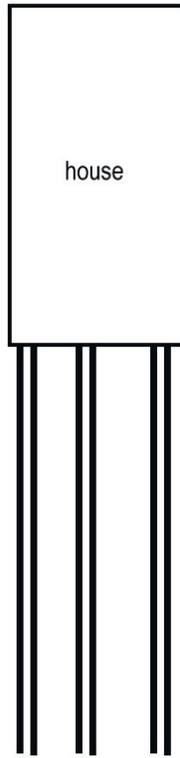
Long yard in one direction

If your yard is long in one direction, but you do not have a wide path then you can put a number of tubes in one wide trench and have them come up from one location outside (see picture: note the screened cover “doghouse” style mini-shed to protect them). They may enter the house at different locations.

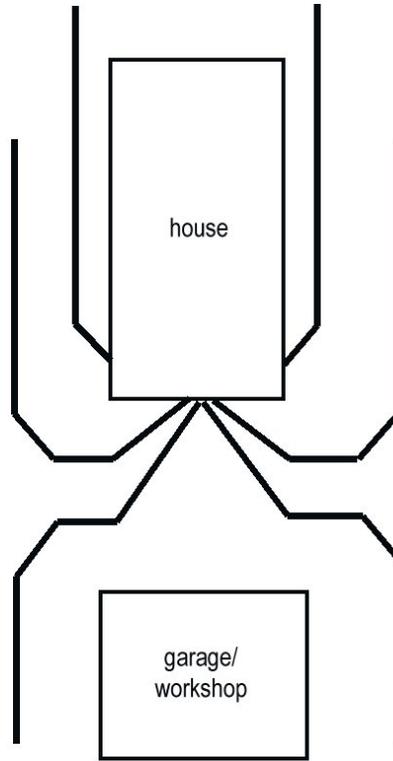


Splay in a wide yard

Placing the earth tubes in a splayed arrangement allows for more room between tubes for maximum thermal transference (tubes too close to each other may reduce their performance), or the ability to go around different objects (trees, sheds, or underground obstructions) in the yard, yet still keep each tube straight (bends reduce efficiency).

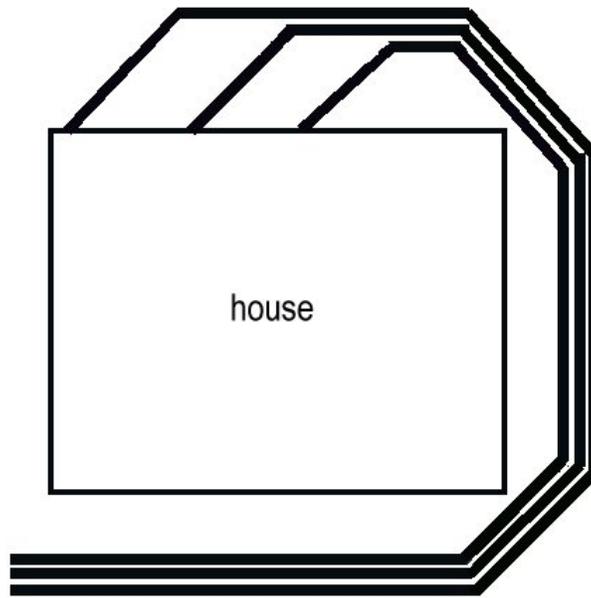


Backyard length



Working around buildings

You can do straight runs if you have the room. If you have to work around buildings and have very little yard space you can do an insect-pattern to fit the tubes in, although this is probably one of the least efficient configurations.



C-shaped half-octagon

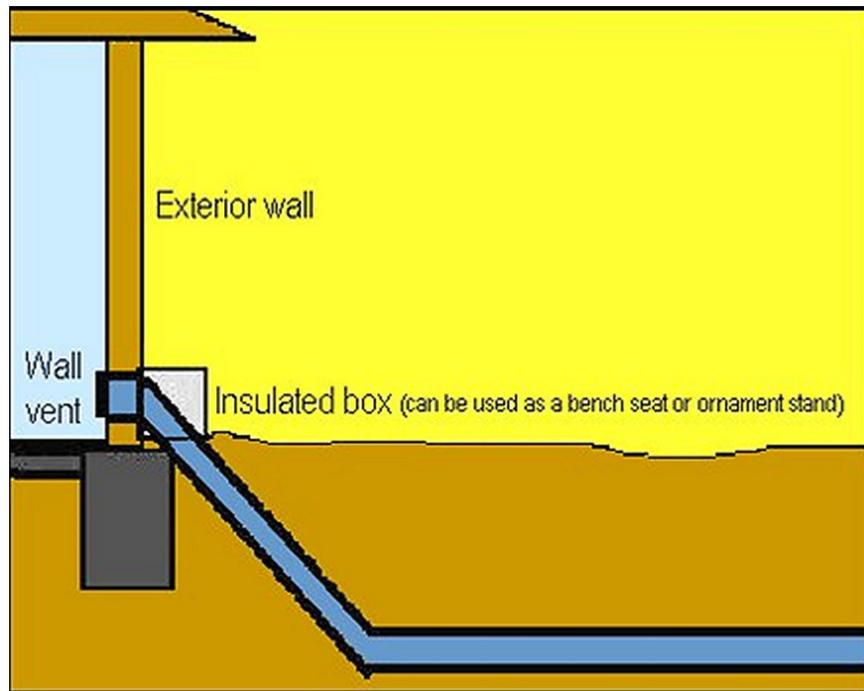
Make sure that when using the C-shaped half octagon that there are no underground obstructions such as pipes or wires or plumbing that would be disturbed or broken by digging here. Also, be aware that once you have a couple of 45-degree bends the chance for restricted air flow increases, so a slow solar fan assist may be necessary.

There are surely many, many more such configurations and ideas that you could come up with, and that people out there already have done, each with their pros and cons. Straight is always best, whenever possible.

Attaching Earth Tubes from Outside

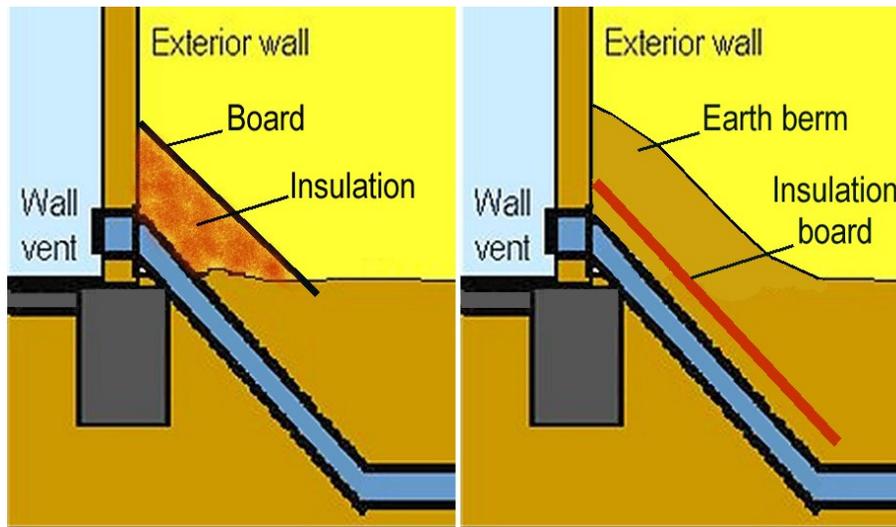
An idea for adding earthtubes to an existing house would be to cut a hole in the outside wall (at the very base above the foundation) and trench it out away from the house from there. Put in a wall vent, place the diagonal part of your earthtube in there FIRST, and then make the earthtube “run” the rest of the way out away from the house. Make sure to place an exterior “box” (packed with insulation) outside over the edge of the earthtube where it comes up out of the ground

and into the outside wall so both UV from sunlight and outside temperature changes do not affect it.



Adding earthtubes to an existing house

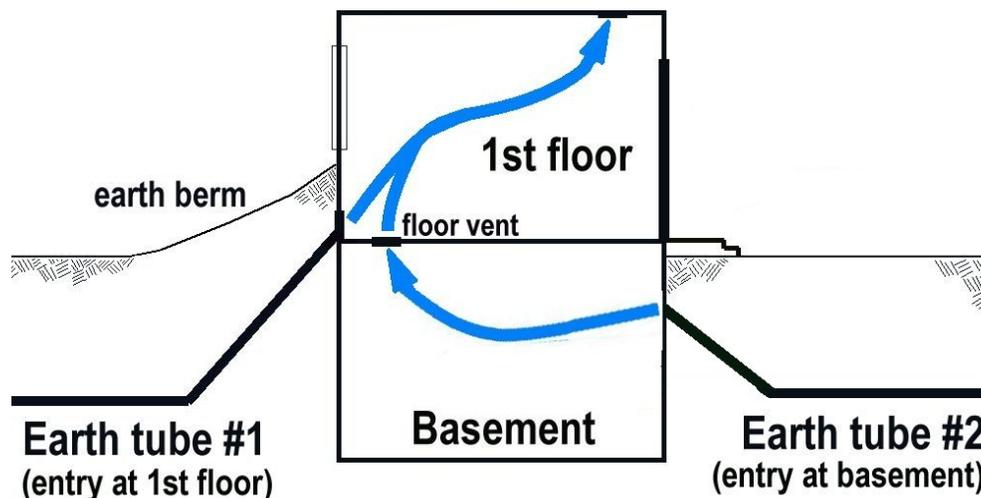
I personally think the “box” idea is lacking in insulating values at the top edge where it meets the house, and the bottom edge where it meets the ground, because these areas are pinched. Boxy is not always better. Perhaps a diagonally-shaped box-top, parallel to the tube, would be a better choice, or an earth berm (if your wall can take the weight, and you should paint on a water resistant barrier on the exterior wall first as well—check with a civil engineer or contractor first).



Alternative ideas for insulating the tube

If you choose to berm earth over the tube where it comes up to the house, be sure to place extruded polystyrene or an environmentally friendly alternative over it as a protection against weather extremes, as shown in the image above, mostly because the berm is not as deep as the buried tube.

Below is an example of how earthtubes can be placed into or above a basement to enter the house. It is important to have tubes angled downwards and away from the house at its point of entry.



Basement or first floor options

Note that in the figure above there are only two earth tubes shown: **Earth tube #1** enters the house at the bottom of the first floor level, and is an example of bringing in tubes to an already-existing house. Notice it is bermed with earth against the lower section of the wall on the first floor. This is not always possible in some houses, but the “box” idea from the figure on the previous page might work too, especially if it is designed at an incline rather than a horizontal-and-vertical standard box shape.

Earth tube #2 above comes into the basement wall, and has an incline prior to entering the basement room. This is mostly for moisture to run back into the tube so water can exit the tube through the holes drilled in the tube rather than dripping into the basement; this design just acts as a precaution. Same goes for radon since it is heavier than air—no sense in having it empty into your house. Normally radon is not an issue as long as the house is not too tight and proper air exchanges occur via the earthtubes and a proper radon outlet. If you have radon in your region then you will want to ensure that you follow codes for the adequate removal of radon regardless of having earth tubes.

SUPPLEMENTAL USES AND RELATED IDEAS

There are numerous ideas that people have utilized to supplement earth tubes, either for air draw via a solar chimney, burying the tubes above grade in hills or earth bermed areas, hiding tubes in foliage, basement and roof options, making spiral earth tubes to catch water, or merely being innovative in their design for other practical purposes. I certainly could not cover them all here, but I will share a few I know about or have at least some knowledge or expertise in.

My goal here in this chapter is not to teach you how (you can likely search online or find a book at the library or bookstore), but to hopefully inspire your imagination to think outside the box and make your home as comfortable as possible by utilizing ideas that already exist—why reinvent the wheel? Earth tubes are an amazing yet simple innovation, but the concept is thousands of years old, and based on what already exists in nature (such as prairie dogs and termite hills and ant beds).

I am certainly not teaching anything new here, but I have done what few have done (earthtubes are not exactly mainstream, but they should be!), so I share it with you in hopes you will learn and spread this knowledge further. Everyone should be using earthtubes (and passive solar design, in my biased opinion) wherever possible to lower energy requirements, reduce electricity loads, save money, and live in comfort! Life should be simple and easy, not complicated and expensive, at least in my view. I have lived both ways, and would definitely build earth tubes again for all the reasons I just mentioned.

