2. LOCATION

INTERFACING WITH LOCAL PHENOMENA

- **With what can we interface?**
- **How do these phenomena work?**
- How is an Earthship placed on a site?

In the Northern Hemisphere, moss grows on the north side of trees and snow melts on the south side of mountains. If you want a log to float downstream, you must place it in the current, not near the shore in an eddy. Earthships must also be placed for optimum interaction with natural phenomena. This chapter explores the natural phenomena of the planet and explains how to interface an Earthship into the existing phenomena of the area.

THE PHENOMENA

The Earthship was developed at 37 degrees North latitude and at an altitude of 7000 feet. The winters get as low as 30° below zero and the summers as high as 100° F. In this climate of extremes, the Earthship (through interfacing with natural phenomena) maintains a temperature of 65°- 75° F with no backup heating or cooling systems. These extremes have demanded evolution of the Earthship's performance, both in terms of heating and cooling itself. The phenomena have been studied in theory and reality, and the interfacing methods have evolved through testing and experimentation, so that at this point, the Earthship can be taken almost anywhere.

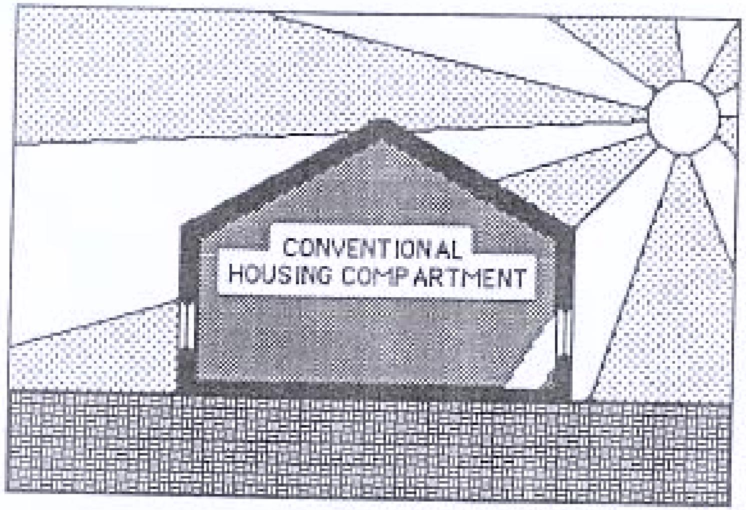
We will first explain how these phenomena determine the design of the Earthship in Northern New Mexico. This will provide an understanding of how to relate to these phenomena as design determinants. At the end of the chapter, we will discuss how the interfacing with these same phenomena varies in different climates.

The phenomena with which the Earthship interfaces are all related to the four elements, FIRE, EARTH, AIR and WATER.

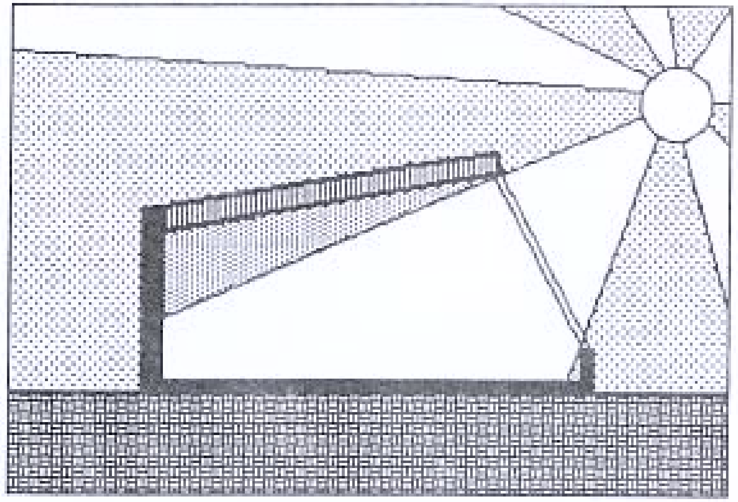
FIRE

Fire provides HEAT, LIGHT and ENERGY. The SUN is unarguably our major source of the above. The sun is a natural phenomenon.

Conventional housing compartments shield the living spaces from the sun, thus disregarding it as a potential source of heat, light, and energy.



An Earthship must **encounter** the sun and interface with it to gather this limitless heat, light and energy. This suggests a different shape for the compartment, and an orientation toward the sun.



This in turn suggests an analysis and understanding of this phenomenon called sun. We must understand this fire in order to interface with it.

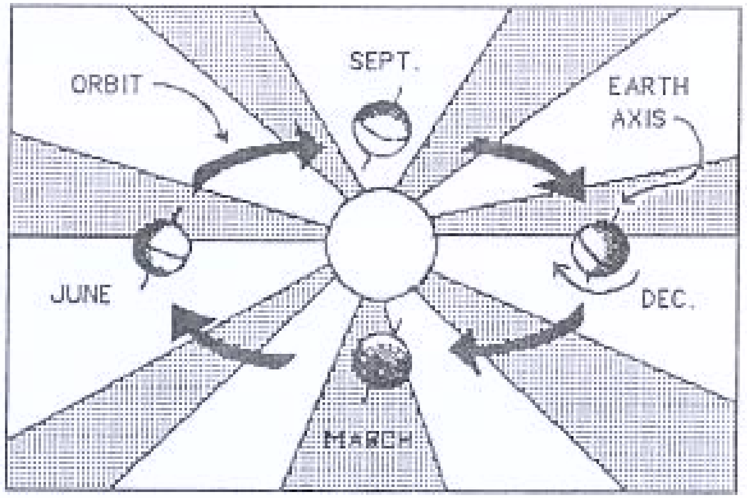
Sun / Earth Relationships

Orbit

The Earth orbits around the sun once a year,in an elliptical path (the shape of an oval), and at an average distance of about 93 million miles (150 million kilometers).

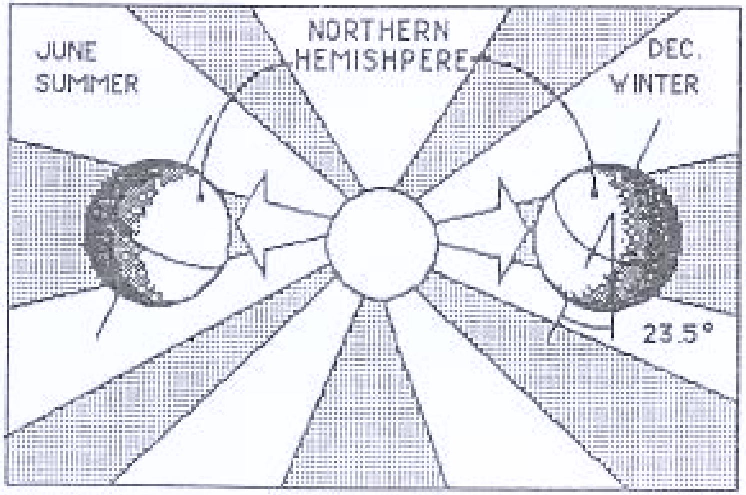
Earth Axis

The Earth also spins about its own axis, which accounts for the apparent rising and setting of the sun.

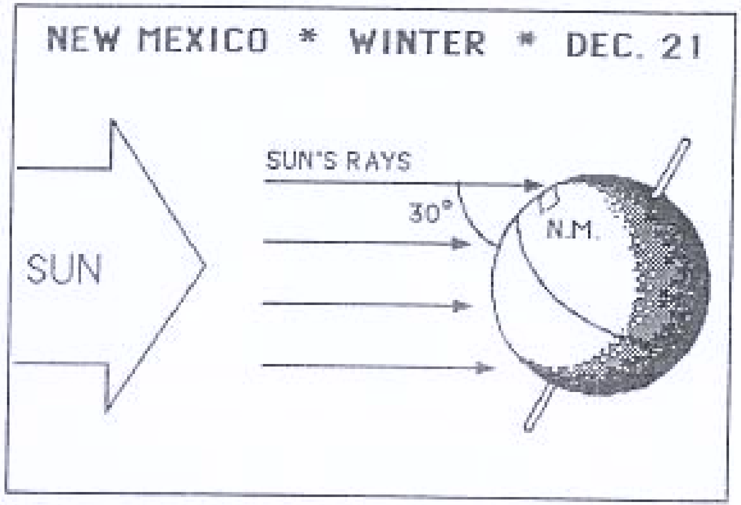


Tilt

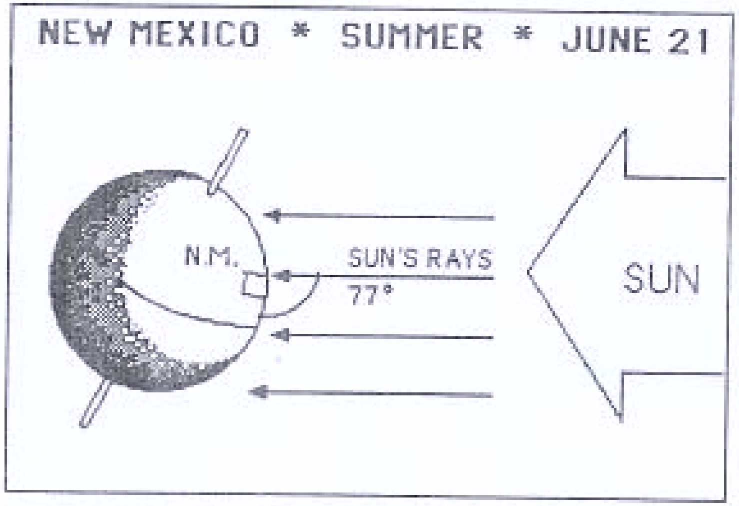
The tilt of the Earth is 23 1/2° from the plane of its solar orbit, which is why (in the Northern Hemisphere) the sun appears lower in the sky in the winter and higher in the sky in the summer.



The opposite is true in the Southern Hemisphere. Due to this tilt, the sun comes to Northern New Mexico at about 30°, relative to the surface of the earth, in the winter,

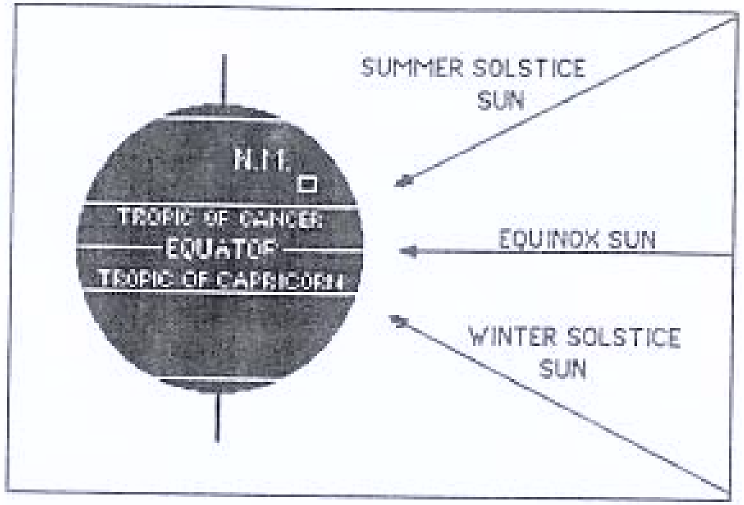


and about 77°,relative to the surface of the earth,in the summer.



Solstice / Equinox

The sun will appear at different angles in the sky from different locations on the globe. Relative to the Northern Hemisphere, it is always at its lowest point in the sky on the day called the *winter solstice*, and at its highest on the *summer solstice*.

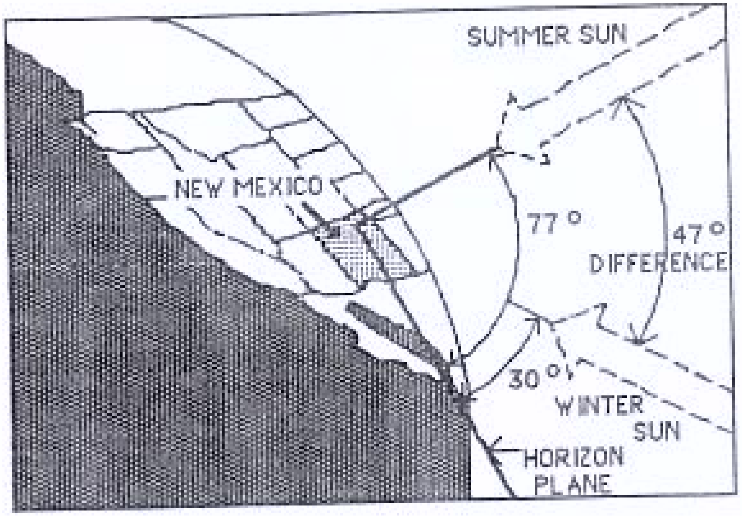


These dates are December 21 and June 21, respectively. In the Southern Hemisphere, it is the opposite. Midway between these points are the two *equinoxes*, March 21 and September 21, on which days the sun is in the midpoint between its solstice positions, i.e. straight above the equator.

Altitude

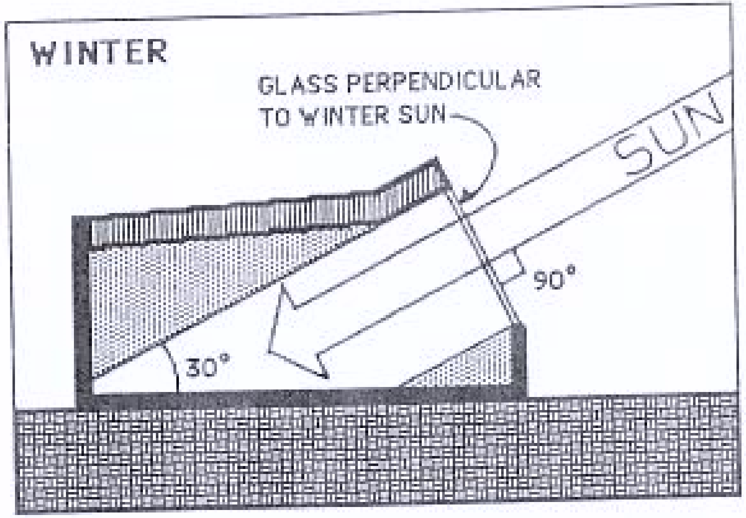
The apparent height of the sun can be measured as its angle above the horizon plane of the earth. This is called its *altitude*.

There is a difference of 47 degrees between its summer and winter altitudes, as seen from New Mexico at noon.

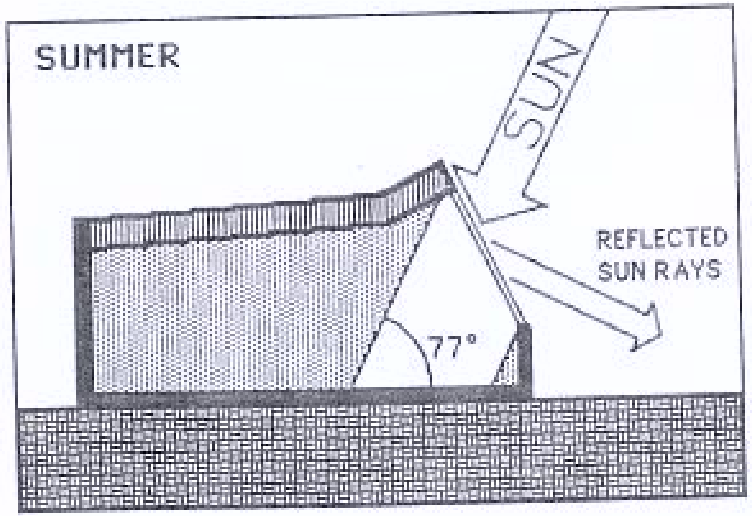


LOCATION - ORIENTATION

IN NORTHERN NEW MEXICO, AND ANYWHERE AT ABOUT 37° NORTH LATITUDE, THE SUN IS AT A 30° ALTITUDE AT NOON ON THE COLDEST DAY OF THE YEAR. THE MOST IMPORTANT THERMAL PRIORITY FOR THIS AREA IS GETTING ENOUGH HEAT THROUGH THE WINTER. THEREFORE, WE FACE THE GLAZING OF THE EARTHSHIP TO THE SOUTH, AND TILT THE GLASS AT 60° TO BE PERPENDICULAR TO THE SUN AT ITS LOW POINT. THIS REDUCES REFLECTION TO A MINIMUM IN WINTER WHEN HEAT IS NEEDED.

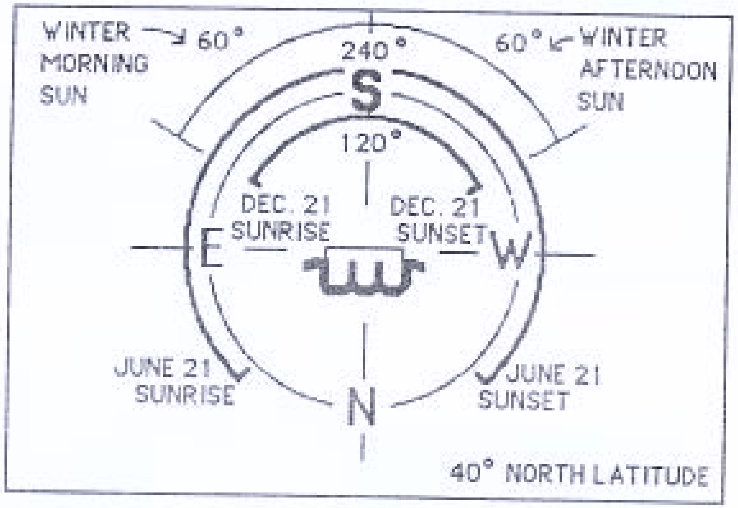


THIS SLOPE ALSO RESULTS IN CONSIDERABLE REFLECTION IN THE SUMMER, WHEN HEAT IS NOT WANTED.



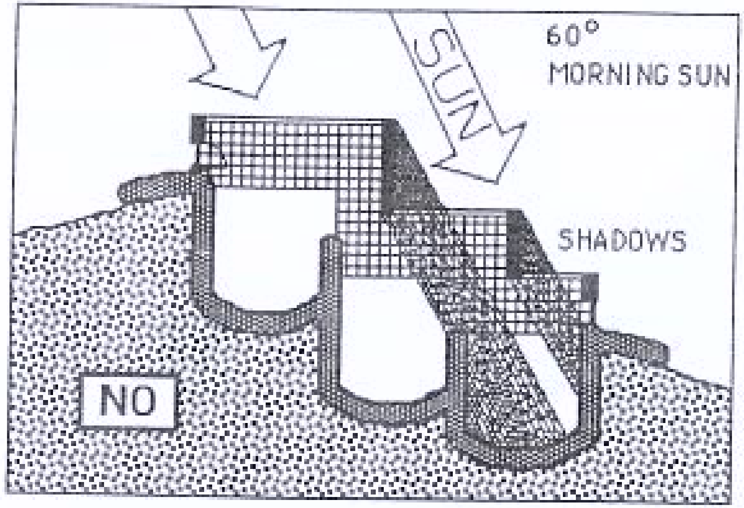
Azimuth

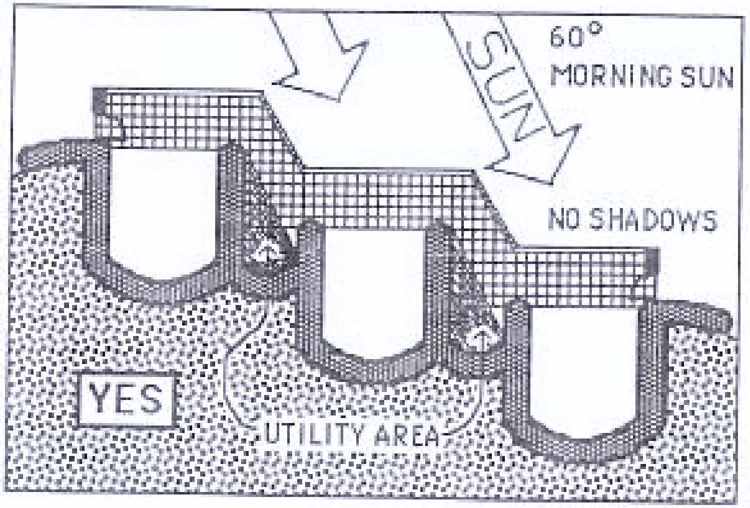
These same phenomena also account for the change in length of days between summer and winter. The sun is not only higher in the sky in the summer, but also goes through a wider plan arc, or *azimuth*. In northern New Mexico, the summer azimuth is about 240° while the winter azimuth angle is about 120°. This means that the winter sun rises 60° east of south and sets at 60° west of south. When heating is and issue, these winter angles must be related to in the front glass face configuration.



LOCATION - CONFIGURATION

AN EARTHSHIP IN NORTHERN NEW MEXICO SHOULD HAVE A FLAT FRONT FACE. IF THERE ARE TO BE ANY PARTS THAT ARE PULLED FORWARD OF OTHER SEGMENTS, THEY SHOULD RELATE TO THE WINTER AZIMUTH ANGLE OF 60°, SO AS NOT TO CREATE ANY SHADOWS THAT WOULD BLOCK SOLAR GAIN.