One of the best ways to enhance earth tubes is to have an energy efficient house to begin with, either by design (such as passive solar design), or by making your existing house more energy efficient by

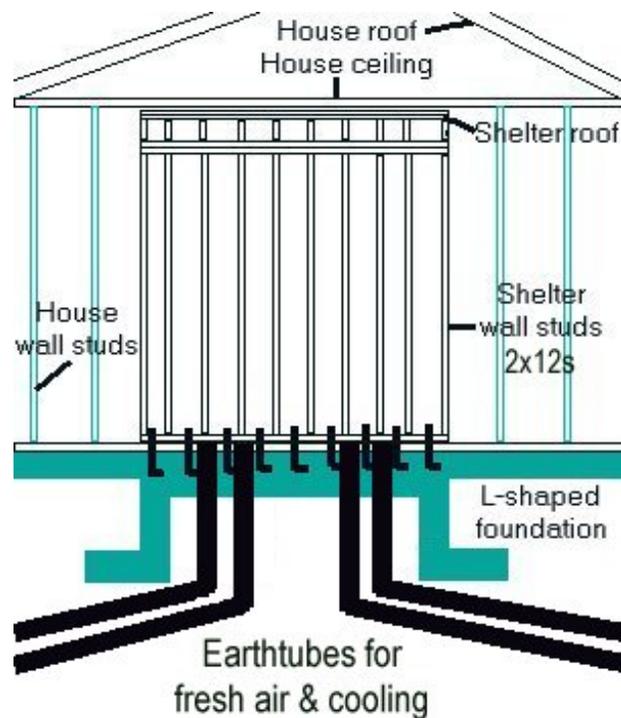
sealing it up and insulating it better, adding thermal mass, and so on. I will cover each of these topics briefly below.

In the last part of the previous chapter I covered how earth tubes could be placed into the basement wall. One advantage to having earth tubes enter through the basement is that it will cool down the cinder block walls (a typical material that basements are constructed from in North America) and will keep the room very cool indeed. In fact, this makes an excellent conversion of part of the room to a pantry or cellar to keep food cool.

Using Earthtubes for a Pantry/Storm Shelter

In one of my other books on solar energy house projects I covered plans for making a pantry with earth tubes as the main cooling feature. Any room where multiple earth tubes are vented into could potentially be a pantry or food closet of sorts, for putting food by for long term storage. This same room, if built extra-strong, could be a great place for a storm shelter, whether in the basement or the main house.

As my earthtubes and solar teacher, Dave Carter said (paraphrased), “What better place to be during a storm, or if a tornado splinters the house above or around you, than in a safe storm shelter where all the food is, plus fresh air coming in from the outside so you can breathe and survive?”



In-the-house storm shelter/pantry

A storm shelter/pantry (combo or separate) can be reinforced with an L-shaped foundation and plenty of L bolts (concrete bolts) every

foot or less to hold the wall system in place. Everything should be bolted (plus screwed, but definitely not nailed) together. Wood glue can be used at all seams for 30% extra strength. Extra reinforcement should be utilized wherever possible, and the wall studs should be made out of 2x12's. Put in a port-o-potty for an emergency bathroom, and shelves for food, and you have a great panic room or storm shelter that can protect you in the event of a terrible or life-threatening storm. It does not even have to be in the basement (which might flood).

This extreme strength is simply not necessary for a mere pantry, however, as only a few earthtubes are needed to keep it extra cool. When using the room as a pantry keep all the earthtubes going to it open (use a few to keep the temperature stable and very cool, with a vent out the top), but if using it as a storm shelter-pantry combo, then only close all of the tubes off except one (so you can keep fresh air in, but not stay too cold) just while you are in there during a storm. Installing thermal mass will help keep this room cool as well.

Spiral Earth Tubes for Tight Spaces

This is one of my favorite ideas, perhaps because I love spirals, or perhaps because it is something I would still like to try. I have heard of others mention this same thing, but have yet to meet anyone who has done it. The spiral earth tube idea would look similar to the C-shape half-octagon mentioned earlier, except that it continues all the way around the house. Because it is a smooth run of pipe in a wide circle, there are also no bends in it, so air flow is not inhibited.

A spiral-shaped earthtube is unique compared to straight runs because it can encircle the house or building since it is made of flexible tubing/piping. If the pipe is thin-walled and smooth, with an antibacterial coating, and no holes or perforations then this would be ideal; however, most flexible tubing that would work (such as being thin-wall plastic material) is corrugated, which usually requires a fan and may have drainage (mold) issues. A non-corrugated pipe should not have these problems.



Spiral tubes around the house underground

Typically bends in straight rigid-tubed earthtubes are not acceptable, at least not any more bends than two or so, but a round flexible hose-like pipe has no serious angular bends, and can flow around the building in one fluid piece (no kinks or elbows), and if placed around the house in a wide circle, or rather several rings of concentric circles (even for a small building or micro-house or cabin) then it is unlikely to cause any serious air restriction on the flow. This makes spiral tubes an excellent space-saving and efficient design, potentially. I have yet to find the right kind of tubing, however, at least that is supplied at a hardware store (it might be found via special order).

The tube could also be sloped downward as it leaves the entry to the house (radon is heavy so can fall this way, away from the house, although in a solid tube radon will not likely enter the tube to begin with). This slope is also important for keeping condensate from dripping into the house.

The slope would cause any condensate to collect in the tube and drain towards the end where a sump pump could pump it out. You would have to keep check on the pump, however, to ensure it is always working, plus have a lead up to the surface of the ground for fresh air intake. The intake would need the same protection from insects and debris or rain as all earth tubes. Instead of a sump you could simply empty it into a deep gravel pit.

Spiral Tube Water Catchment

Another option for the condensate (mentioned above) is to direct it into a catchment container (instead of a sump/gravel pit), such as an underground water tank or cistern, which could serve as a greywater tank for watering plants or such. The water would not be considered potable/drinkable (although it would technically be distilled) unless there was: 1) no possibility of contamination of the water collected, and 2) the tube itself was food-grade material. I am not aware of any food-grade flexible tubing that is at least 4" (10 cm) diameter in long lengths that is thin-walled, so if any of my readers discovers piping that works, please contact me through my website at sunstar-solutions.com.

Although this tubing might be difficult to find for purchase, I love this design because it serves a number of needs... one is a free greywater/emergency-water source, and another is that you can have the tube in a vertically-placed spiral (cylinder-style) in the same trench (saves digging and cost) as it winds over top of itself (with a foot or so of dirt in between layers) to save space. Alternatively, multiple tubes could be placed side by side in the same trench, or even run in different directions next to each other in a wide trench.

One could also berm over the spiral tubes above ground, if desired, to run it higher than ground level. This would allow less digging of deeper trenches, which could be useful in areas with bedrock or a high water table. Berming would have to be significantly

wide, however, to ensure there is enough earth between the outside air and the tube, as if it were placed 6+ feet (2+ metres) underground. I will cover more about earth berming in the next section.

Earth Bermed & Earth Sheltered Homes

Cooling or warming your home by earth tubes is based on the principle that the earth itself is a stable or near-constant temperature, but there are other ways to enhance your earth tubes or otherwise take advantage of the thermal-constancy of solid ground. Pile up the soil!

In addition to using earth tubes you can also cover your house (walls and/or roof) with earth (the home must be structurally designed to handle the load as earth is very heavy, so talk with a structural engineer or architect). This piling up of soil is called berming a house, as in an earth-bermed or earth-sheltered house. In effect, the house itself becomes a sort of giant earth tube, because the temperature inside becomes more steady, and without the need for as much heating and cooling. If designed well, one could consider eliminating the need for earth tubes (at least for A/C purposes, but not for ventilation).

If you live in an area of high humidity, then you could cool your home by earth berming, building an Earthship (tires with rammed earth, which is extremely labor intensive), or utilizing all or partial underground house construction. Earthtubes would be essential at this point if you want fresh air, not to cool the home necessarily, but to remove excess moisture that these homes tend to accumulate. All buildings need to breathe, and in areas of higher radon in the soil, keeping this heavy carcinogenic gas out of your home is as important as letting it out if it gets in.

Some people, especially if living in a hilly area, make above-grade earthtubes by laying the tubes on the ground (on gravel) and covering them over with a very thick amount of soil/dirt via a tractor. This would also work well if a hill was right next to the house as you could dig right into the hillside for both your house and/or your tubes. Insert, in the image of your mind, a Hobbit house from the Lord of the Rings movie, which is a concept many people love; however, this is a tremendous amount of earth moving. It can be effective if you have a lot of extra dirt lying around, especially if your hillside faces south (in the northern hemisphere) so you can use windows on that side to

take advantage of the sunshine for passive heating of your home in winter.

You can also use the same berming idea if you have shallower trenches (or live in a place where you cannot dig too deep due to a high water table, or bedrock, etc.) and do not mind the long and high hill in your yard. An example of a house idea with an above-ground berm would be this bermed house and rock-earth fence combo.



Bermed house and wall

Source: Faerie Magazine Facebook photo
by Viktoras Kaubrys <http://bit.ly/1ODgg15>)

Besides wall systems that are water tight and strong enough to withstand the forces of the earth pressing against them so they do not cave in, there are two features that are often used in berming or earth sheltering a home or building—clay and insulation. Clay is for keeping water out and insulation is for keeping extreme temperatures out of your house.

Insulation, although it does not seem like it would be necessary, actually is sometimes needed for different reasons. If the house's edges are exposed to the outside then there will be an earth-air contact where the earth gets very thin against the house, and stable temperatures only exist where many, many feet (metres) thick of soil are present. Placing extruded polystyrene (blue board or pink board, or preferably an eco-friendly version of such that is watertight and compression-proof (Styrofoam leaks and is NOT a good choice here)

in areas where the soil is not as thick helps act as a thermal buffer to stop or slow thermal lag. The insulation can be placed in a variety of ways, but usually parallel to the wall, somewhere in the dirt between the wall and the outside edge of the berm, is most common. I suggest speaking to an engineer or to what the codes are in your area for such.

In earth sheltered homes bentonite clay is also often used as a layer(s) in the berming process to shed water away from the structure. Clay repels water and is often used in multiple layers that slope away from the house to stop rainwater that soaks into the soil so it does not make its way into the walls or leak into the house. These clay layers, along with earthtubes that help the house breathe, keeps mold and mildew from forming in the house by keeping it dry. Weeping tiles outside the wall near the foundation are also a good idea, but should be used strictly for collecting and draining away water from the foundation (in other words, do not use them for earth tubes!).

Cave houses & Rock Homes

Another version of an earth sheltered (or bermed) house is a cave house, typically cut out into a rock face. The energy efficiency works on the same principle... the ground itself, surrounding the house would be the cooling mechanism, the same principle that stabilizes the temperatures in earth tubes.

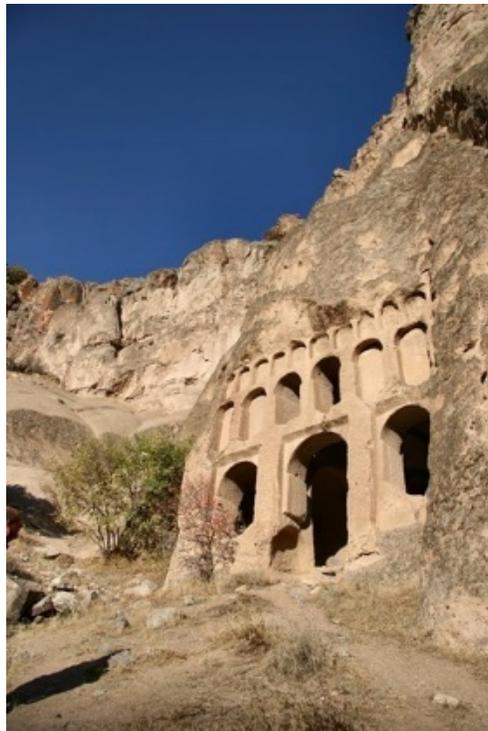
Old cave-houses tend to be dark, cold, and damp, but in modern cave houses, coupled with passive solar principles, their openings face the south (if designed well) to allow in sunlight and warmth during winter so are quite comfortable, light, and airy feeling. The experience of living in the side of a huge rock or cave house, when properly designed, is much like walking into a well-lit room with earth-plastered walls where the earth creates the buffer between the inside of the home and the outside elements (whether cold or hot).

Unless you use a prefab design or an engineer, it is not recommended to just use any kind of cave for the purposes of living. For instance, caves can be fraught with dangers of collapse or leaking gases into the room. This is especially true of caves that are in sedimentary rock, which have layers of rock or earth that can

separate and cave in, or can provide passages between the rock to allow things to pass through (including insects, water, and radon). You will want to ensure your cave house is not in a high-radon area (or has proper ventilation to draw it out), or have some testing done as sometimes radon levels vary widely within the same region. Your specific location can be tested.

The most stable caves are usually in thick (monolithic) limestone, sandstone, tuff, or granite, which have a uniform matrix so do not tend to slough off.

Cave houses are rare and more difficult to build and probably #1 as labor intensive methods go. Compare that to standard earth-bermed or earth sheltered homes, which come in as #2 for labor intensive house-building methods that can keep your house cool, but they can be constructed nearly anywhere. Lastly, the #3 (easiest) method of labor intensive methods—for cooling a house using the earth—is actually just installing earth tubes, which may or may not be able to be done everywhere, depending on codes and rules and regional variations.



Rock-cut temple in Cappadocia, Turkey (source: Wikipedia)

Cave homes are found all over the world, but a few places they are popular (although these cave homes are very old and small, and were not designed passive solar so tend to be dark and possibly claustrophobic) includes Andalucia, (southern) Spain, Cappadocia (a World Heritage site) in Turkey, and the Sassi di Matera in Italy, to name a few.