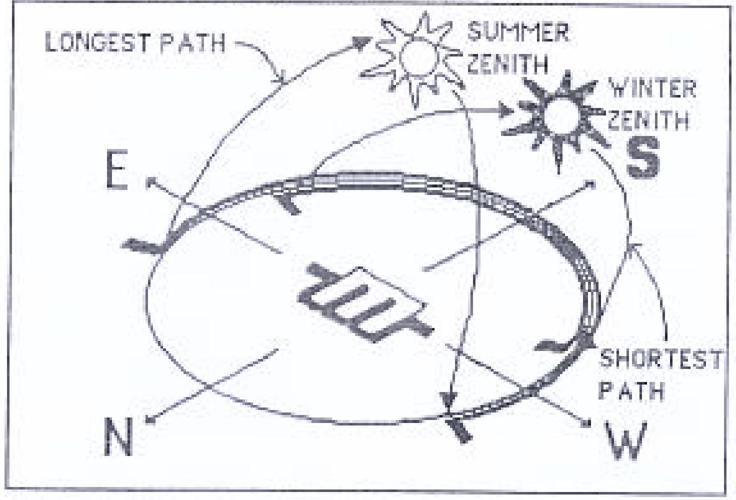




Solar Arc

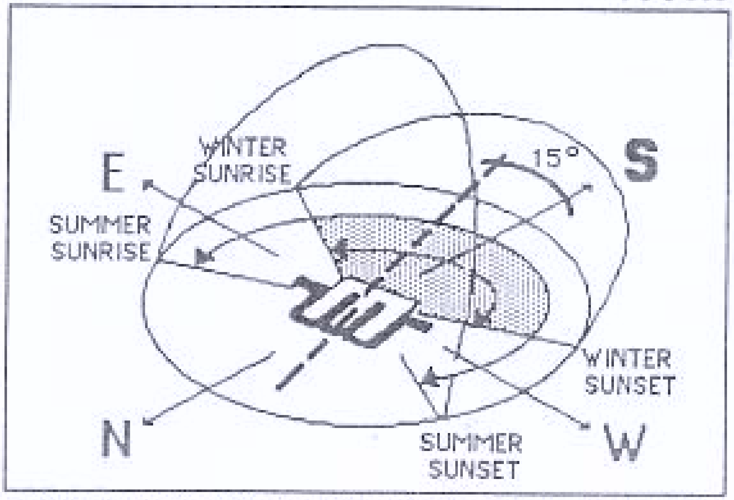
In combination, (altitude and azimuth changes) the sun appears to move through our sky in a 3-dimensional *solar arc*, as the earth rotates.

This path changes every day from shortest and lowest on the winter solstice to longest and highest on the summer solstice. It is always symmetrical about its high point (its zenith) at noon, which also points to true south.



LOCATION-STRATEGIC AIM

EARTHSHIPS IN NORTHERN NEW MEXICO ARE POSITIONED SO THAT THEIR NORTH-SOUTH

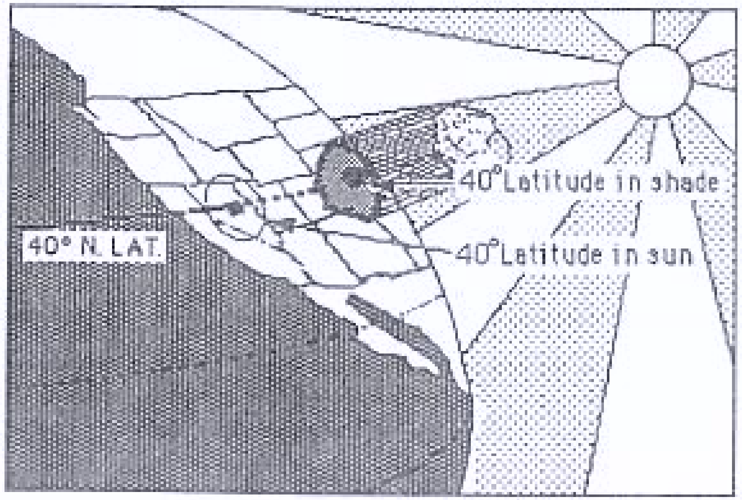


AXIS IS SLIGHTLY (10-15 DEGREES) EAST OF TRUE SOUTH. THIS ALLOWS THEM TO CATCH THE HEAT OF THE SUN A LITTLE EARLIER IN THE WINTER MORNINGS.

Percent Solar Possible

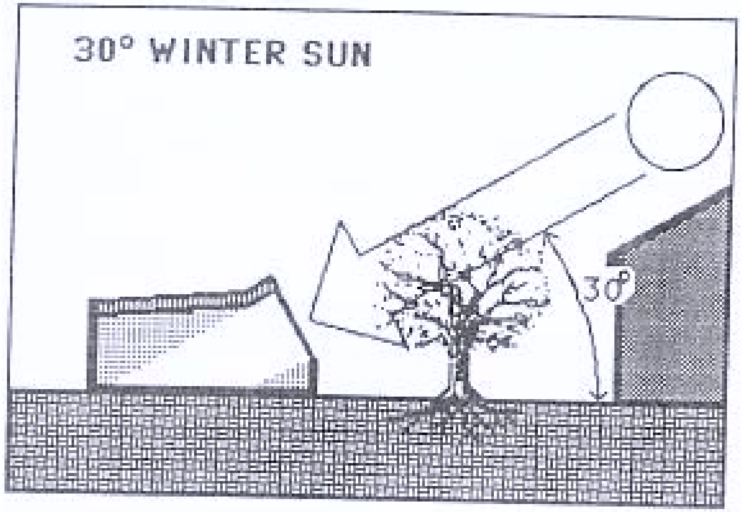
Different points on the globe get different amounts of sunshine, but places along the same latitude lines see the same number of sun hours on any given day. Also places along the same latitude, will see the sun at the same altitudes. This means the solar orientation for an Earthship will be the same on any given latitude assuming the elevation above sea level is the same. Climate obviously varies with elevation difference.

Places that are on the same latitude may not get the same amount of actual sunshine, due to clouds, smog, haze or any other conditions that might block out the sun.



LOCATION - SOUTHERN EXPOSURE

ON DECEMBER 21, WHEN THE SUN IS AT ITS LOWEST POINT IN THE SKY, IT IS ONLY 30 DEGREES ABOVE THE HORIZON AT NOON. AN EARTHSHIP IN NORTHERN NEW MEXICO MUST BE LOCATED WHERE THERE WILL BE NO OBSTRUCTIONS THAT MIGHT BLOCK THIS LOW WINTER SUN. A FEW DECIDUOUS TREES (THOSE THAT WILL LOSE THEIR LEAVES IN THE WINTER, THEREFORE LETTING SUN THROUGH WHEN IT IS MOST NEEDED) ARE OKAY.



EARTH

The earth receives, stores and refines the heat, energy, and light from the sun. There are many earthly phenomena involved in these processes. Since the Earthship receives the sun much the same as the earth itself does, it would obviously employ the same processes of interfacing with the sun that the earth itself uses.

Heat

A brief discussion of the way heat moves (thermodynamics) is necessary here to explore these processes.

Heat Energy

Heat energy cannot be created or destroyed, but it can be converted into other forms, channeled to and contained in specific places. Whatever renewable energy source is locally available, there is a way to convert it into a form we can use and put it in a place we can use it from. *Heat energy* can be converted into *electrical*, *chemical*, or *mechanical* energy.

Heat Transfer

When free interchange of heat takes place, it is always from the hotter (place or body) to the colder. The hotter will lose energy and the colder will gain energy until a state of equilibrium is attained. Cool mass walls will absorb the sun's heat, but when the sun goes down and the air in the room cools, the heat will slowly be drawn back out of the walls.

conduction

The process of heat energy moving through a material (the sun heats the south side of a mass wall and the heat moves through the wall to the room on the north side of the wall).

radiation
Radiant energy is transmitted as electromagnetic rays, which can travel through space (even a vacuum). They heat any object which intercepts them (the sun heating the earth and you).
convection
Convection is the movement of heat in liquid or gas. The source heats the gas and the currents within that liquid or gas carry the heat to you. (Subtle heat from warm thermal mass travels through the air to warm you).

Comfort Zone

The *comfort zone* is the set of conditions at which humans are comfortable to perform everyday tasks. It is a very different set of conditions for each location and culture, but all are affected by some of the same environmental phenomena:
ambient air temperature
the temperature of the air surrounding the body (without taking humidity into account)
relative humidity
the percentage of water vapor in the air relative to to maximum amount of water vapor it can hold at a given temperature
air movement or speed
how fast the air is moving adjacent to the body, it can be affected by ventilation
temperature of adjacent objects
Sometimes called *mean radiant temperature*, this is the effect of heated mass upon a body (if the air in a room is cool, but the walls and floor are warm, then the perceived temperature is higher)

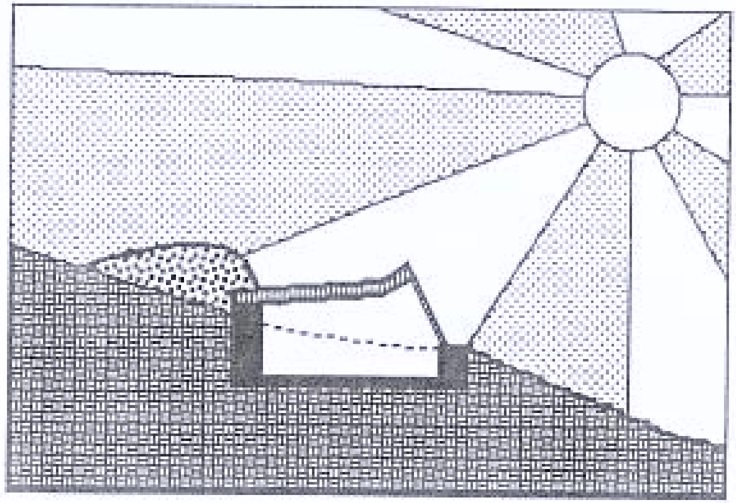
Matter

All matter is made up of molecules which have weight or *mass* (weight is actually the effect of gravity upon mass).
specific heat
All mass has the ability to store heat, yet some substances have the ability to hold more heat per unit weight than others. The term for this capacity is specific heat.
thermal conductivity
Thermal conductivity is a measure of how fast heat is conducted through a unit thickness of a substance.
thermal mass
Thermal mass is a term for any mass used to hold or contain temperature. For example, our bodies are made up of about 90% water. Our bodies hold a 98° temperature due to the *thermal mass* of this water. **The ideal material for thermal mass would hold a lot of heat and give it off over a long period of time.** Water is one of the best natural materials with regard to these properties. Earth, adobe sand, rock, brick and concrete are also good thermal mass materials. Earth is the least expensive and most readily available, however, and can also be stabilized for structure. This is why it is the ideal material for the Earthship. The more dense the matter, the more heat it will hold. Therefore tightly packed or rammed earth is a

very good container or "battery" for storing "comfort zone" temperature in.

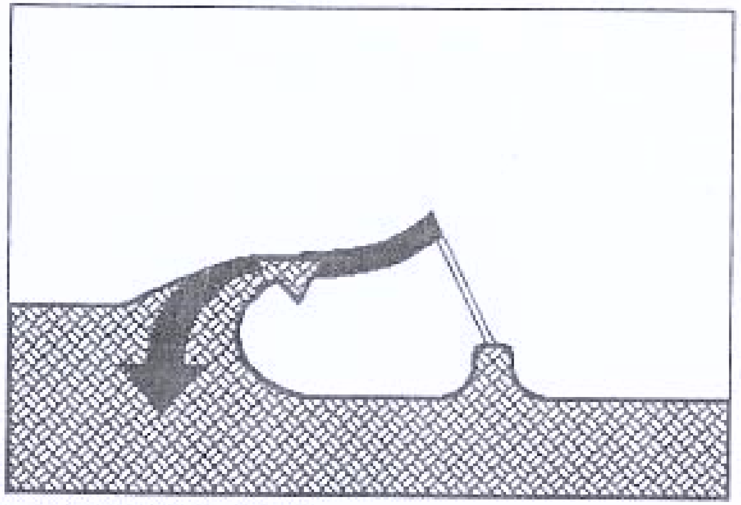
LOCATION - MASS

THE INDIVIDUAL SPACES (I.E. INTERIOR AIR VOLUMES) WITHIN THE EARTHSHIP MUST BE INDIVIDUALLY SURROUNDED BY ABUNDANT DENSE MASS TO STORE AND GIVE OFF THE HEAT OBTAINED FROM THE SUN. THE HIGHER THE VOLUME OF MASS, RELATIVE TO THE AIR SPACE YOU ARE TRYING TO HEAT, THE MORE STABLE YOUR COMFORT ZONE COULD BE. THIS CAN BE ACHIEVED BY VERY THICK INTERIOR WALLS AND SUBMERGING THE VESSEL INTO THE MASS OF THE EARTH AS MUCH AS POSSIBLE. IN NORTHERN NEW MEXICO, SOUTH SLOPING HILLSIDES ARE THE BEST, BECAUSE THE EARTHSHIP CAN BE SUNKEN INTO THE MASS OF THE HILL WITHOUT HAVING TO DIG A PIT IN FRONT FOR LETTING SUN IN.