There is no reason why someone could not find the right location and rock type and make a cave home that is passive solar for plenty of natural light and heat, as well as electrified by solar or wind power (or similar). Most cave homes are going to be rural as they are obviously not usually found in cities, except in some of the old cities I named above, or similar.

Roofs of Earth, Water, & Air

Some people cool their homes by shielding their roof from the sun via a *green roof*, that is a *living roof* of sod or grasses or other shallow-rooted plants. This is a form of earth sheltered home, so the wall system, roof beams and supports have to be specially designed to hold up the incredible weight from the dirt and water. A green roof acts as the temperature buffer that any other bermed home does, except that it is on top of the house rather than just the sides.

There are a number of concepts that exist for *domed houses* where rows of tubes are placed through the roof and around all sides of the dome. Sometimes air or even fluid is pumped through these tubes as a form of temperature control, although rarely do dome houses use soil on top of the roof unless the dome itself is made of earth—this meaning earthen blocks, such as adobe homes with barrel vaults or domes like you will see in the Middle East. I have seen and been inside of a number of buildings with adobe dome roofs (much more rare than the thousands of adobe-walled houses that exist, many well over a century old) in the desert region around El Paso, Texas where I lived for 23 years.

Another model that replaces air tubes or water tubes is a *solar roof pond*. Roof ponds were invented by one of the original solar pioneers, Harold Hay, and are another way to absorb and release heat to/from a house (remember that heat seeks out cold). Water is actually the best medium for thermal mass (thermal storage) since it can absorb and release heat (or cold) four times as efficiently as adobe, rock, cement, brick, etc. However, be aware that roof ponds require special building construction as well since water weighs 8 lbs./gallon (.96 kg per litre). The idea is that in summer you shield the roof with a rigid insulated cover (can be automated) during the day, and allow the water to keep the inside of the house cool, and then during the night you open the exterior cover to let the water release the warmth from the water into the cool night sky. At dawn you close up the insulated cover and do the process over again. This keeps the house cool in summer. During winter you do the opposite: allow the sun to heat the water during the day, and shield it from the cold at night, to help keep the rooms warm overnight.

Although this concept of a solar roof pond was popular for a while (even using old fashioned waterbed plastics as bladders to hold the water), it has run out of favor due to issues with weight, moving parts, and possible leakage, but the concept itself is sound. Running tubes through newer materials like PEX tubing is more popular, including for *radiant floor heating* systems, which is a lot easier than running water through the roof, especially since heat rises and feels better on the feet than all the heat being stored at the top of the room in a roof pond.

A similar idea of using water is a *solar pond* that is external to the house, using a brine water mix that absorbs heat from the sun's rays, and then pumps it through tubes into the house during winter (or the reverse to cool the house during summer). These systems have limitations, although some have provided enough heat to generate electricity or provide other uses if done on a commercial scale.

One could argue that a simple *batch solar water heater* or two where the water is run through in-home radiators could accomplish the same thing as a solar pond, perhaps less expensively and far easier, especially if the system is backed up by a gas water heater

coupled to some 1" (2.54 cm) copper pipe—that is wound around a woodstove flue pipe—that recirculates the heated water (this would need check valves and a release valve to protect from overheating). Some people just use solar energy to heat the water, and others use boilers or other systems as well. The options here are varied and almost limitless as to the ingenious ideas people have come up with and tried, many with great success. Chances are, if you think of something, someone else has thought of it too, and probably already tried it.

Key Principles on Energy Efficiency

All of these ways mentioned above are merely options for heating and cooling a home via alternative ways rather than a standard HVAC system, which is actually the least efficient way to heat and cool homes because they are designed to change the temperature of the air only. Why? Because air loses that temperature quickly, and that is why HVAC systems are continually having to run constantly to reheat or re-cool the air, and why heating and cooling bills cost so much. Air simply does not hold temperature very well or for very long.

Forced air systems heat quickly, force the air around by blowing it with a fan (which causes energy loss) through ducting that is sometimes not insulated (more energy loss), the temperature of which is short-lived, and so in trade costs more. Mechanical devices inevitably break down, and furnaces and air conditioners are not always cheap to purchase, plus consume enormous amounts of energy/fuel. This is probably the worst possible scenario for heating and cooling a house, yet it is the one that is popular because “everyone does it” when there are far better and more logical methods (passive solar design being #1, and earthtubes enhancing that).

Energy waste and energy costs are one thing, and I will not even go into the aspect of climactic change and pollution issues and the carbon footprint each of us contributes to. I could speak about increasing efficiency first, and then reducing our dependency on such backwards home heating and cooling systems (forced air/HVAC) as they do in Net Zero or Net Positive homes, but seriously, having a comfortable home that does not cost an arm and a leg, plus every penny in your pocketbook, AND that helps save the earth is just common sense... at least to me. Most standard houses built by contractors are designed backwards as well, “because that’s how everyone does it”.. but that is another story for another of my books.

There are far more efficient ways to keep a home’s internal temperature stable, or to heat and cool it initially, and reduce the energy needed to maintain that temperature. Having adequate amounts of thermal mass (e.g., with passive solar design) inside a *house* is what makes it feel like a comfortable *home*. Insulating it well

on the outside walls/ceiling/foundation edges is what keeps the temperature stable as well, by preventing losses.

**FUNDAMENTALS OF ENERGY
EFFICIENCY**

Thermal mass is key
Insulating the envelope is the trick
Passive solar design is the secret

Some facts you need to know for sure when it comes to comfort levels and efficiency whether you use earth (or earth tubes), or water, or air for heating or cooling...

1. **Earth** or other solid thermal mass materials are used for stability in temperature (it transfers hot/cold the slowest)
2. **Water** is favorable for both storage and thermal transference
3. **Air** is the least favorable for thermal storage but best for quick transference

Depending on what you want to do, this could change your perspective on ways to efficiently heat or cool your home, depending on where you live, and what you want to accomplish.

These simple principles are why earth tubes work so efficiently, as a completely natural process—they utilize the earth's temperatures for stability, and use the moisture (water) for temperature transference in the tubes, which in turn cools and dries the air (or warms it in winter) for use inside the house. In essence, earth tubes utilize all three principles at once, in a balanced way; if designed well they should not have issues with mold or radon, and should help heat and

cool your home to reduce combustion-heating costs (if coupled with passive solar may further reduce or eliminate the need altogether), and should use nature itself rather than electricity to work.

If one needed supplemental heating in winter after utilizing earthtubes and/or passive solar home design, then a simple homemade rocketstove, a nice woodstove, or a professionally built masonry stove fireplace (the kind with a double burn chambers)/Finoven is all that would be needed; one could then eliminate any HVAC system altogether.

Trees and Shrubs

Trees and bushes or shrubs are also excellent additions to any front or backyard, which can serve doubly for passive cooling. In the northern hemisphere (reverse it for the southern hemisphere) trellises with vines help shield the hot southern or westerly sun from beating down on your west walls in summer, or they can keep the sun out of windows on the south side, thereby keeping your house cooler.

Alternatively, tall pine or other evergreen trees set in a row (or staggered in two rows, parallel to the house) about 25' (7.6 m) away from the house can produce shade on the west side, which is the area that gets hottest on those long hot summer afternoons. The trees will bring the first shade.

However, you will want only deciduous (trees that lose their leaves in winter), if any at all, placed in the south and east so that it shades the house in summer, but allows the sunlight through the windows during winter so you can take advantage of the solar gain into your home for passive heating.

Of course, the only real expenses with plants/trees are their initial cost, and for fertilizer, and water to keep them alive, but the potential savings in utility bills can really add up, not to mention the comfort factor of your home.

You can collect and store or even reuse water to cut down on your water bill. Ways of collecting water (plants especially like rainwater) include rain catching systems, and gray water (greywater) systems that recycle clothes washer and shower water.

Arroyo/canal and other surface water harvesting techniques are also viable alternatives in certain areas, if your government allows it (certain places such as Colorado and Washington state do not). This way you can water trees and bushes and other plants without the high cost of buying water from the local utility/service company. Installing a water well may also help reduce monthly expenses, although may have initial costs. Check with your state regulations on systems such as these for your area.

Remember what I covered earlier in the book about shrubs and bushes around the opening of earth tubes? This makes not only a

great camouflage for the tubes that stick out of the ground, but also protect them from breaking down in the sun, are deterrents for children and animals, and the foliage pre-cools the air going into the earth tubes.

Chimneys for Ventilation Draw

There are other ways to cool and warm your house other than just earthtubes, although some of them utilize similar principles of physics, and sometimes opposite ones.

Have you ever seen a termite mound, or a picture of one? These are tall towers of earth built by termites. The biggest ones are often found in Africa, Australia, as well as South America.



Termite mound in Litchfield National Park, Australia
(source: Wikipedia)

Typically found in a termite mound is a subterranean nest, over which is built the mound or tower, which sticks up above ground several feet into the air. Vent shafts and open chimneys are found in some of these nesting sites. The sun may warm the mound/tower above ground, which draws air up and out, and therefore creates a vast ventilation system through the underground tunnels.

We can learn from nature. Similar to the termite mound, there are manmade towers or systems that can be used in similar ways. Such is the convection process of a solar chimney.

Air flow is the goal, and warming the tower, or chimney, by using the sun is exactly how a solar chimney works. I will cover this, as well as a few similar ideas such as cooling towers, and an earth lodge weathervane, which catches prevailing winds and keeps high winds from entering the chimney (causing backdrafts).

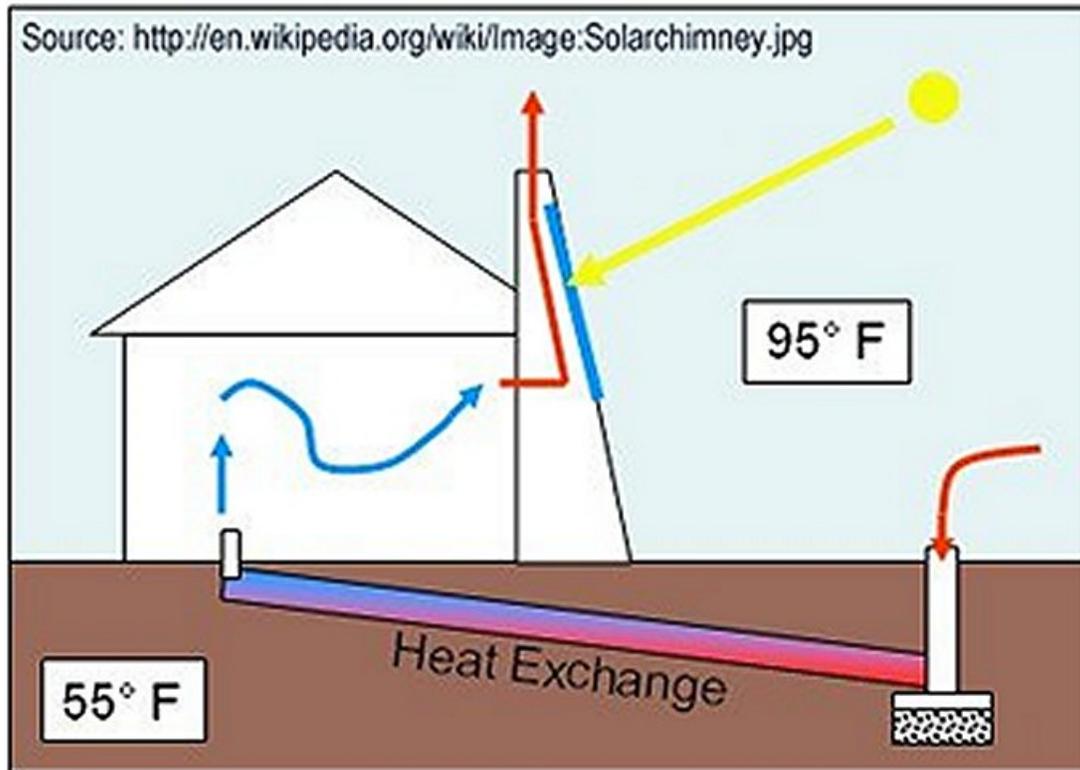
Solar Chimneys

A solar chimney is an excellent way to avoid having to open windows upstairs, or in the attic, or trying to choose which window to open in a single-story home. Solar chimneys help warm the upper air in the house, aiding the convection and draw of the colder air into the rooms from the earthtubes.

Solar chimneys are basically located at or create a high point in the house as a chimney that goes up through (or beside) and above the roof line. They can be made of brick and painted black (to absorb more heat from the sun), or can even be made of wood or other materials with a piece of glass placed on the solar/sun-facing side (it usually has insulated sides, forming a small airspace between the glass and the chimney walls) to warm the chimney up fast.

Other options are to use black stovepipe, or regular stovepipe painted black, with a vent cap or spinning turbine vent on top (as I covered earlier—so a stovepipe used in this way is a solar chimney, in effect). The existing stovepipe flue on a woodstove may double for this purpose. The chimney (a vertical shaft) works on the natural stack ventilation process that causes an updraft. Warming the stack/chimney with the sun just helps this process along.