Thermal Movement

When a substance is heated, it will expand; when it is cooled, it will contract. Earth, concrete, wood, and all building materials are affected by weather in this way. This is called *thermal movement*, and can cause a brittle material like concrete or masonry to crack. Masonry buildings may also be pushed by the swelling of frozen earth or water around their foundation walls. An Earthship is more "of the Earth," and it will accept and experience similar thermal movement to that of the Earth. Consequently, it will move with the Earth rather than resisting it. It is very expensive to make foundations that resist the Earth. An Earthship must interface with the Earth, rather than resist it.



LOCATION-SOIL

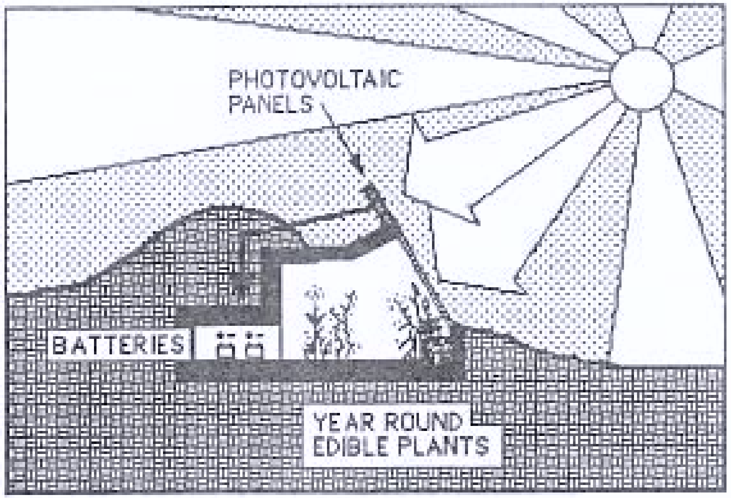
EARTHSHIPS MUST BE BUILT OUT OF EARTH ON STABLE, *UNDISTURBED EARTH*. THE

DESIGN IS NOT MEANT TO RESIST THE EARTH, BUT TO JOIN IT.

Energy and Light

Green cells in the leaves of plants and trees harvest the sun's energy. They change the sunlight into chemical energy by the process of photosynthesis. This chemical (food) energy is then transported to the rest of the plant for use or storage.

To make the most of this phenomenon, the Earthship must provide sunlit areas for photosynthesis to happen <u>within</u> its interior space. This allows for year round growing of edible plants. The Earthship must be oriented toward the sun for this to be possible.



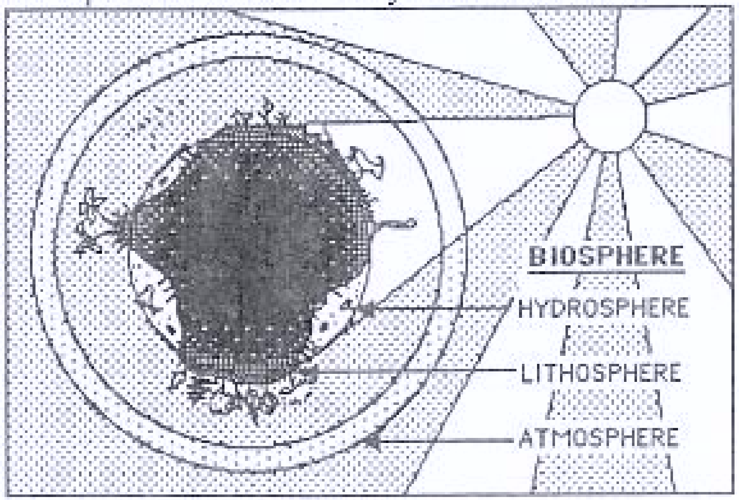
In addition to this, the Earthship must perform a similar "harvest" for electrical energy. Photovoltaic cells, mounted on the roof of the Earthship, change sunlight into electrical energy, which can then be transported to batteries for storage and use.

Natural sunlight can often be used instead of artificial electrical light, if it is appropriately allowed into an interior space. This reinforces the solar orientation of the Earthship once again.

life

The interfacing of the Earth with the sun (and with water) is responsible for what we call life. There are certain functions of life itself that must be interfaced by the Earthship.

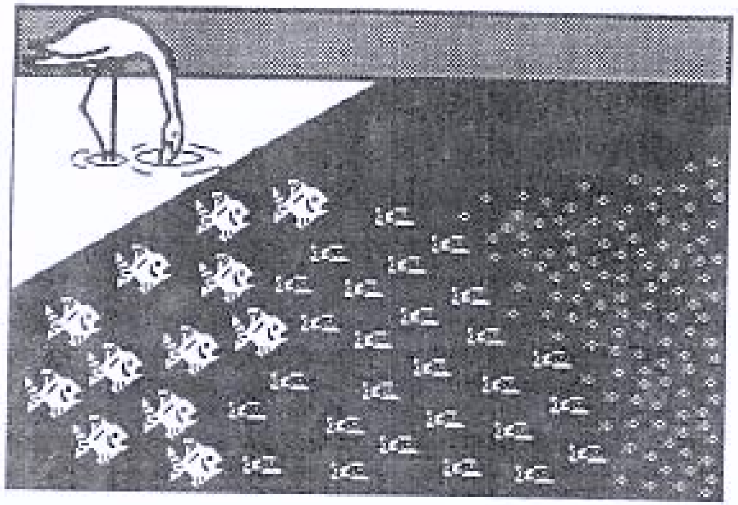
The *biosphere* is the region surrounding the Earth that supports life. This includes the *atmosphere*, the *hydrosphere (oceans)*, and the *lithosphere* - the outer layer of the Earth.



Everything between, including all of life, is powered by the sun. The less we pollute the biosphere the better it will be able to support us. The sun is the most abundant energy source available, it is free and its direct use does not harm our biosphere, where as man made power plants are destroying it.

food chain

Through photosynthesis, the sun's energy is stored in plants, and can then be used by animals, including humans, for their energy.



Thousands of plants become the food for hundreds of small creatures who are eaten by scores of larger creatures, who are eaten by single large predators. In a natural *community*, there are just enough of each type of organism to feed the next group and still have enough survivors to propagate the species.

The intertwinings of life, death and decomposition are continuous natural life cycles.

production

The inclusion of greenhouse space in the Earthship design brings some of these processes into everday life, and in doing so, also conserves the energy of commercial food production. Energy does not need to be used for centralized growing of food, (possibly using very much of it to raise livestock), then packaging and transporting the food products to a local market, refrigerating them, and finally bringing them home. By interlacing our homes with natural phenomena, they can produce much of the food we need, thereby greatly reduce general energy consumption.

Geothermal

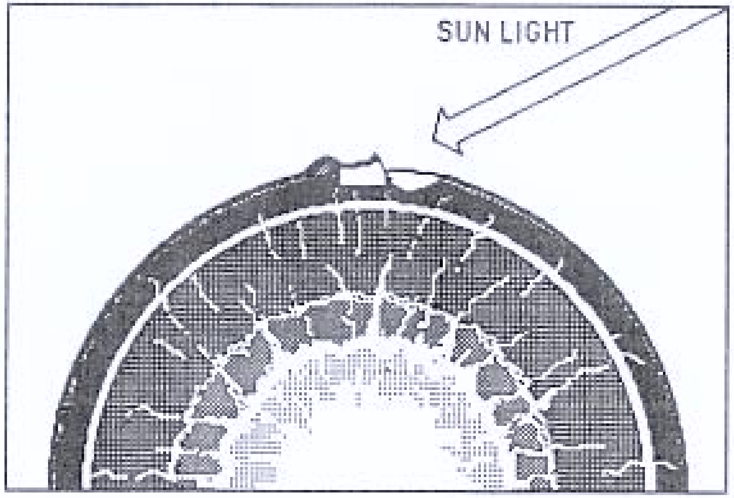
The earth is not only heated by the sun, but is heated from within. The tremendous pressure of gravity pulls the entire mass of the earth to its center, creating heat and melting rock into magma. The result is called *geothermal* energy.

Ground Temperature

At even the outermost layers of the earth this heat can be felt. Just four feet below the surface, the *ground temperature* remains remarkably constant, especially compared to climatic conditions above the ground. At a four foot depth, the temperature is usually between 55° and 60° degrees F, which is much more comfortable than weather conditions of both summer and winter. By tapping into this natural *thermal constant*, the Earthship can remain consistently comfortable, because this is only 10 degrees away from the North American comfort zone of 70 degrees. The Earthship tempers this natural constant up to 70° in the winter via heat from the sun. In the summer, this massive constant tends to drag the 100° air temperature down to 70°.

<u>LOCATION-DEPTH</u>

IN NEW MEXICO, THE DEEPER AN EARTHSHIP CAN BE SUBMERGED INTO THE EARTH, THE EASIER IT WILL BE TO MAINTAIN A COMFORTABLE TEMPERATURE.



A SUNKEN GARDEN OR "PIT" MAY NEED TO BE DUG IN FRONT OF A SUBMERGED EARTHSHIP SO THAT DESIRED SUNLIGHT IS NOT BLOCKED. MANY UNDERGROUND BUILDINGS HAVE BEEN BUILT THROUGH THE YEARS. IT HAS BEEN CUSTOMARY TO INSULATE THESE BUILDINGS AWAY FROM THE EARTH. AN EARTHSHIP MUST NOT BE INSULATED FROM THE EARTH. IT MUST INTERFACE WITH IT, THUS TAKING ADVANTAGE OF THIS TREMENDOUS THERMAL CONSTANT.

WATER

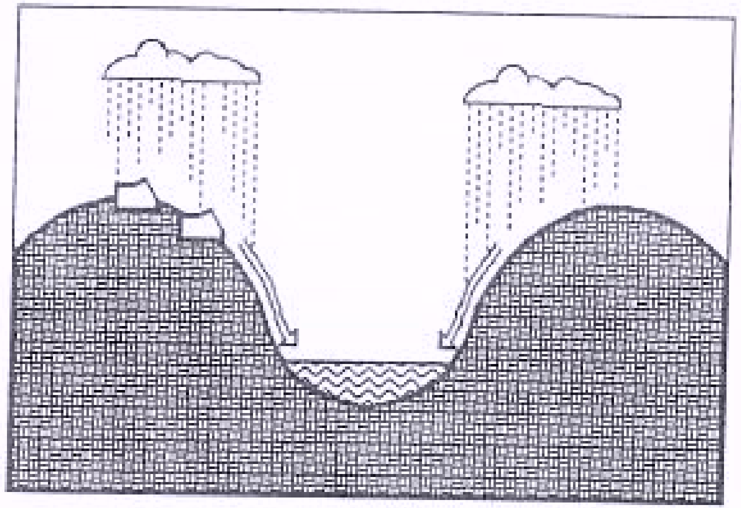
Water interfaces with the Earth, Sun and Air in many ways to create and sustain life. The Earthship must both avoid and encounter water to provide human habitat.