The design in the next picture shows an earthtube design slightly different than the kind covered in this book, at least in the vertical shaft at the tube entry, as well as the need for a sump pump or deep gravel drainage well. There is a slight 2-3+ degree grade on the earthtube also, so that the water conveniently (without the need for gravel or holes drilled along the tube) drains down the tube into a much deeper rock drainage pit. This version would also allow radon to drain downward away from the house.



Solar chimney
(source: Wikipedia)

Again, it would be important to shield the incoming air with an air filter and/or mesh to keep sand, debris, rodents, and other sources of bacteria out of the rock pit; but like a qanat and the backside of a windcatcher tower, the cold air that drops down into the pit cannot get out except by being drawn out, which is accomplished through the tube and into the house and out a high window or solar chimney, etc.

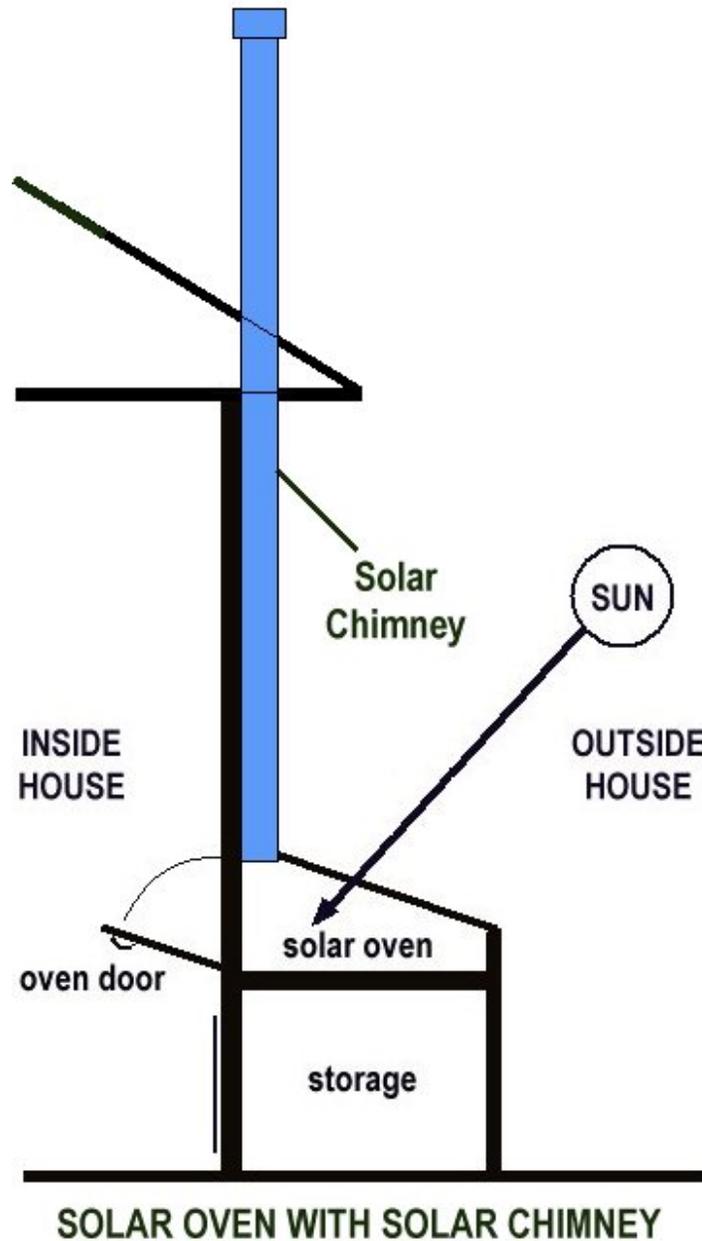
On a system like this the air inlet would be better designed if it rose above grade at least several inches or a foot or more, and capped with a rain guard that had meshed vents on the sides (like what is used on a woodstove chimney) so air can get in but not debris or rain.

A solar chimney or excellent air drawing mechanism might be essential with this design since the "hot air rises and cold air falls" rule would be violated based on the angle of the earthtube (air gets cooler as it travels through the earth tube so would naturally want to fall back

away from the house). The cold air would have to be “sucked” up the tube into the house, and the solar chimney would help this process along. Of course, one could argue that this is not much different than the 45 degree angles on the earthtubes this book presents, therefore also violating the concept. Perhaps a solar chimney might actually work similar to a low-grade fan, drawing air at a slow rate.

As a side comment concerning solar chimneys, I have to say that I love designs that have multiple purposes and can be utilized at different times of the year. For instance, a permanently mounted *solar oven* with a solar chimney above it (together attached to the south side of a house) could be used in summer for cooking, which keeps the heat out of the house.

A solar oven like this (see next illustration), with a solar chimney heat-escape built above it, could also be used to draw the hottest air out of the house and allow the earth tubes’ cooler air into the house.



SOLAR OVEN WITH SOLAR CHIMNEY
Solar oven would have a chimney built above it

During the fall harvest you could use the oven as a *solar food dryer* by placing thinly sliced vegetables on racks and covered with an opaque shade (under the glass, but not touching the food) to keep it warm (not hot! You do not want to cook the food) inside the oven, while the moisture leaves up and out the solar chimney; adjust the

flue damper to control moisture and heat levels for optimum food drying.

During winter you could close off the chimney but use black metal pots filled with water and topped with a black lid (or glass jars painted black on the outside, with little holes poked in the lids for steam vents) placed in the solar oven so it can absorb the sun's heat—when you crack open the oven door it would allow both moisture and heat into the house to help warm it passively. This is much like a *solar window box heater*, except that you use the solar oven that is already in place instead of having to make one separately for daytime supplemental heating.

There are lots of options for being creative and this is just a simple example. *Solar water pasteurization* can also be done in a solar oven of this type. Again, multiple uses.

The list goes on... but I will just pique your interest in solar projects of that type for now, and not delve into them too deeply as those are topics for other books (I have one on *How to Make a Solar Oven*, as well as *How to Build a Solar Water Distiller* that covers solar water pasteurization methods as well). Once the world of utilizing natural principles opens up to you, then the options and combinations therein also blossom from the minds of creative people.

Cooling Tower

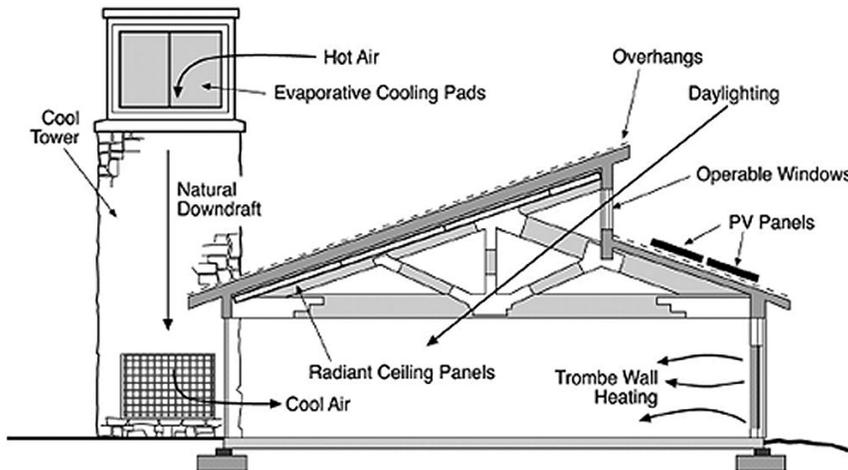
The wind scoop is used to cool a house, but on the opposite principle as earth tubes—they are really only effective in desert climates.

I have covered earthtubes as being aids to removing moisture/vapor from the air, therefore making it cool and dry by the time it enters the house. A wind scoop usually adds moisture to the air, and utilizes the wind and downdraft concept to cool the air inside the house, either by water falling down the tower, or else a pool of water in the middle of the lower (basement) room.

In arid climates, a pump inside evaporative/swamp coolers are used to add moisture to the air, and then blow it into the house via a fan. Similarly, a passive downdraft cooling tower could also be useful in the same way. This is a tower, similar to the solar chimney, but without any solar impact.

The wind blows outside and scoops itself into the top of the tower, where moisture is added in a steady but small stream (like a very high but thin waterfall), which evaporates as the air falls and cools, then picks up speed as it falls. This cool moist air is a relief to the hot dry air experienced in hot desert climates, but it can be a waste of water as well, since water is a precious commodity in arid places. The pool of water in the bottom room may be more efficient in regards to water use.

So how does this wind tower work? It depends on the design, but there can also be “pads” at the top of the tower (multi-directional) that are saturated with water (continually, or via a misting system that causes flash evaporation), and the air is cooled when it enters the tower, similar to a swamp cooler. The cool air falls down through the tower and enters the house via horizontal slats. If the tower is central to the house, with rooms branching off of this area, then potentially all of the rooms could be cooled this way since it will “dump” and spread out once it hits the main floor. Remember though, this is a system that works on the OPPOSITE principle that earthtubes work.



Source: NREL and NPS drawings, Zion Visitors Center (cooling tower), and the website:
http://upload.wikimedia.org/wikipedia/commons/c/c5/Zion_Visitors_Center_Cool_Tower.PNG

Cooling tower

for arid areas
(source: Wikipedia)

Cooling towers ADD moisture to the air (in arid areas only), while earthtubes REMOVE moisture from the air, so cooling towers work best in arid or semi-humid areas—but a warning(!)... they are hard pressed to work effectively in areas of very high humidity.

Sometimes the best methods for a particular climate is learned from indigenous peoples who lived in those areas for thousands of years and already figured out some of the best ways to do things. Study and learn from them!

Earth Lodge & Weathervane Venting

When I lived in Nebraska during the 1990's I traveled around and visited a number of interesting places, one of which (besides the century-plus old straw bale church in Arthur) was an Earth Lodge near Kearney, which is a building of natural materials (mostly trees for posts, branches for cross members, and bermed by sod/earth), built and designed after the local indigenous population that used to live in the area and left behind archaeological evidence of their structures.

The Great Plains and Eastern Woodlands cultures built these semi-subterranean structures decades ago, and particularly, the Pawnee who lived in the North Loup and Platte rivers (south-central Nebraska). They stopped constructing these by around 1875, although the Anikara today still use the design.

An oblong “tunnel”-shaped entrance (like an igloo would have, except squared instead of rounded at the top, made with smaller posts and branches and earth) served as a way to get in and out of the earth lodge. This photo below is very similar to what we saw.



Earth Lodge exterior

(source: "Glenwood earthlodge" by Billwhittaker at en.wikipedia. Licensed under CC BY-SA 3.0 via Commons

https://commons.wikimedia.org/wiki/File:Glenwood_earthlodge.jpg#/media/File:Glenwood_earthlodge.jpg)



Earth Lodge interior

(source: <http://www.kearneyhub.com>)

As shown in the picture above (the difference being that the side walls we saw had earthen “benches” dug out into the earth with a lower/dug-out/sunken floor instead of just vertical poles rising from the sides), more long beams were laid down from these outer posts all connecting to the four center posts/beams in the middle. The very center between the four posts, on the dirt floor, is a fire pit, which serves as the central heating for the building during colder months.

Because it is bermed with earth all the way around and over the top the shelter tends to stay quite warm in winter, and cool in summer. The earth is what stabilized the temperatures inside most of the year, which is helpful in extreme weather conditions like one can experience in the plains.

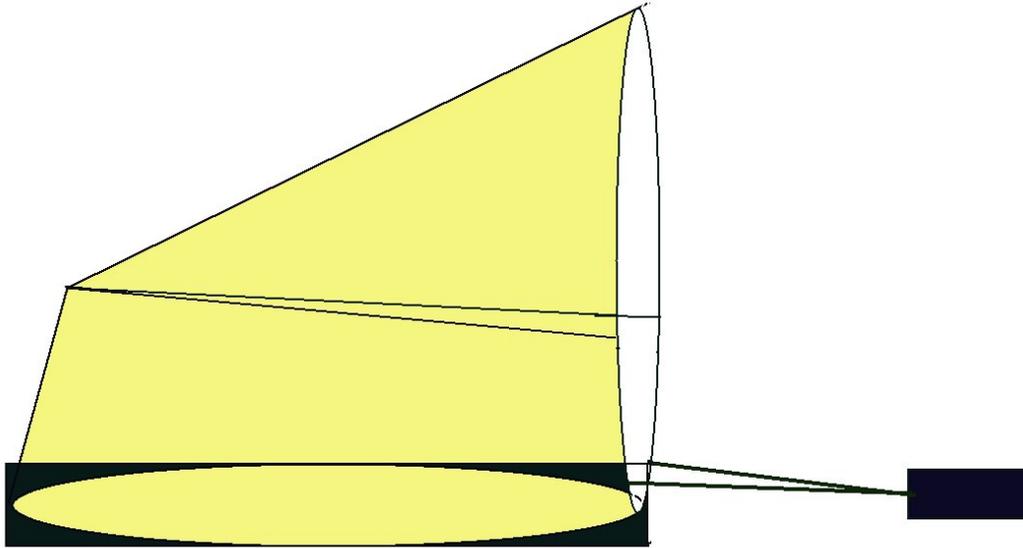
Weathervane-Like Smoke Vent

The one feature I remember in function, but not so much in visual imagery, is the earth lodge weathervane-style vent protection, which protects against prevailing winds by keeping them from entering the chimney/vent hole.

The hole in the center of the lodge serves two main purposes—it allows light to enter the lodge, and it allows smoke from the fire out. The possible drawbacks of these holes is that it also allows rain in, and backdrafts can occur due to the wind. The natural domed shape of the earth lodge should ideally help prevent this backdraft issue, since it is taller at the apex, but the “chimney” and draw aspect is limited since it is so short in height and of greater width than a regular chimney. So smoke actually did tend to backdraft into the earth lodge at times.

One of the ways around these problems is by adding in some flaps, like what exists on a teepee (also spelled tepee, or tipi), and look like large ear flaps that can be opened and closed, which prevent wind, sunlight, or rain from entering. The difference between this and the “weathervane” style I mention (which surely has another name I

cannot recall) is that like a real weathervane, the protective flap or cover (made of light fabric) would oscillate or turn/twist on a small base and had a “tail” so it would be blown to turn away from the wind’s oncoming direction, just like a weathervane.



**Weathervane-style vent protector
(keeps wind and rain out—could be used for earth lodge, solar chimney, or earth tube opening)**

In the picture above, the square part of the base is stationary over the hole and four corners of the vent hole, but the round part of the base spins. The tab/stiff flag on the end of the sticks or rods holding it in place (sticking out away from the hopefully-fire-resistant material cover) is pushed by the wind and aims the opening of the device in the direction the wind is blowing towards. My depiction above is not as it was actually made, but is as close as I can remember—it has been over 20 years! I am positive someone could devise a better design than this crude drawing portrays. Its function is what is important here.

What this did was protect it from winds that would otherwise blow directly inside, or cause backdrafts and put smoke all around the lodge, making it hard to breathe—a problem the earth lodge builders

had, which is why they devised this more modern vent protector since the public toured the earth lodge regularly and they wanted to ensure people were comfortable and not coughing and hacking when visiting.

As I remember, this weathervane-style cover was manmade and not necessarily what the Native American Indians used on their earth lodges, but as people's ingenuity is exercised based on need, it becomes useful, and this is the only place I have seen this particular feature utilized, and so I share it here for your perusal and consideration. These types of protective covers could easily be made for the tops of earthtubes (inlets) or—if fireproof—over chimney or even solar chimney openings, if desired.

Tunnel Opening Cools in Summer

Getting back to the earth lodge itself, as related to earth tubes... one last feature about the earth lodge design that is practical is the long entrance. The doorway would be covered by blankets or animal skins except for a couple inches or so at the bottom, next to the dirt. This would allow a little light to enter at the bottom of the doorway so one could see when entering or leaving, but also to keep most of the hot summer air out, and allow only a little of the coolest nearest-the-earth air into the structure.

Like an earth tube, the small amount of air that comes into the slit/opening at the "tunnel" doorway drops in temperature as it enters. As it descends down the tunnel/entrance it cools off more, being covered by the earth and shade.

Remember that in the earth lodge we visited, the main room was lower in depth than the outside ground, so it was inset/in-ground as a semi-subterranean structure, half-built into the earth. This means the tunnel's floor was slightly sloped downwards, which allowed cool air to enter and fall naturally, especially as it cooled down. Coupled with the earth sheltering effect of the bermed walls, the summer air temperature inside the lodge was cooler than outside (which is what we experienced the time we visited)—much cooler.

Of course, the vent hole at the apex of the dome serves as the high window or chimney as the exit for warmer air, drawing in cooler

air from the doorway far down the tunnel because these are the only entrance/inlet and exit openings in an earth lodge. This, in functionality, basically produces the same effect that earth tubes would in a modern house.

Other styles of earth lodges do not have this feature of a long entrance, and sometimes the door is very close to the lodge itself. In the case of this one we were able to view up close back in the 1990's, it was spectacularly impressive in design and efficiency for staying cool during the hot, sweltering summer temperatures.

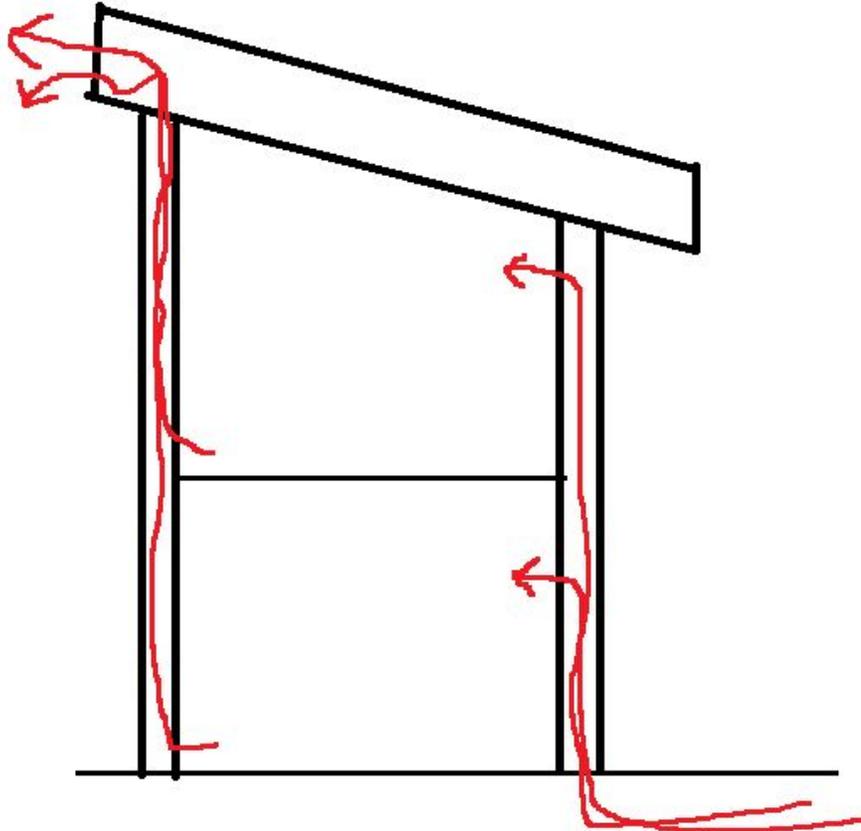
Other Designs

Other designs that people have made, or are making, which people have told me about and given permission to be shared here are below.

Bill Traub Witnessed These Earth Tubes

This information was witnessed by Bill Traub of Seattle, Washington about a house on the Olympic peninsula:

“From my memory when I was working on this house there were several flexible plastic tubes run from under the home, originating point unknown, and terminating either at the basement or second story inside of the interior walls. Exterior walls were, of course, insulated so none of the pipes were located here. I never found the source of, starting point of, these pipes but assumed it was under the foundation (slab) or else out somewhere in the yard where the opening had grown over. The interior walls were sheet rocked so these dead air spaces were basically ventilation pockets spaced throughout the home. Each pocket that was created could draw air from the cool ground and then was vented into the room near the top of each pocketed space. Each space was created by wall studs on the sides and sheetrock front and back.



“Where there wasn’t an incoming pipe there was another one vented into the attic so air traveled from the ground, through the vent in the wall, into the room from vents near the ceiling, then back into the walls in other vented wall space and up into the attic. In the attic was a very large, very high capacity fan. It drew air out of the attic which in turn created a vacuum which sucked the air in the previous pattern up into the attic. This cooled the home very effectively once we figured out what the whole thing was. In the winter the attic space could be warmed by the sun and the process might have been reversed, just probably not as effectively as the cooling was. I don’t know, we never had the chance to give this a try. I don’t know if this was a home owner thing or a contractor that incorporated this into a design.”

INDOOR AIR QUALITY

The air quality of earth tubes can vary depending on what materials are used, how they are built, how they are maintained, and local factors such as levels of radon in the soil and what region they are built in. The earth tubes we learned about had no issues, and they had been 'running' successfully for a 5-10 years, depending on the dwelling they were utilized at. We copied their exact styles and also had no issues with mold or any other contaminants. We were very careful to not deviate from what we learned worked for them, so as to not cause potential problems.

The only thing we did differently when we built our earthtubes is that we buried them half as deep as the other earthtube-owners buried theirs. However, since we were only planning on using them during summer, rather than year around, plus the fact that we had a high clay content in the soil (very conductive, which is excellent for thermal transference from ground-to-air) we did not have any issues at all in regards to their efficiency at cooling the air.

We lived in southeastern Nebraska at the time so had fields of wheat—and therefore wheat straw—and corn fields surrounding our property. The access to inexpensive straw bales (not hay bales, which are a food source), typically used for animal bedding material, was one of the reasons we chose to build our house with them. The result is that we had an extremely insulated house (R-50 insulation value) made out of these straw bales with a passive solar design, so in fact, our house was far more efficient in regards to energy use than your typical standard-constructed house that a contractor would build. This would explain why our earth tubes worked more efficiently than did some of the homes we visited that used them, simply because once the air was cooled via the earth tubes, the house did not allow the hot summer air to infiltrate through the walls as quickly as standard homes.

The air quality was also excellent. I am personally more sensitive than most, in physical constitution, so am susceptible to fungi and bacteria, etc., and even got foot fungus from the soil (by going

barefoot in summer, so quickly learned to wear sandals or flip flops) when no one else around me did. So whether externally or internally affected, I have to be careful about what I breathe and what I touch, including molds or gases. Yet I had no issues at all with our earth tubes. The air ever so gently flowing out of them smelled sweet and was cool and dry. Never did I smell anything foul or musty, nor did I experience breathing issues or sickness while living in the house, and neither did the person who bought it from us complain about any breathing issues after we sold the house back in 1999.

Nevertheless, there are people who have had some bad experiences with the air quality from earth tubes, but I dare say that not many of these few reports talk about the details in the differences about how they were built, what materials were used, if the joints were sealed well, if the tubes were perforated or not, if the tubes were corrugated or smooth-walled, whether or not the tubes had an antibacterial coating or not, what angles the tubes were made (if the bends were too many or angled wrong, therefore restricting flow), or a host of other possible variables.

That said, I am wary of reports where earth tubes had problems, simply because no one—to my knowledge—has done an extensive study on earth tubes that were built right vs wrong and what those differences were that caused the issues. That does not mean I deny there are problems, but that until a proper study is done to find out WHY or HOW these problems occurred, we simply must admit we do not have all the answers yet.

Because of that, I am equally wary of reports from people who claim earth tubes should be banned or not built or used simply because a few in some areas have had problems. Just to say that “earth tubes are no good because they leak radon into the house” or “earth tubes suck because they do not cool properly” when there was a fan added or was built out of the a poor choice of material(s), simply does not justify the argument with enough detail to make a reliable judgment on the matter.

If there were a grant or funds available to do such a study I would gladly participate in managing it and would combine forces with universities or other professional entities and/or persons that could

conduct the study without bias; this kind of study would obviously need to include current and past users of earthtubes from multiple countries. More serious studies on the efficiency and building methods, air quality, as well as their long-term use, and other factors, are needed, for sure.

Although our family personally had no problems with the tubes does not mean others have not, and just because some people have experienced air quality problems does not mean *all* earth tubes do, or that the idea behind them does not work and so the whole concept should be thrown out. There is no reason to make lump decisions just because of inaccurate data. I say inaccurate because we simply need more documentation on what the detailed features are between earth tubes that work without problems, compared to earth tubes that have air quality or other issues, and how those issues can be overcome, or were overcome, or if the people gave up without trying, or what they tried that did or did not work.

This lack of data might be as simple as being some aspect of the region in which they are located... the soil, amount of radon, types of microbes or molds, or simply because they have a faulty design, or that even though the design was good the owners built or used them incorrectly. Maybe they were built well but later experienced ground shift and the tubes cracked, letting in bacteria and allowing molds to grow. Who knows? There is a lack of data, and so I plead that more information be made available before claiming that earthtubes “do not work” or similar mindsets.

Perhaps it is the scientist side of me that is speaking here, but until a thorough assessment is made regarding these details—which is horribly lacking, since I have yet to find anyone who knows any serious studies in this field of earth tube construction—I personally would not trash all earth tubes simply because of a lack of proper data. Prove it wrong... falsify the ‘good earth tubes’ that work, and then you will have me convinced. Until then, I will chock it up to human error or possible unknown factors, which could be environmental or a chance in circumstance, etc., which obviously no one has the answer to yet. These are the questions we need to be asking, and the answers we need to be seeking.