Runoff

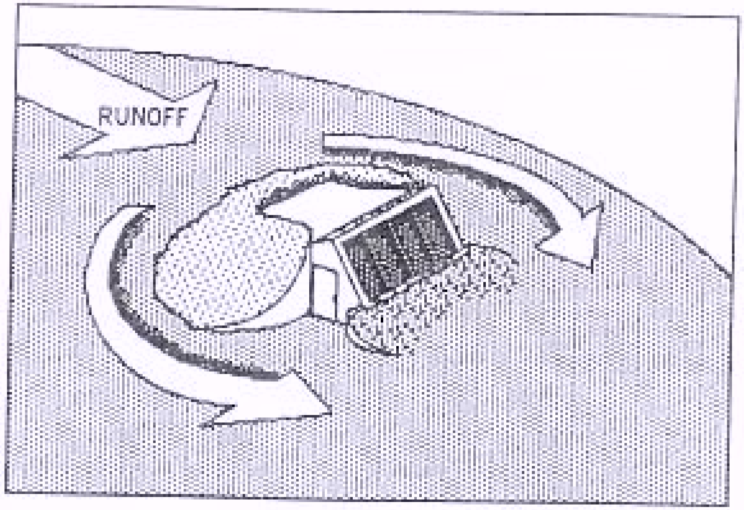
Due to the movement of ancient glaciers, water and wind erosion, earthquakes, volcanos, and other geological phenomena, the surface of the earth has many peaks and valleys. The largest and deepest valleys are full of water-they are the oceans. Water flows from the high points all the way down to these oceans, if it does not flow into an underground reservoir or evaporate first. Water also comes to the Earth by rain. That which is not absorbed into the ground and therefore is free to spill downhill is called *runoff*. On any site there will be some locations which have less runoff passing over them than others. These are the better locations for Earthships. Interfacing with natural runoff patterns can create a dry pocket or <u>island</u> for the Earthship.

LOCATION - HEIGHT ON SLOPE

THE BEST LOCATIONS ARE THOSE WHICH ARE DRIEST - USUALLY CLOSE TO THE PEAK OF THE HILL WHERE THERE WILL BE NO WATER RUNOFF FROM HIGHER PLACES.



OBVIOUSLY, NOT EVERYONE CAN LOCATE ON THE PEAK OF A HILL, SO RUNOFF LANDSCAPING MUST BE EMPLOYED. THE MOST CRITICAL ISSUE, IS TO NOT LOCATE THE EARTHSHIP WHERE THERE WILL BE A LOT OF WATER RUSHING TOWARD IT. RUNOFF SHOULD BE CHANNELED AROUND THE EARTHSHIP. AVOID PLACES WHERE WATER COLLECTS.



Water Table

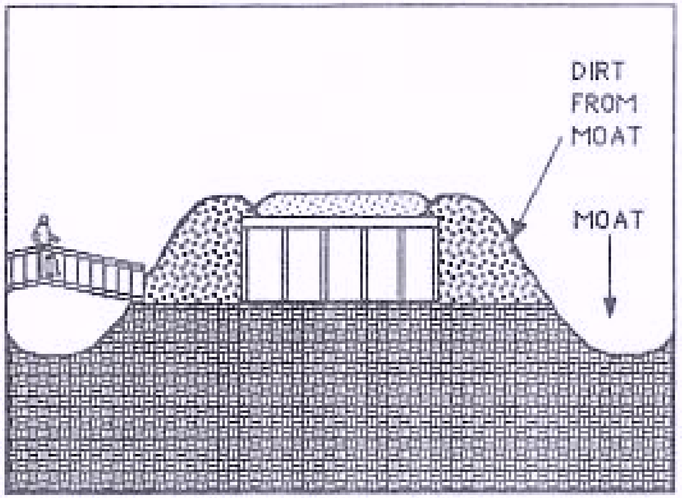
Water that is absorbed into the ground may be absorbed by roots of plants or may percolate down into underground voids. Under almost any site there will be some water, although it may be hundreds of feet down. The depth of this moisture is called the *water table*. Often it is within 10 feet and may be only a couple of feet down on a wet site.

LOCATION - MOISTURE

WET SITES MUST BE AVOIDED. AN EARTHSHIP MUST BE AT LEAST FIVE FEET ABOVE THE WATER TABLE! RECORDS ARE OFTEN KEPT FOR THE AVERAGE WATER TABLE OF A SITE, AND FOR THE HIGHEST POSSIBLE WATER TABLE IN THE SPRING. THE BEST THING TO DO IS TO HAVE A HOLE DUG, IN THE HEIGHT OF THE SPRING RUNOFF SEASON, DOWN BELOW THE LOWEST POINT THAT THE EARTHSHIP WILL POTENTIALLY OCCUPY. IF THE EARTH

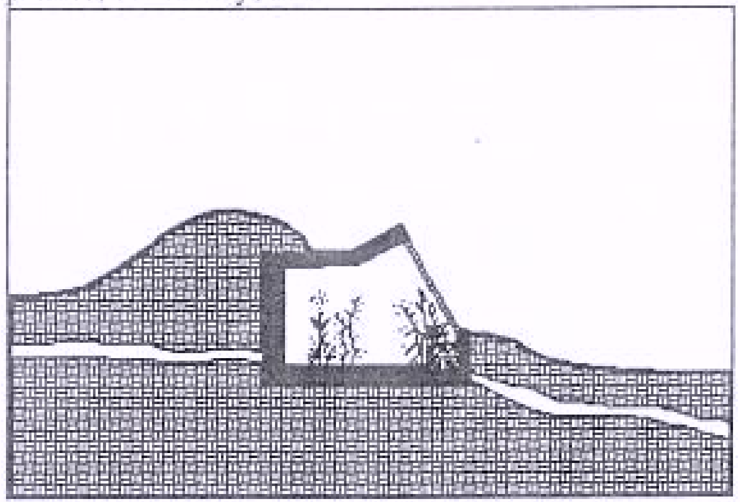
FIVE FEET BELOW THE EARTHSHIP FLOOR IS TOTALLY DRY, THERE SHOULD BE NO PROBLEM. IF WATER IS DISCOVERED, THE FLOOR SHOULD BE PLANNED TO BE WELL ABOVE IT, OR ANOTHER LOCATION SHOULD BE CHOSEN.

AN EARTHSHIP MAY EVEN SIT ON TOP OF THE GROUND, IF IT IS DRY, AND IF AMPLE DIRT CAN BE OBTAINED TO BERM UP TO THE ROOF ALL AROUND THE HOUSE. OFTEN THE DIRT CAN BE OBTAINED BY DIGGING A SLIGHT RUNOFF MOAT AROUND THE EARTHSHIP.



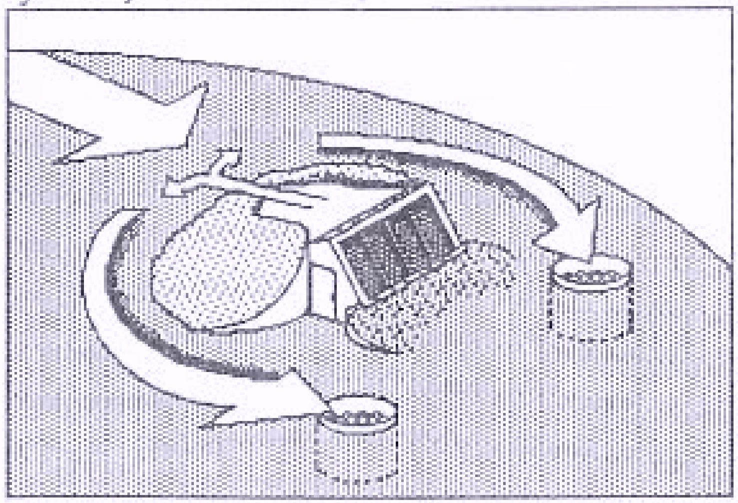
Springs

Springs are small, contained, naturally occurring, streams of water. An underground spring is to a water table as a stream is to a lake on the surface. If an underground spring is discovered on the site, it can be channeled directly through the Earthship to be used for plants, humidity, etc.



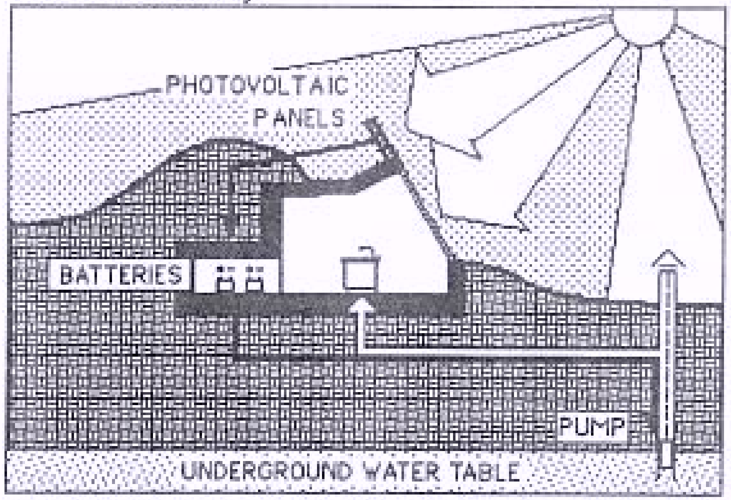
Rain

Since Earthships interface with existing runoff, their roof water can be combined with runoff patterns and caught in cisterns (catch water systems) for domestic use.



Wells

If enough domestic water is not made available via springs and/or cisterns, then a well is necessary.



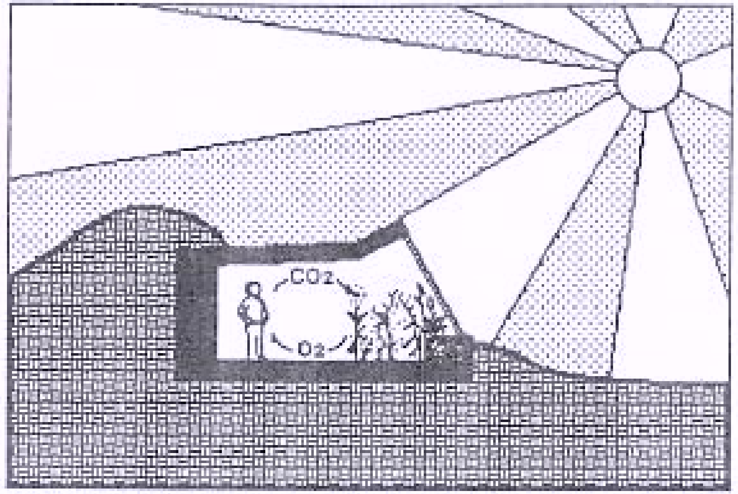
In this case, the well can be pumped with electric energy harvested by the power system of the Earthship, which can be sun or wind generated. Sun power systems are a result of photovoltaic panels on the southern face of the vessel. Wind devices can be incorporated into the structure in the areas where the wind is a reliable source of energy.

AIR

Air plays an important role in the processes that support life. There are also patterns and characteristics of air movement which, when aligned with, enhance the livability of a human habitat.

Respiration

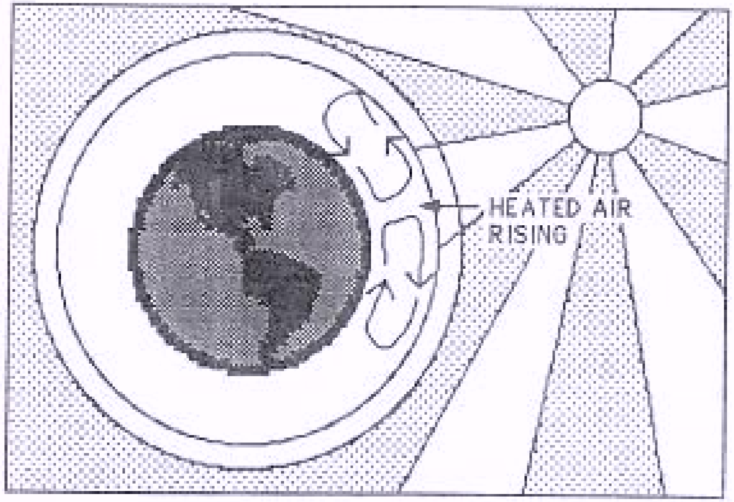
Carbon dioxide must be present for photosynthesis in green plants. By-products of this process are oxygen and water vapor, which can be used in the respiration of animals, who exhale more carbon dioxide. On a huge scale, there is a global breathing exchange going on between all plants and all animals. **By cutting down the rainforests, we are cutting off our own oxygen supply.**



The breath exchange can take place on a small scale inside an Earthship.

Wind

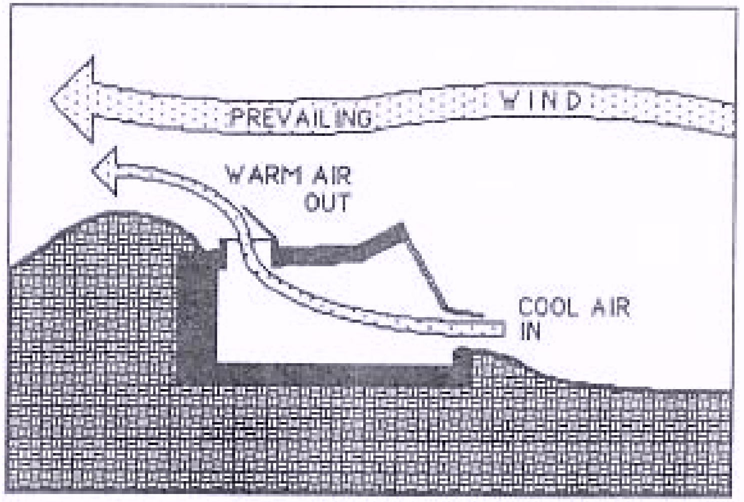
Wind is created by the uneven solar heating of large masses of air. The air rises as it gets heated, pushing and pulling the air masses around it.



Often wind is predictable due to climatic and geographic conditions, and will come from one direction most of the time. If there is such a *prevailing wind*, it can be interfaced with, for ventilation or power. For ventilation, a raised opening facing away from the wind will draw air out of the house as wind blows over the opening. For power, the arms of a windmill can turn a generator, which creates electricity for use or storage.

Stratification

As a fluid (liquid or gas) is heated, it rises; as it is cooled, it settles. This produces what is called *stratification*. If the warmer air at the top of a space is allowed to escape, cooler air will be pulled in, if there is an inlet. Earthships have a high operable skylight and a low window in each room to allow warm air to escape and cool air to be drawn in.



This also allows individual air movement control in each room. Even when the hot sun is "charging up" the mass, enough natural ventilation can be allowed to keep the space comfortable and full of fresh air.

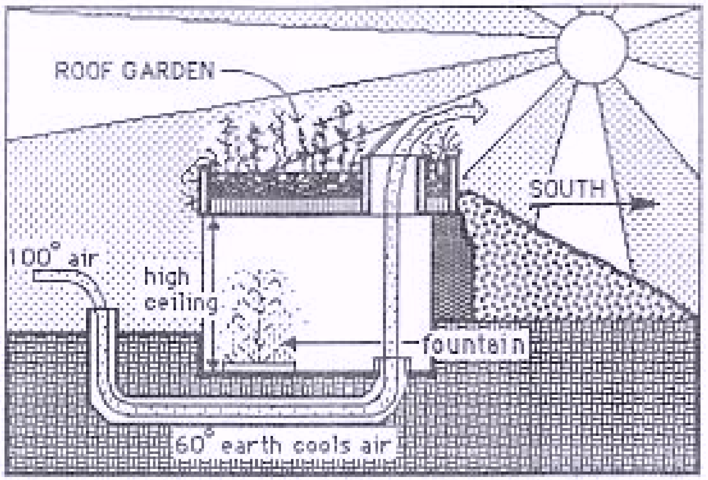
Through interfacing with the various phenomena discussed in this chapter, the Earthship provides an inviting, comfortable environment for humans and plants without the need of human-made energy. The phenomena around us can provide for all of our needs if we learn to align with them.

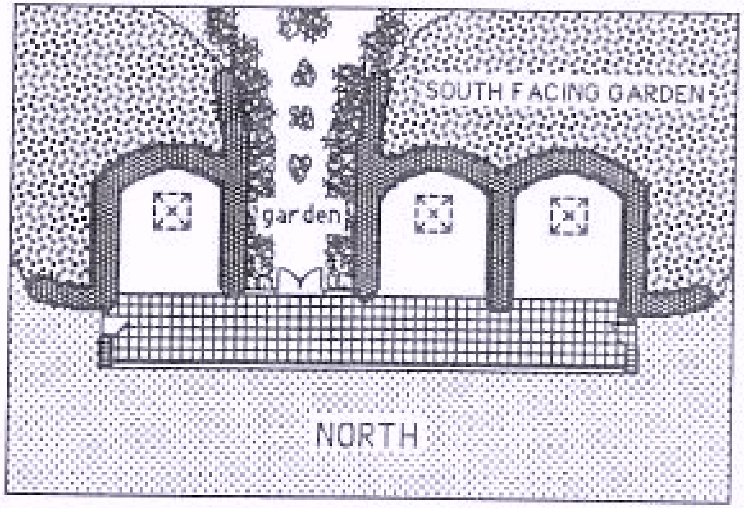
LOCATION — REVIEW

We have now seen various ways of interfacing with the four elements: FIRE, EARTH, WATER and AIR. The result is that these natural phenomena have actually determined the design of the Earthship in northern New Mexico. Many methods of interfacing would be the same in any climate. For instance, water run-off is dealt with similarly in Florida and in Ontario. One of the major aspects of the Earthship is that it holds temperature (not just heat). This is why it can be taken anywhere - hot or cold. Some methods of interfacing would be different in differing climates. The most basic modifications for a few climate extremes will now be discussed. If your climate is a combination of these, the Earthship should be designed for the most extreme conditions.

HOT ARID

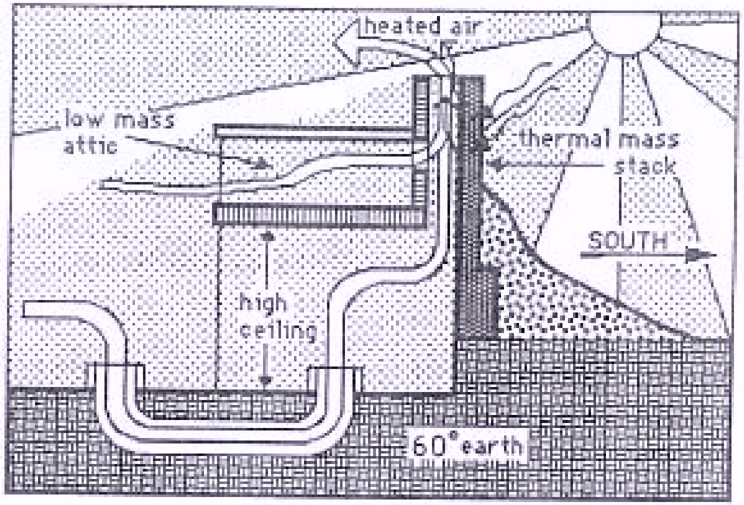
NO SOLAR GAIN IS WANTED IN A HOT ARID CLIMATE. TO ACHIEVE THIS, THE EARTHSHIP IS TURNED AROUND TO FACE THE NORTH. PLENTY OF REFLECTED LIGHT CAN STILL ENTER THE INTERIOR SPACES, WITHOUT THE DIRECT HEAT OF THE SUN. THE COOLNESS OF THE EARTH CAN STILL BE TAPPED INTO. THE 60 DEGREE EARTH CAN COOL INCOMING 100 DEGREE AIR BEFORE IT REACHES THE LIVING SPACES. HIGH CEILINGS WILL KEEP THE WARMER AIR OVERHEAD. FURTHER COOLING CAN BE ATTAINED BY EVAPORATION, USING FOUNTAINS OR EVEN CLAY JUGS OF WATER. PLANTS HELP TO LOWER AIR TEMPERATURE. HOWEVER THE FOOD PRODUCING AREA SHOULD BE SEPARATE FROM LIVING AREAS SINCE IT REQUIRES DIRECT SUNLIGHT. EITHER A ROOF GARDEN OR A SOUTH FACING GARDEN WOULD WORK.