In the meantime, there are a few details I can cover regarding the radon or mold issues or other possible air quality problems. One of the few reports I found online that talks about this subject is the *Earth Tube Ventilation Systems—Applicability in the Canadian Climate* (Research Highlight, December 2011 issue, Technical Series 11-103, retrieved from the CMHC (Canada Mortgage and Housing Corporation) at: <http://www.cmhc.ca/odpub/pdf/67558.pdf>), which states that condensation from warm and humid air inside the tubes has the potential (say some authors) to grow bacteria or mold. A number of PassivHaus (called 'Passive House' outside of Germany/Europe—an Institute for super-insulated passive solar home design and low-energy buildings) proponents have only anecdotal evidence of issues with air quality from earthtubes located in northern Europe, particularly in Scandinavia. However, it is not a problem in Central Europe, but no one is sure why these problems are basically nonexistent in the latter area. Some issues have been reported in Sweden as well. My question is why? No reliable source seems to be able to answer this. I think, as stated before, it is simply because no one has done an unbiased and comprehensive study on it. Reporting issues after the fact is not the same thing as researching and studying it in-depth, and future outcomes can be heavily influenced by those who write negative (or positive) reports.

My motto is to do whatever works. If it works in one area, copy that model in that area and it will likely work again (keep it local). If it does not work in an area, do more research and find out why, and make improvements. Do not mimic what does not work in one area (although some designs may work in another area) unless it is to test a hypothesis. It is important to know *why* certain earth tubes in certain areas are not functioning as intended, and *how* that compares with systems that do work.

In the same publication above, it also states that the earth tube field is not completely understood so we should use caution in areas where problems have been experienced, to which I agree. Some of the northern European climates are similar to parts of Canada, which this Canadian publication counts as relevant, yet no supporting data is provided.

Interestingly, they do note that some of the systems “address the condensation and IAQ [Indoor Air Quality] concerns by not having the ventilation air pass through an earth tube to temper the ventilation air.” They mention that an alternative method to utilizing earth tubes in these areas is a brine or glycol loop (closed) along with a heat exchanger (at the heat recovery unit’s entrance) as a possible solution to air-based issues, although there is also no data I have found yet in Canada on how beneficial this may or may not be, in comparison.

Remember that earlier in this chapter I mentioned that qanats have been used for centuries, if not longer, in parts of the dry/desertous Middle East, so regional differences may play a part in their ability to be “safe” from particular kinds of molds or bacterial influence, or similar. This aspect cannot be ruled out, that is, until it has supporting data, since it may be a user error problem due to cultural sharing—that being people copying the building of faulty designs of these systems to begin with, or how they are taught to use them (incorrectly).

I am almost begging someone to do this—and so I reiterate—a comprehensive study is in dire need before we have more accurate worldwide data on modern manmade earth tubes. Yet, there is ample evidence in local areas as to what works and what does not. Again, I say, copy what works in a local area and stay far away from what does not. Investigate closely. This also goes for radon.

Radon is a radioactive gas (from decaying uranium) that is found naturally in the ground, in some areas more than others. Radon filters up through the ground into basements and homes and along foundations or other inlets. Over time, if breathed long-term, it can cause cancer or other health problems.

There are ways to check for radon in a house; home inspection services can do a simple test to check for radon in any home, or you can get a kit from a hardware store. You can also get rid of radon from a house, but also it is important to prevent it from entering in the first place, including through earth tubes. This is why solid pipes are preferable to perforated pipes, not only for reducing chances of mold, but also radon infiltration through weep holes.

Radon gas infiltration is covered in a publication titled *Radon – Soil Gas Infiltration Control: A Comprehensive Review of Radon Resistant Construction, Mitigation Requirements and Options in Ontario* (published by OBEC (Ontario Building Envelope Council) by B. Decker and B. Wood, retrieved from: <http://obec.on.ca/sites/default/uploads/files/members/CCBST-Oct-2014/B6-2-a.pdf>) at the 14th Canadian Conference on Building Science and Technology.

What they say about radon includes that standard buildings already “do not adequately control its ingress and that ... [there are] minimum building code requirements that could result in elevated radon in buildings.” Evidently standard building methods and construction codes are not always enough to render a building safe whether it has earthtubes or not; however, “passive design and diligent quality control can mitigate the impacts of radon ingress and reduce the requirement for active (energy consuming) control systems.” This is important because energy conservation (i.e., having a “tight house”) in green building means we also have to make sure that earth tubes do not pull in radon and that there is adequately designed ventilation for its exit. Lastly, the authors of the paper say that—whether in commercial buildings or residential—active mitigation systems that are used to reduce levels of radon can be benefited by energy savings by using SSD (sub-slab depressurization) methods for ventilation.

The point here is that no matter whether radon comes into the home or not, proper ventilation exits are important, not only for indoor air quality (radon aside, and especially during winter since people tend to close up the house in cold weather) but also to allow potential radon to escape if it is present.

This would be true for any house, whether or not it has earth tubes. In my view, then, it rarely should affect one’s choice to install earth tubes, only that radon (if existent) should be properly dealt with regardless of whether the tubes are installed in the home. It is rather an easy fix to remove radon, as well as prevent it from entering the house, or the tubes for that matter, which can be controlled simply by

its design (solid non-perforated tubes that are slightly angled to drain away from the house into a sump or gravel pit).

Generally the escape for radon in a house can be through a proper air flow exchange rate, which the exit in the house provides. I have read articles about homes with earthtubes that have been found (via radon testing) to have no more radon inside than was detected in outside levels. Of course, a house that has perforated tubes that leaks radon in, and has no escape out of the house, would obviously fill the lowest part of the interior with dangerous levels of radon (radon is heavier than regular air so sinks, but it normally will dissipate in four days as long as the entry source is blocked).

This means, as far as earth tubes go, that using solid tubes (as opposed to perforated tubes) is important since perforations allow radon into the tubes, whereas solid tubes do not. The spiral earthtubes mentioned in the previous chapter come to mind here.

Additionally, a few holes along the length of the horizontal tube for condensate drainage, like the earth tubes we built and that I cover in this book, are unlikely to pull in much radon as the majority of the tube is solid (just make sure joints do not leak), but having holes does up the chances that radon could infiltrate, but it is not known to what degree since I am not aware of anyone who has tested this.

Proper house/building ventilation is key in the case of air quality in any home, just as proper construction and materials and use of earth tubes is the key for maintaining good air quality throughout the life of their use.

Example of Bad Air Quality from Earth Tubes

I would like to share with you something that is available on the Internet at the Green Building Advisor website:

<http://www.greenbuildingadvisor.com/blogs/dept/musings/belgian-passivhaus-rendered-uninhabitable-bad-indoor-air>

In this account of a house built to Passivhaus standards in Belgium, there were problems. Because of this some changes occurred thereafter in their designs and use of earth tubes in Passivhaus homes. I am sharing this not to dissuade you from

making the tubes and using them, but to educate on what kinds of things can go wrong, and what to avoid so the same mistakes are not repeated. Just because earth tubes can be made does not mean they should be in every region or specific place, depending on circumstances, weather, the builder, soil type, geology and geographical variables, the contractor/builder, or other things.

This particular single family dwelling was finished in 2005 (Belgium) but declared by the authorities in that locality as 'uninhabitable' soon thereafter due to problems with the earth tubes, which were causing indoor air quality problems. Within two years the house was abandoned. Earth tubes later became less popular in that area, which also affected their construction in other areas due to the negative news in the media.

This is understandable considering what the family went through and because of the cause of the problems. Indeed, they should not have been built this way so as to cause health issues. In fact, in my opinion, it would be better to not have earth tubes at all than to have earth tubes that cause health issues (passive solar design with adequate thermal mass in the home's interior should be enough to heat/cool with minimal supplemental heating/cooling method(s) if designed properly).

A discussion about the problems in the home were covered by Dr. Hugo Hens, a professor (Physics unit) in the Department of civil Engineering in Belgium's University of Leuven in his paper "Passive Houses: What May Happen When Energy Efficiency Becomes the Only Paradigm", which was discussed in Chicago's 2012 ASHRAE Winter Conference.

The house was a two-story house with 2,034 square feet, and was completed in December 2005. The foundation was slab on grade with seven inches of R-36 foam insulation. The wood framing had 12 inches of R-43 cellulose insulation with a vapor-permeable exterior sheathing (wood fiberboard), and R-43 insulation under a sloped roof. The space heating was a heat pump (air-to-water), and They also had argon-filled triple-paned windows electric resistance backup. An MHRV (mechanical heat recovery ventilation) with fresh air intake was provided by an earth tube buried underground. Air leakage rate was 0.68 ach50, for those who would like to know details at this level.

This house sounds standard enough—at least as Passivehaus standards go—but *problems started soon after the family of five moved into the house.*

First began the health issues of coughing, headache, shortness of breath and dry throat, pain and weakness in the muscles and legs, diarrhea, fever, nausea, being pale and tired, plus loss of taste. Some symptoms were evident by visitors who stayed there for a couple of days. The university hospital confirmed their medical diagnosis.

The family claimed that the house was very humid, too cold in winter, and too hot in summer. Opening attic space helped keep it habitable. They found these problems in the house:

- No ventilation of the air space between the wall sheathing and the brick veneer.
- Voids were left by the insulation contractor at the top of the outside walls.
- The earth tube had water standing in it.
- Interior OSB wall board was damp.
- The air flow in the HRV (heat recovery ventilation) was less than what it was designed for.

U.S. builders typically know that some of these designs regarding brick veneer can be risky, especially after a rain, which can cause a humidity issue in OSB known as solar driven vapor flow, which can activate formaldehyde release (measured at unsafe levels) from the OSB during the hot season. Similar problems of vapor-permeable sheathing due to brick veneer inward solar vapor drive (in Cincinnati, Ohio) occurred in 1999 where wall rot occurred in hundreds of homes. Had rigid foam sheathing been used instead of the fiberboard, the walls would not have had this issue.

The earth tubes in the Belgian home were evidently a mistake as well, since stagnant water from rain, along with construction dust (located in supply ducts) were discovered. The contractor attempted to fix the ground pipe in 2006, however unsuccessfully because rainwater again collected within it. Between the 80% humidity occurring over a long time period, mold began to grow. According to the report from IAQ testing it “revealed the presence of spores of penicillium, aspergillus fumigatus, aspergillus versicolor and aspergillus niger.” The HRV supply filter was also over-humidified due

to this situation, causing mold growth as well. The indoor air quality was atrocious as a result.

Between the non-working earthtube and the ventilation problems, as well as the walls themselves causing issues, this house became toxic to live in. It is imperative that all owners or builders are aware of potential health risks when dealing with homes that do not breathe properly. By 2008 this house became and was declared uninhabitable due to the extremely poor indoor environmental quality and the family moved out. Not only were the contractors scrambling to fix the multiple issues, but the family's lawyers got involved as well. Be aware that although this house had earth tube issues, a lot more was obviously going on here.

Lessons learned are mentioned above, but it begs the question to me as well as the source of this information whether the earth tube was sloped down to a sump pump (doubtful).

My personal take on this is that the most ideal home is green built to Passivehaus (Passive House) or LEED standards for passive solar design, and incorporates earth tubes if 1) the house is in an area that can support their construction and use, and 2) the tube is non-perforated, slopes downward away from the house, has a sump or diverts water so it cannot pool and grow stagnant, and any local requirements for radon are met.

An alternative to earth tubes for natural cooling would be geothermal—meaning earth sheltered or earth bermed homes, because it provides the shelter of the earth so that the tubes are not necessary; however, this construction and design method tend to be very heavy and more expensive to build, and owner builders have to be especially careful that their design does not cave in on them. It is highly recommended in these cases to hire professional architect(s) and/or civil or structural engineer(s) to design the home, and to have professional contractor(s) build it. Do not forget a radon mitigation system, if necessary.

CALCULATIONS FOR EARTH TUBES

The information for this short chapter was provided by a friend of mine, Olan Volan from Holland, due to his background in physics, and to help the earth tube installer find ease in the decision-making process for designing and building the tube system.

His goal here was to find out what size (diameter) pipe is the most efficient for an earth tube when considering air flow and surface area (inside the tube), together. The calculations are for smooth plastic tubes, meaning thin-wall PVC pipe but Olan says that steel thin pipe would be about the same.

NOTE: These calculations are given mostly in the metric system for his original notes so I added in the Imperial/US amounts. Also, be aware that he uses a comma in place of a decimal point; for example 30,4 cm = 30.4 cm.

I will allow his notes to remain his own and did only minor edits to ensure it is as clear as possible. I will skip all of the former dialogue we had and go right to the bottom line.

Q&A for the Tubes

Sharon Cornet:

Is this tube figured for non-perforated and no holes drilled?

Olan Volan:

The tube is a plastic smooth tube, thin-walled PVC.

When there is enough difference in height one exhaust should be enough. The advantage is then that it becomes "self-cleaning". No holes drilled in the tube for flow. In English one calls it laminar flow.

Sharon Cornet:

So it slopes for drainage out one end rather than draining into gravel via holes underneath a near-level tube?

Olan Volan:

Holes will be in the way of a smooth flow. It should be sloped so that one end should be from 15 to 25 cm (6-10 inches) higher than the other end.

On the Subject of Earth Tubes

An earth tube is a tube underground that lets in outside air and cools it by means of lower ground temperature in summer, or heats it in winter. The then-cooled or heated air goes into the house. What do we have to know to predict the workings of this pipe? We must know its inner surface so that we can figure out how much energy can be passed on from the ground to the air or from the air to the ground. Other basic stuff to know is how much energy can be stored in a given amount of air for a given rise of temperature, so knowing the speed of the air and the intake temperature of the air is, of course, important too.