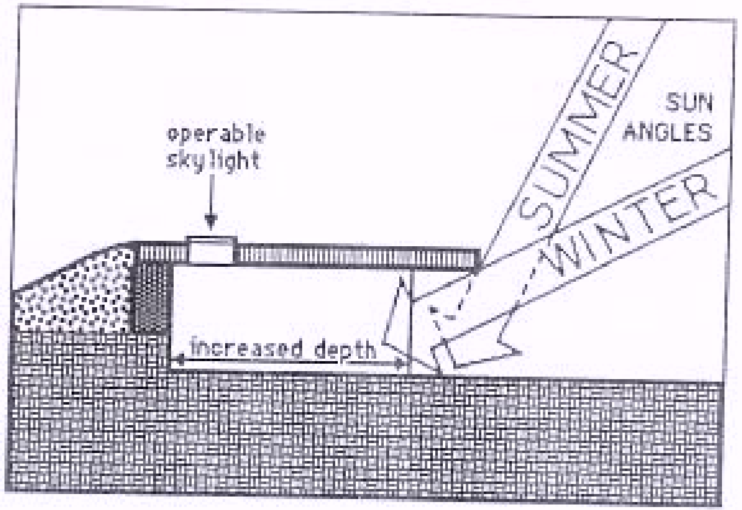
HOT HUMID

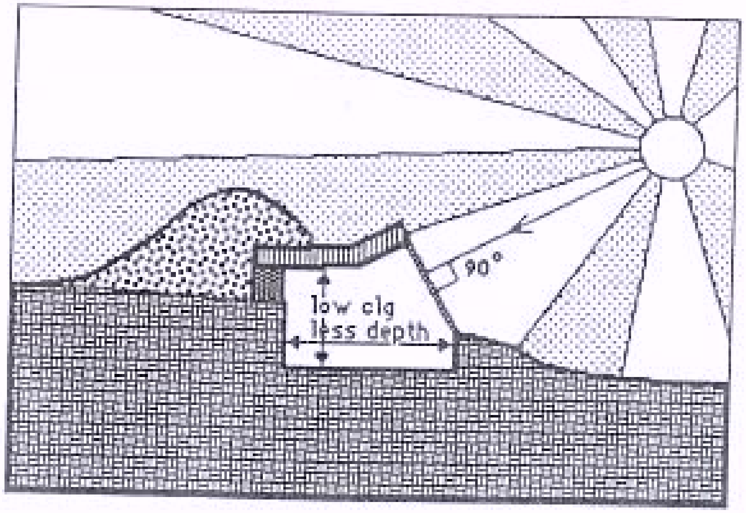
THE EARTHSHIP SHOULD ALSO BE TURNED TO FACE THE NORTH IN THIS CLIMATE. THE CRITICAL FACTOR HERE IS VENTILATION FOR COOLING AND EVAPORATION. AIR PASSING OVER OUR SKIN HELPS PERSPIRATION TO EVAPORATE, THUS COOLING THE BODY. THIS CONCEPT CAN WORK TO COOL AND REDUCE HUMIDITY IN AN EARTHSHIP. TO HELP INDUCE VENTILATION, A DARKLY PAINTED STACK WITH THERMAL MASS BUILT IN TO IT CAN BE USED. IT WILL COLLECT HEAT DURING THE DAY AND SLOWLY RELEASE IT AT NIGHT. THE AIR INSIDE IT WILL THEN BE WARMED UP AND RISE, PULLING MORE AIR BEHIND IT. THIS INDUCED AIR MOVEMENT KEEPS THE EARTHSHIP VENTILATING CONTINUOUSLY. ROOFTOP SPACE CAN BE USED AS AN UMBRELLA TO SHADE THE INTERIOR BELOW. A LOW-MASS ATTIC WILL NOT HOLD HEAT AND WILL ALWAYS COOL OFF AT NIGHT. AGAIN, SUBMERGING INTO THE EARTH WILL HELP DRAG DOWN THE AIR TEMPERATURE. HOWEVER IN HUMID AREAS MORE ATTENTION MUST BE GIVEN TO GROUND MOISTURE. LOCATING THE EARTHSHIP ON HIGH GROUND IS IMPERATIVE.



TEMPERATE

A TEMPERATE CLIMATE MAY BE A NATURAL CONDITION THAT IS NEARLY COMFORTABLE FOR HUMAN HABITAT. THE MASS OF THE EARTHSHIP WILL BUFFER ANY TEMPERATURE EXTREMES THAT DO OCCUR. THE MASS TO VOLUME RATIO IS NOT VERY CRITICAL SO THE ROOMS MAY BE DEEPENED AND WIDENED TO THE MAXIMUM THE STRUCTURE WOULD ALLOW. THE GLASS DOES NOT NEED TO BE SLOPED, AND THERE CAN EVEN BE AN OVERHANG TO SHADE THE INTERIOR FROM UNNEEDED SUMMER SUN. HERE THE SOMEWHAT REDUCED MASS WILL SIMPLY BE USED FOR A STABILIZING EFFECT ON THE COMFORT ZONE.





<u>Cold Climate</u>

The Earthship *is* designed for cold climate conditions. For <u>extreme</u> cold, the depths, widths and heights of the spaces should be decreased to increase the mass relative to the air volume. The angle of the glass should be at 90 degrees to the lowest winter sun. The building should be submerged into the earth as much as possible.

Overhangs should be avoided as they effect spring and fall heating potential. Airlocks(see chapter 3) should be considered. Bathrooms should be on the solar face. Earth parapets should be very thick to keep structure below frost line.

The Earthship can be taken anywhere. It is designed for extremes. Solar Survival Architecture is available for consultation on Earthship location for unusual situations.

3. DESIGN

FOLLOWING THE DIRECTIVES OF CONCEPT AND NATURAL PHENOMENA

- **The basic module**
- **How these modules can be combined to design a house**

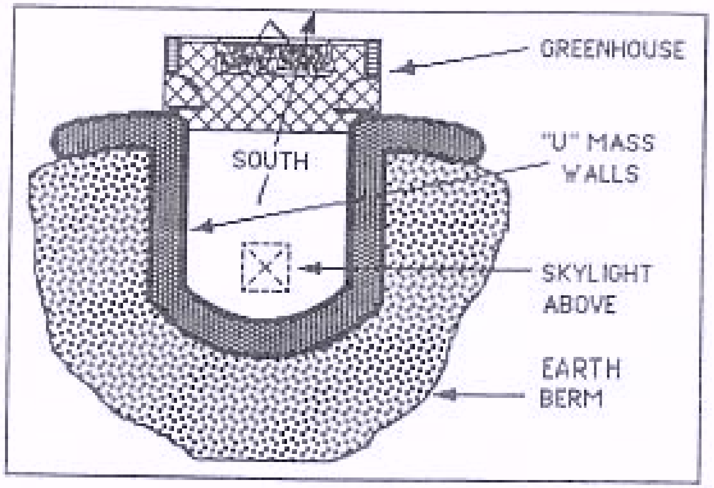
Fast cars are designed in wind tunnels, i.e. the wind dictates the design of the car. Likewise, natural phenomena dictate the design of an Earthship. The design schematic of existing Earthships is presented in this chapter as it relates to local phenomena. Within these parameters, personal needs and desires are dealt with. The issue of performance versus tradition is discussed from the perspective of "Live simply so that others may simply live."

Chapters One and Two have described the concept and the methods of interfacing that have evolved into the Earthship. They have shown how the elements through their very nature can determine the nature of the architecture. Interfacing with these phenomena delineates the form of the simple module which can provide for the basic human needs of shelter, water, oxygen, food, temperature and energy.

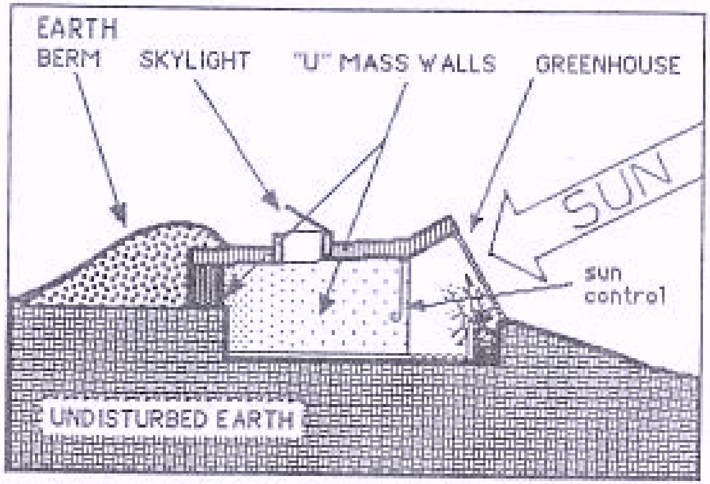
This chapter will review the parameters of this module, and show how these modules can be combined to design a house.

MODULE REVIEW

The module, itself, is an individual U-shaped space or room, with mass on three sides, glass on the fourth, and a skylight in the ceiling above the U of mass. Earth is bermed up on the outside of the mass walls for even more mass. Often the U shape is partially submerged as well. In places where heating is required, the wall of glass is oriented to the south and sloped for maximum solar gain on the coldest day of the year. *Because the modules are U-shaped, they will often be referred to as "U's."*



The module is actually constructed in two parts: **the U** (three mass walls), and **the greenhouse** (the glass wall).



The mass U is the main living space for humans, and the greenhouse is the main living space for plants. The greenhouse is always in sun, whereas the U space has the potential of sun control.

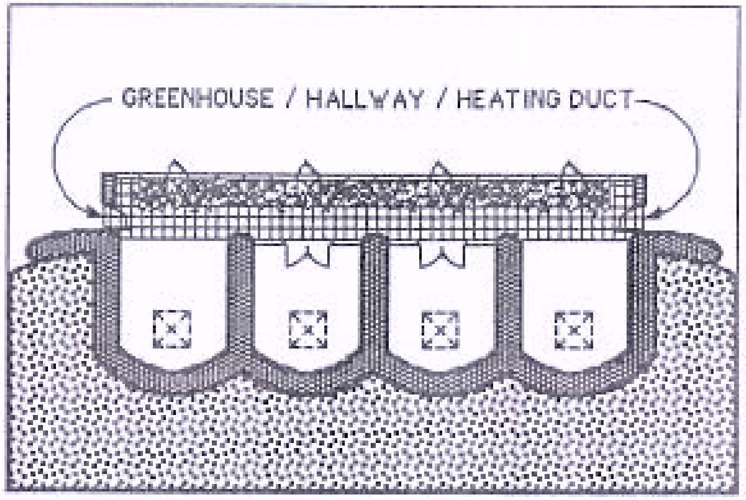
This module can be as small as anyone wants to build it, but it should not be larger than 18 feet wide by 26 feet deep. The 18 foot dimension is the largest recommended span between the mass walls, because longer spanning structural members are uncommon and expensive. The 26 foot dimension is as deep as the module can be and still be comfortably warm. If the total area of the room exceeds these dimensions, the volume of air space becomes so large that the surrounding mass can not keep it within the comfort zone of 65°-75°.

RULES OF COMBINATION

The module is *not* a house, but is an individual room. This room *cannot* be expanded to make a house, but must be multiplied. A house is therefore a collection of modules, strategically placed in relation to each other and the site. There are, however, some specific rules of how the modules can be put together.

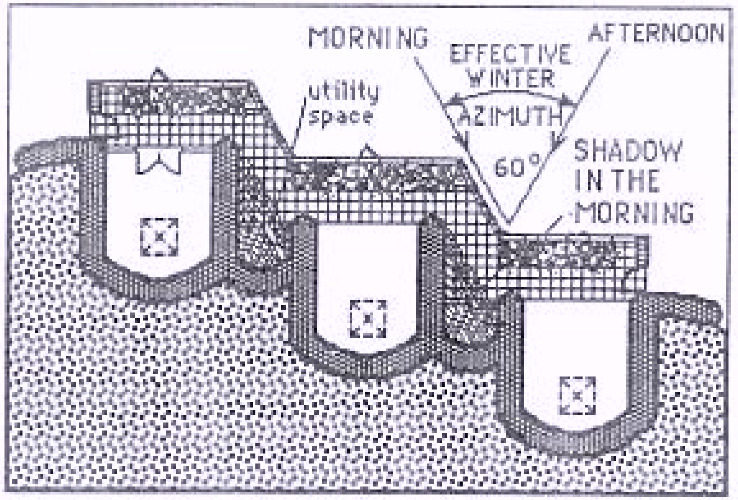
Straight Row, East to West

U's can be constructed right next to each other with exactly the same solar orientation, and sharing a common mass wall. The greenhouse then becomes a hallway, the means of circulation from one U to any other. It also acts as a heating duct, since it is where the direct solar heat gain collects. The greenhouse can actually be closed off from some U's while remaining open to others. It is the main circulation vein and the heating duct for servicing the individual U's. This allows the U's to maintain their simplicity and mass without the expense and lack of performance that other circulation patterns would bring. The simple module is preserved.