We should start by determining the surface by using the math for the circumference of a circle and then multiply it by its length, then the next thing to know is the amount of heat that goes into air per quantity per rise; this is normally called heat capacity. The flow rate with which the tube and earth can pass on energy is normally called the u-value. The scope of this piece is to give the reader a basic idea of the rules

of thumb for an earth tube. For those more into physics there is the formula in two parts (part two is for the "extraction" function).

Olan Volan's Earth Tube Calculations

I have rounded the numbers up or down to the nearest inch or foot, etc. in the Imperial units/US customary measurements, based on Olan Volan's calculations in metric. The terms "pipe" and "tube" are used interchangeably.

Tube Diameter

Okay, so far: 30,4 cm (12 inches) pipe diameter is the optimum size, though 5 cm (2 inches) deviation gives a result within the 90 percent range.

Tube Depth

The same goes for depth, but there the deviation can be 50 cm (20 inches) to remain within the 90 percent range.

Distance Between Tubes

Last is the land needed for one tube: this is pretty dependent on the soil but 1,25 meters on both sides ought to be the norm.

After 3 meters (10 feet) deep results improve slowly but the cost of digging goes up exponentially.

I can tell you in feet: 1 foot pipe /10 foot deep /4 feet apart

The transfer between pipe and air is around 4 btu/ft²/degree F/hr

1degree centigrade, 1 watt /ft²/hr or 11 w/m²

This is where my doubts begin... around 2.

2btu/ft²/F/hr

This is much less than people think.

The biggest influence is diameter...

Then depth...

Then soil.

Simple Math Calculations

["Simple" is relative. For Olan Volan, with his physics mind, this is simple, but for me... I will do little more than blink at it and call it the flux capacitor. *wink wink*]

The basic goal is to eliminate the calculations and develop good rules of thumb. The rules of thumb should be enough for normal stuff. Of course, a high rise building with a shopping mall is another story. Normal stuff to me are houses up to around 2-300 m² (2,153-3,229 sq ft) floor space.

$$\rho \beta g \Delta h (T_{out} - T_{ext}) = \sum_i \rho \zeta_i \frac{V_i^2}{2} + \sum_j \rho f_j \frac{L_j V_j^2}{2 D_j}$$

A 30 cm (12 inches) tube has a circumference of 2*3,14*15=94 cm (37 inches). Multiplied by the length of 15 meters (49 feet) it has 14,1 m² or 151,8 ft² its surface is 15*15*3,14=706 cm² or 0,76 ft².

When we want a flow to the V1 standard then: 300/3600=83,3 liters per sec (22 gal per sec).

This is around 3 ft³ per sec.

The transfer is around 4*151 =600 btu per hr

This is 600/3600 around 0,1666 btu/sec

Air holds 0,054 btu for 3 ft³

Air Transfer

I will proceed slowly with some knowledge about air. Air in calculation has 1/1000th the heat capacity of water or 1 watt per m³ (similar to a cubic yard) per degree centigrade. Those more knowledgeable in physics know that air is a substance that varies a lot due to its changing content of water.

So our next step is towards a better understanding of the transfer. We have this air that comes in and has a difference of 50 degrees C (122 F) with the tube so we have to lose 50*0.054btu per second. The problem is that the difference between the ground and the house in temperature is around 12 degrees. Or we can get rid of max 0.1666*12. The case is then that these two equal each other out. Of

course there is some rounding off but it is close enough for rules of thumb for normal houses, normal being 300 m³ (392 yd³).

I assume everyone knows that hot air can hold more water than cold air, thus we have to figure out the water to get rid of it. It's fairly easy: air at 50 degrees holds around 75 gr /m³ (2 oz/yd³) and at 12 degrees (C) it holds around 10 gr/m³ (0.27 oz/yd³) so we have to get rid of 65 grams /m³ (1.75 oz/yd³) of air. It's going to be less but for calculating we keep the 90% relative humidity and we assume all day is on midday, we then get: 65*300*6 (hrs)=117 liters (31 gal) per day or around 4 ft³ that is washing your earth tube. As one can see, the fear of mold can be washed away. *smiles*

Pressure Differences

This one calculates your pressure differences (for the die-hards only):

$$V = S_{ch} \sqrt{\frac{2 \beta g \Delta h (T_{out} - T_{ext})}{S_{ch} + S_p \left(\frac{S_{ch}}{S_p}\right)^2 + \frac{\beta_{ch} L_{ch}}{D_{ch}} + \frac{\beta_p L_p}{D_p} \left(\frac{S_{ch}}{S_p}\right)^2}}$$

Some Notes on the Calculations of Tubes

I did not account for curves in the earth tubes or connections (where I live tubes of more than 4 meters in length are not so easy to find); it lowers performance, as will the water collecting outlet or any type of filter. The "exhaust" calculated was a chimney with even distribution in the tube, a myth that will also lower performance. Let's hope the 4btu /ft rate given by the producer is correct as the earth-to-tube rate. All in all my guess is a 50% result, and the good part is that this calculation did not take into account that you do not have to carry away the amount of heat calculated all day. When the system works at 50% you are in the clear. □ The bad part for me is that I will have less water too. These rules of thumb are "undercalculated".

EARTH TUBES Q&A

This last section is a basic Q&A (Questions and Answers) compilation based on things people have asked me, or that I have learned along the way, which you may want or need to know. Much of it is covered in the rest of this book, but I provide it here as a quick lookup method to a few basic questions.

How much do earth tubes cost to make?

The cost is usually about \$150 USD per earth tube.

How much do earth tubes cost to run/use them?

Once you build them, the price to use them after that is FREE because they are completely passive and have no moving parts.

How many earth tubes do I need?

You will need about one earth tube per average room, or two for large rooms such as oversized living rooms or great rooms.

Can earth tubes be used for any kind of building?

Different sizes/styles of earth tubes (ground-coupled heat exchangers) have been used for residential houses as well as commercial and even industrial buildings. They are usually smaller for homes, and easily built, but grow in diameter and length (and sometimes complexity) in order to be efficient enough for larger buildings, however some larger systems have been tried but failed to produce the desired effects while others have been successful. I teach small-sized residential earth tube construction for owner-builders here in this book.

Are materials to build earth tubes hard to find?

Earth tubes can be made using common materials from your local hardware store—thin-walled PVC pipe, PVC primer/glue, elbows,

couplings, screen materials, and utilize inexpensive electric tools like drills and a jigsaw (or hacksaw).

Can earth tubes really replace an air conditioner?

Yes! If they are built according to the specifications in this book (size, length, type, use, and maintenance, etc.), they should readily replace any air conditioning use you may have now. It does depend on the energy efficiency of your home, however. A *mobile home/trailer* may only find a small drop in temperature inside, whereas a *standard constructed house* will get more relief, an *energy efficient home* will find even more of a reduction in air temperature from the summer heat, and a *superinsulated and/or passive solar home* would find the highest air temperature differences between inside the house and outside ambient air temps. This amount of efficiency can range approximately 5-30 degrees Fahrenheit (3-16°C) between these types of homes.

One can always offset this by adding extra earth tubes to make temperatures cooler in the house (if the house is less energy efficient), which should help, although the cost would need to be compared with the cost of simply adding more insulation, caulking to tighten air leaks, etc. to see which is more cost effective and will reap you the most benefit. Or you can always do both (increase energy efficiency, while adding earth tubes for cooling), which would help it from both directions.

How do earth tubes work?

Earth tubes draw air in from their inlet (furthest away from the house/building), which is approximately 100' (30 metres) away from the outlet (where the air enters the building). When all the windows and doors are completely shut, except for one or two up high, convection causes the warm air to exit the house, therefore drawing in air from the earth tubes.

As air flows *slowly but continually* through the tubes, the ground's stable cool temperature (during summer) cools it, causing moisture from the air to form/condense into droplets inside the tube, which drain out holes into gravel. The air flowing into the house is cooler

and dryer, and keeps the temperatures inside the building lower than outside temperatures.

In winter, this process can help heat the air (called heat tempering) to warmer temperatures than the outside air, although other systems are typically needed to finish heating the home the rest of the way (a furnace, woodstove or fireplace, passive solar design, electric or gas heater, masonry stove fireplace (or Finoven), or other method).

Do earth tubes need fans or pumps?

When designed properly earth tubes do not need any pumps or fans or electricity to “run” as they are completely passive systems. If a system “needs” to be more complicated by requiring such devices then it is probably designed wrong or may be more costly to run and may require more maintenance (e.g., corrugated tubing instead of smooth walls restrict air flow and cause puddling of water and may grow mold, or too many or the wrong kind of bends in the tubes can cause issues with natural air flow).

If a fan is absolutely required you can use a solar PV powered fan, otherwise it is going to cost you to run it. A contractor I know suggested using a pipe reducer and a fan to force cooling of the air, but fans pushing air through the tube too fast could deplete the ground temperature affecting the tubes and cause an inefficiency due to thermal lag (the earth’s temperature cannot keep up pace with a forced system that takes more than the earth can replace in the same amount of time). I definitely do not recommend using fans unless absolutely necessary, and then only low-level fans.

What are temperature differences inside and outside the house?

A standard older or newer house will have a 10-20 degree F (5-11 degrees C) drop in temperature inside compared to outside. We had a passive solar straw bale house, which was superinsulated and designed to keep the sun out in summer, so experienced a 30-degree F (16°C) drop in temperature, even though it did not have much thermal mass (other than partial dirt floor and partial wood floors) built inside the house yet.

Can earth tubes be used with new or existing houses?

Yes, earth tubes can be designed into a new house plan (prior to breaking ground, preferably), or they can be built and the house retrofitted to accommodate them. This might be more challenging to retrofit for adobe or rock or other solid walls, however, but not impossible. You will want to discuss options with a structural engineer first.

What is the air quality like from earth tubes?

When earth tubes are constructed properly, used correctly, and maintained properly, then the air coming into the house should be as the same quality going in from the outside (although certain types of air filters can be added, if desired, but may restrict air flow). A few studies have shown that earthtubes in certain areas of northern Europe have some issues, but not in central Europe, but whether the former is due to regional types of mold or bacteria, or user error, or a faulty design of the tubes passed from one person to the next, has not been thoroughly investigated or documented.

Radon should be minimal if the tubes are designed correctly, and any house in a high-radon area should already be designed to rid radon build-up anyway. All homes—especially energy efficient homes built tight—should have an adequate ventilation system, in which case many times earth tubes can provide for proper air exchange rates.

Mold and bacteria are not typically a problem in the types of earth tubes that we constructed and that I teach to build here, as long as they are properly built, maintained, and used. I cannot vouch for other types of earth tubes designed by others in different regions of the planet, although the concept is adoptable. The key is to not allow water to stand in the tubes, ever, so proper drainage is paramount.

Can you clean or sanitize earth tubes?

People have tried multiple ideas to sanitize earth tubes but without much luck. If there are issues they need to be fixed first (obstructions removed, leaks sealed, etc.). Some people have suggested running bleach-water through them, but this would not work on cleaning the walls at all and the water would exit tubes if there are drainage holes.

Others have considered connecting a rope and dragging a soft bleach-soaked ball through them (risking getting stuck). Tubes generally will not need to be cleaned at all if they are built correctly and used properly. The ones we built in the late 1990's had never been cleaned.

The only sure thing I know of, without all of this fuss for removing/killing possible mold, bacteria, smells, biological issues, or the like is by an ozone generator placed at the tube outlet (inside the house) and directed solely through the tube to the outside for any manufacturer-recommended time. Do NOT breathe ozone as it can damage the lungs when the generator is running. Ozone is used to kill mold and odors in houses.

Do you need a sump pump?

Typically the earth tubes drain condensate from the tube into a gravel bed, so no, a sump pump is not needed. There are, however, some designs that utilize a sump pump, but it is not usually required with the type of earth tubes that I teach to build here.

Can you use earth tubes year around?

If the earth tubes are buried well below the frost line (at least 6-10+ feet (2-3+ metres)) then they can probably be used year around—in summer to cool the home, and in winter as a heat tempering tool, and also to feed a fire (woodstove or fireplace or furnace), if desired.

It is important to note, however, when they are used for heating there is a slightly greater chance for mold growth due to the heating/cooling of the tubes back and forth (particularly during spring/fall when temperatures are swinging cyclically), but only because mold grows faster when heating air and it is bridged by cold air in between. One recommendation is to close off the tubes during spring and fall and just use them during summer for cooling, and winter for pre-heating the air or feeding a fireplace/woodstove.

How do earth tubes remove condensate?

There are small holes drilled into the bottoms (only) of tubes where the condensation drains into a gravel bed. In some designs non-

perforated tubes are sloped away from the house and the condensate may go into a deep gravel pit, cistern for collection, or a drain sump may be used.

What are average soil temperatures year around?

It depends on where you live and what kind of winters and summers you have. Generally speaking, the deeper underground you go, the more stable the temperature. The air moving through the tubes in the earth at deeper depths, will follow those temperatures closely. Ambient temperature below the frost line, at an 8' (2.5 m) depth may drop to 41 degrees F (5°C) in winter, and rise to around 65 F (18°C) in North America. It is not usually logistically or economically feasible to place earth tubes below the 10' (3 m) level.

Can earth tubes be used in a humid climate?

The short answer is yes, although there is some debate for tropical areas, so be cautious there. There also appears to be some misconceptions floating around the Internet about whether or not earth tubes can work in humid climates. I think the misunderstandings come from poor designs, based on everything I have read. I will give an example of high humidity where the tubes work fine...

We visited local homes in Nebraska and copied the designs of their earthtubes, which had been used for five years, and even 10 years—the owners said they worked great in that humid climate. We made our own tubes when we built our straw bale house, then finally moved in and used the earthtubes (mid-late '90's). In 1999 we sold the house, and the new owner used the earthtubes after that.

In fact, when it is 99% humidity outside and 99 degrees F (37°C), it is a cool and dry 70 degrees F (21°C) inside the house—a 30-degree (F) difference! So yes, if designed properly, earth tubes can absolutely be used in hot humid climates. If someone is having trouble and it is not a design problem or user error has been ruled out, and if the heat and humidity levels are extremely high all of the time (like in Florida), then it could probably be remedied by adding extra earth tubes to deal with the humidity levels, as well as by lengthening the tubes by

at least 30%+ to allow proper cooling and full dehumidification to take place within the tubes.

In using earth tubes the whole idea is that you WANT humidity to condense inside the tubes, but also to drain away (the key to success) so that it does not become stagnant or promote mold growth. In order to properly dehumidify super-humid air, lengthening the tubes to at least 130 feet (40 m) and make sure they drain very well and have no standing water in them whatsoever. Adding extra tubes should logically help, rather than hurt, even if you have to double up. I have breathed the air in Florida (I lived there for 7 years as a teenager) and my lungs did not work well on super-humid sunny days (especially after rain) so I know all too well the factors involved—the earth tubes need to be effectively sized and installed in adequate numbers to be able to handle the load, but drainage to keep the tubes ultimately dry enough is key. If you cannot accomplish this then it would be recommended to avoid using them.

How long should earth tubes be?

We were told that, for completely passive earth tubes (no moving parts), 70 feet (21 m) might work okay, that 100' (30 m) is ideal, and that 130' (40 m) is better, but that after that the temperature does not really drop enough to make the extra cost worthwhile. We used 100' tubes and they worked well for us, as did they for other people in our region. How much land do you have? Are you utilizing a fan (if so longer tubes are essential)? Is it much more costly to add a few 10' sections to the tube? If not, consider going up to 130' long, but I personally would not recommend going less than 100' in length unless you simply do not have the room in your yard, in which case you might have to add more tubes to compensate.

How wide should earth tubes be?

We were told to use 4" (10 cm) diameter tubes, which worked excellently for us. 6-8" (15-20 cm) tubes could be used for extra air flow or to feed larger rooms (or more than one room) but these tend

to lose efficiency after this size for homes (commercial buildings may find larger tubes useful in a different application, however).

What pipe materials are needed?

We were advised by our contractor/teacher and earthtube owners to stay away from metal, concrete, gutter drainpipe, weeping tiles, or corrugated pipes at all costs as they could have mold, bacteria, air quality, corrosion, or other issues associated with them. I have heard of people using metal tubes that had an antimicrobial smooth surface on the inside with luck but I have not used them. The successful earth tubes we witnessed working are what we copied exactly as they built them, and that utilized 4" (10 cm) diameter thin-walled PVC sewer pipe (unused). Thin-walled pipe is needed for greater conductivity and thermal exchange between the air and the ground temperatures. Thicker-walled pipes do not allow for proper thermal transference.

How deep do earth tubes need to be buried?

Although 20 feet (6 metres) and beyond has the most stable ground temperatures, it is not always feasible to dig this deep, and is costly and may not be worth the effort. Half that deep is probably ideal, but anything below 6' (2 m) is fine, typically. If you want to use the tubes during winter they definitely need to be well below the frost line. We only used ours in summertime and had very conductive (clay) soil, so only buried ours 2' (61 cm) down and they worked very well for us, which actually surprised me.

What kind of soil is best?

Highly conductive soil is best for thermal transference, which would be clayey soils. Regular "dirt" is good. Sandy soils are poor conductors. Some gravel or rock mixed in the soil (if it exists in-ground already) is okay as long as it does not compromise the tubes' integrity.

Wetter soil will remain the coolest, while dry soil will tend to be warmer. I cannot vouch for the wisdom of this, but regarding physics principles this would be a good idea... one could potentially dig a deeper trench and place one tube over a second one underneath (at

least a foot (30 cm) apart on center, filled with dirt and then the gravel layer just under the top tube) to take advantage of the wet cooling effect from the top tube's dripping condensate, which will leach down and wet the dirt over the bottom tube, therefore making the bottom earth tube cool more effectively.

Does the ground temperature change?

Any time you draw thermal properties from the ground it is subject to change. Systems that use fans to blow air through the earth tubes tend to overuse the earth and draw from it faster than the temperature can be replaced (called 'thermal lag', which is the time that is required to remove or add heat from mass), thereby reducing efficiency of the ground in its ability to bring a steady supply of cool air to your house during summer (or warm air during winter). This is why I recommend passive cooling earth tubes (no forced-air fans or moving parts) because it does not deplete the ground's ambient temperature faster than it can replace it.

When earth tubes are designed passively the air moves very slowly, a natural process through convection, and properly cools through the physics principles of condensation and thermal transference (heat loss). SLOW-MOVING AIR is key! The thermal lag is met in near-equal measure in a passive system, so ground temperatures remain more stable than with "forced" or active systems. Hence, passive cooling via earth tubes without fans will continue to cool or warm the house longer than trying to force it via mechanics. Active systems cost more and require longer tubes and/or extra tubes to compensate for robbing the ground of its thermal properties too soon or much.

Are earth tubes a ground-coupled heat exchanger?

Basically, yes. The earth's subterranean temperature is fairly stable over time, with lower swings than we find in the air. Thermal lag keeps this a slow process compared to ambient air temperatures, in fact, but the earth's temperature will rise and fall depending on the season. A ground-coupled heat exchanger captures heat and/or can dissipate the heat to the ground. This is how geothermal systems work.

If air for a building is blown through a heat exchanger for heat recovery ventilation (HRV) it can be called 'earth tubes' and is a type of heat exchanger for harnessing natural geothermal energy. However, HRVs can also be (and are usually) mechanical (MHRVs) and used in ductwork along with a furnace, so be aware of that. Earth tubes are also called earth-air heat exchangers (EAHE/EAHX), or a variety of other names, depending on where you live.

Ground-coupled heat exchangers can also use water or a heat transfer fluid (like antifreeze) in a closed-loop tube system underground, which raises the temperature of the earth underneath the home rather than blowing air through it into the house. In areas with mold or radon issues that cannot be bypassed or adequately controlled, this type of closed-loop system may be beneficial.

Earth-air heat exchangers of different types have been used in conjunction with solar chimneys, cooling towers, and qanats in hot arid or semi-arid regions for thousands of years (in Persia and other areas in the Middle East). Earth tubes are similar to geothermal heat pumps or downhole heat exchangers, but are generally far easier to install (owner-builders can typically do it with the proper knowledge, whereas more costly and complicated electric systems require a professional installation and can be costly).

Can earth tubes be used anywhere?

I would say that earth tubes could probably be used in many places around the planet, but in very cold climates they would have to be buried well below the frost line. In some cold climates they may not work as well. In extremely cold climates, say many people, they do not work at all. For instance, the tubes would easily get damaged in permafrost zones, and also would not work in latitudes that remain frozen year around. However, for the rest of the warmer and habitable places on the planet, they may be useful.

Regional differences do occur so check for what types of earth tubes are used in your local area by asking passive solar home builders, checking online blogs or forums, asking local natural building groups, and so on.

Be aware that earthtubes also cannot work in super-humid areas or with a high water table, such as Florida, where the water table is a mere few inches (10+ cm) to a few feet (1-2 m) down below the ground's surface—this would cause the tubes to be underwater and would fill up with liquid so no air could pass through (drainage is key). However, they may be placed within an extra-thick earth berm above ground, or in a hill or mountainside, if it suits your circumstances. If you dig and hit bedrock, this may also be a deterrent to using earth tubes, or if the ground is too rocky (if you can dig a trench, then soil infill could be used over the tubes, however).

Outside of these situations, earthtubes typically work well in either dry, hot, arid climates or some hot humid climates (for the latter you would need an extra number of extra-long earth tubes for proper dehumidification, and ensure excellent drainage). You must have sufficient space to dig the trenches and install them, however. Thermal conductivity of the soil (clay being best, sand being worst) is also a factor in how well the tubes will work, as is moisture content. One benefit in super-humid climates might be to stack the tubes one over another (with space in between) so the dripping condensate flows down through the gravel and then the dirt that surrounds the tube(s) below it, improving thermal transference. This would, therefore, cool the tubes faster and to a lower temperature (as well as the air flowing through the tubes).

What is the environmental impact of earth tubes?

Contrasted with the high utility bills and use of fossil fuels, air pollution, energy use, and materials involved to build, maintain, and use forced-air HVAC (heating, ventilation, and air conditioning) systems that typically cool or heat a home (especially in North America or developed nations), earth tubes are a godsend in regards to reducing effects on global warming (not to mention your pocketbook).

People spend up to a few hundred USD/CAD per month to heat and cool their homes; whereas, for what they might spend on utilities for one or two seasons, they could install earth tubes and benefit from

the cost savings (which are FREE if the earth tubes are completely passive with no fans or mechanical systems associated with them) for the lifetime of the tubes or the house. Earth tubes are a passive cooling technique utilizing geothermal energy and are a sustainable alternative to standard systems for cooling (and heating).

A Follow-Up Note From Sharon Cornet

I have sad news since publishing this book in early January 2016. I do not keep in touch regularly with the owner (a friend of mine) of the straw bale house and earth tubes we built back in the 1990's, but every so often we talk. Sometimes it is years between times of communication. I'm hoping that there will be some grace shown here because I was simply not informed by the owner until after this publication that the tubes are no longer in use. It was a while back, and so I am making this update, which I feel is appropriate as a kind of disclaimer as well as just an FYI. I am surprised I did not know or remember this (I do not recall him telling me)! *sad face* The earthtubes worked so well for years, but someone (I will not name who because there was a falling out between those people) cut the tube inlets off and water infiltrated and so they were ruined. *frown*

Before that the tubes worked as I stated in this book, but he admits that now—even though it is a straw bale house—the summers are so stifling hot and humid the house is now too hot so they are forced to use an A/C because the tubes were cut off and have since been closed off permanently. We sold them the house as a completed shell but evidently they did not put or keep enough thermal mass inside for temperature stabilization when they finished it out inside. Otherwise they still might not need an air conditioner. Bummer for them.

I had contacted him in hopes he would be willing to do some testing on the tubes, but alas, it is disappointing to hear that the tubes we built are no longer in use, so have not been used up to the 17 years I thought they had been. I did not know about the water infiltration, and whether that was due to the tube ends (inlets) being sawed off and

exposed to the rain and debris, or if it was because the gravel was not deep enough, leading to the high-clay soil repelling the water and backing up, or both.

I apologize for any misunderstanding my book may have caused in my claims that the tubes have been used all of these years when they had not been 'running' all of this time. They did work well as he told me they did for many years prior to this occurrence. Rather than try to fix every spot in the book I am simply stating it here and hope that people can write to me with their stories and experiences with earth tubes and hopefully be willing to have some testing done to promote the educational aspect of these tubes for the common good.

Overall I still think that earth tubes are an excellent addition to a house, if they are built and used correctly in the right area. Of course, the other option is to build an earth-sheltered/earth-bermed house and then the earth would cool the home rather than needing tubes. Tubes might also allow for fresh air and possible water collection as well, however, so there are pros and cons to every decision, whatever it may be.

If I had to do it all over again I might make the same kind of earth tubes, but rather, ideally I would use a 12" diameter single, flexible, smooth, food-safe, thin-walled tube that could coil around the house as my first choice; but alas, I know of no such place to purchase such tubing as of this writing. It would be highest at the house, and sloped downward and away from the house, into a deep gravel pit or sump or separated water catchment that would not affect air quality within the house. This design would be nearly impossible to grow mold inside the tube, especially if sloped to the specifications of Olan Volan in the 'Calculations for Earth Tubes' chapter. It is still debatable, however, if this design could be used in very cold climates, or severely hot-and-humid climates, such as the tropics.

I wish you, the reader, well on your endeavors to cool your house naturally to not only save on utility bills and find ease and comfort in your home, but also to help save the planet from unnecessary carbon

dioxide and other pollutants in the environment due to mechanical, electricity-eating, manmade inventions. Living in tune with nature will help save the earth, which includes those animals and plants and people who live upon it. May we all unite with a single eye towards this end. Permaculture principles come to mind here: Take care of the earth, take care of people, and fair share (share the surplus back to the first two).

***Save the earth with earth tubes
and the earth will save you!***