Staggered Row, Relating to Azimuth Angle

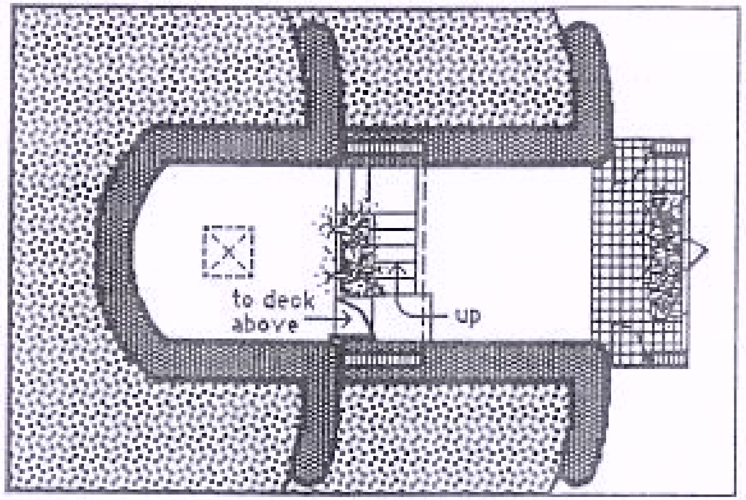
As was shown in chapter 2, individual U's can be stepped back from one another without causing shadows on the glass of the adjacent U's. The back U can be located far enough over so the connecting glass is within the effective winter azimuth angle. This angle is derived by the location of the winter sun between 10 A.M. and 2 P.M. It is between these times that the sun is most effective for heating. In northern New Mexico, this is a 60° angle. The space generated between the U's can become a very thick mass wall, or an indirectly heated utility space. All major living U's should get full sun across their south side between 10 AM and 2 PM.

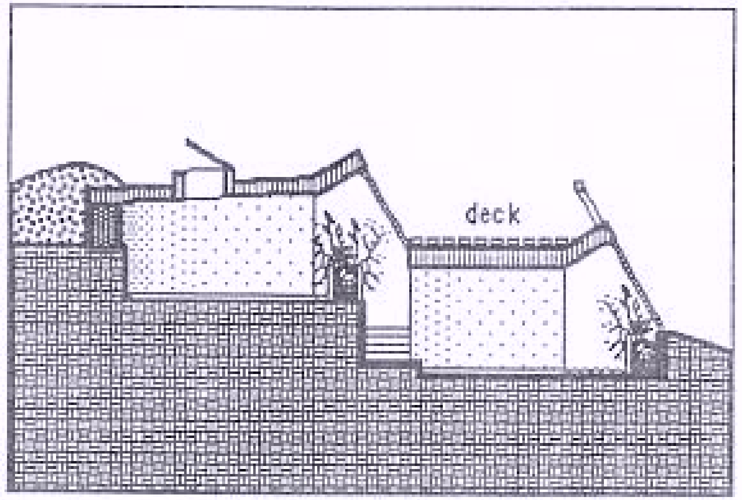


The results of this kind of combination are much like those of the straight row. The greenhouse becomes the circulation hallway and a heating duct, connecting the simple U modules.

<u>Straight Step- On Slope</u>

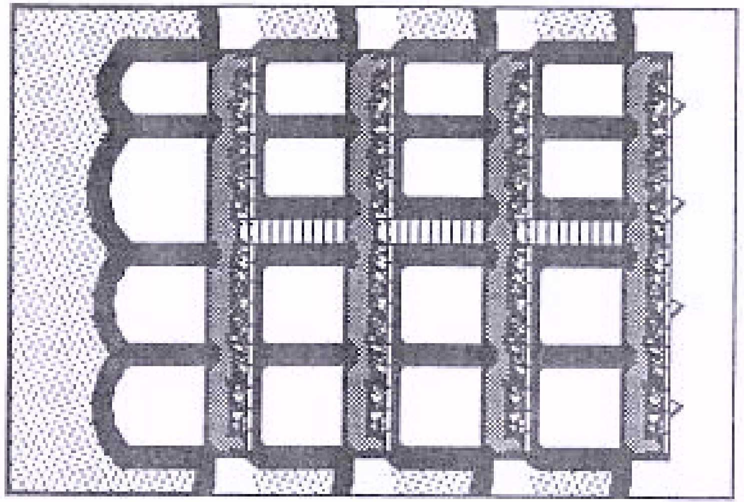
Two U's can be put one behind and *above* the other, making them like steps on the slope of the site.

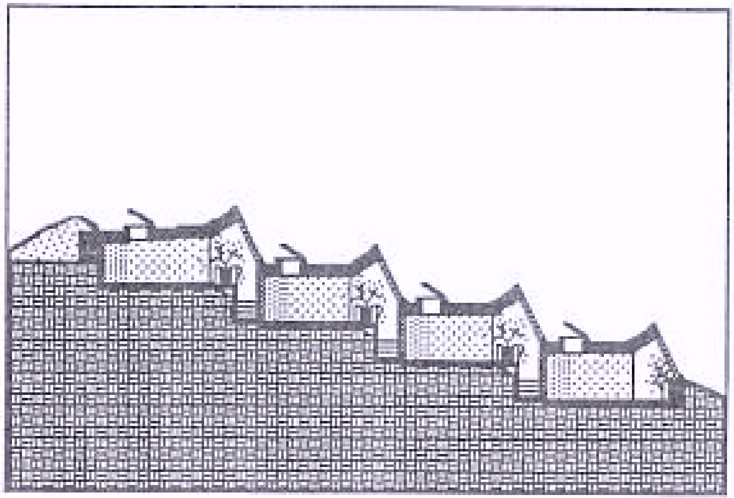




Each level can still be insulated all around by earth, and can still have the full height of glass on the solar side. The roof of the lower U can then become a deck in front of the U above. It is necessary to have a sloping site for this kind of combination.

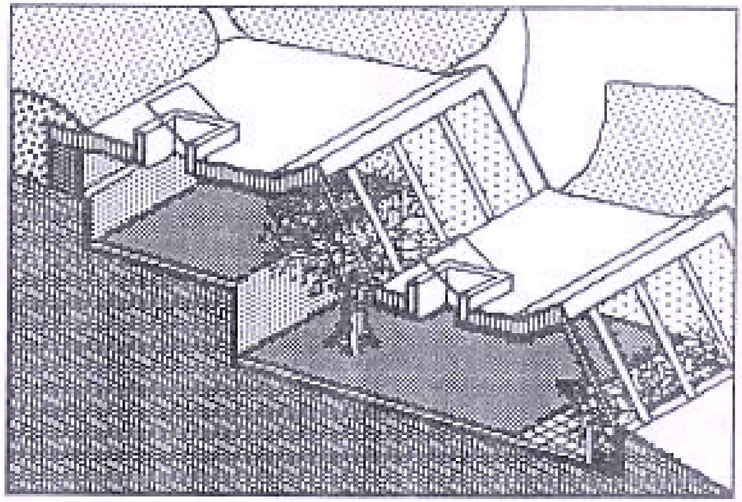
Many U's can be combined in this way, creating a square grid of U's, in plan, that step up the slope.

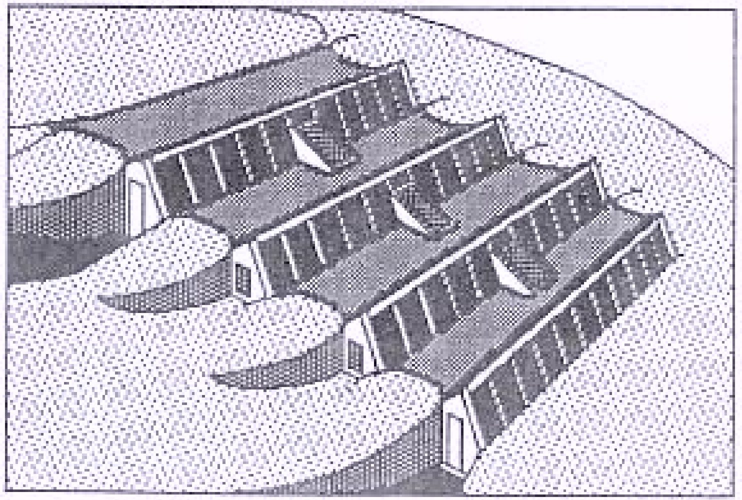




The "greenhouse / hallway / heating duct" still functions as in the previous examples, thus again leaving the simple modules intact.

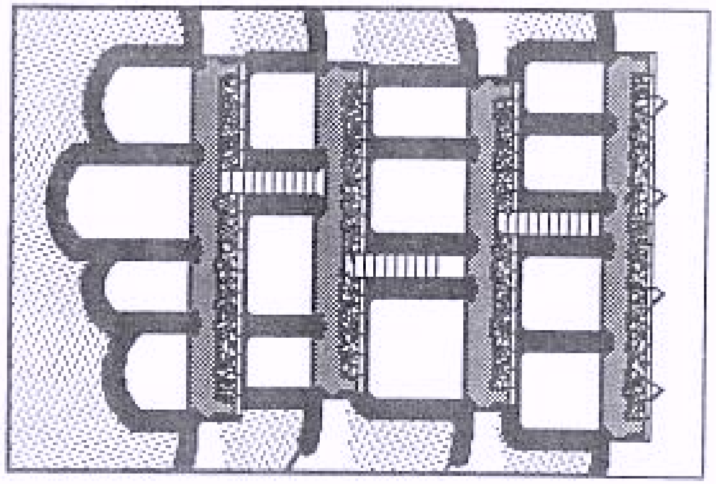
There can be an overlap between steps, creating a space in the middle that is 2 stories high inside. This is good for fruit and nut trees.





Staggered Step

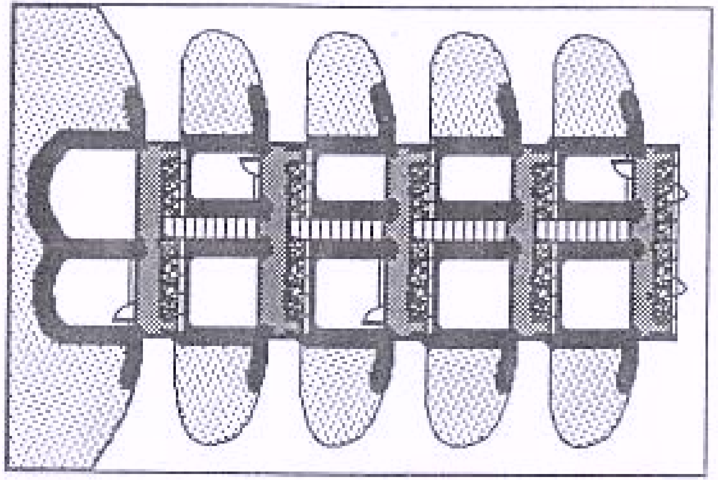
When U's are combined like steps, the number and size of U's in each row may vary. This allows a series of different U arrangements stepping up a hill. Again, the heating duct / greenhouse / hallway is applied on each level.

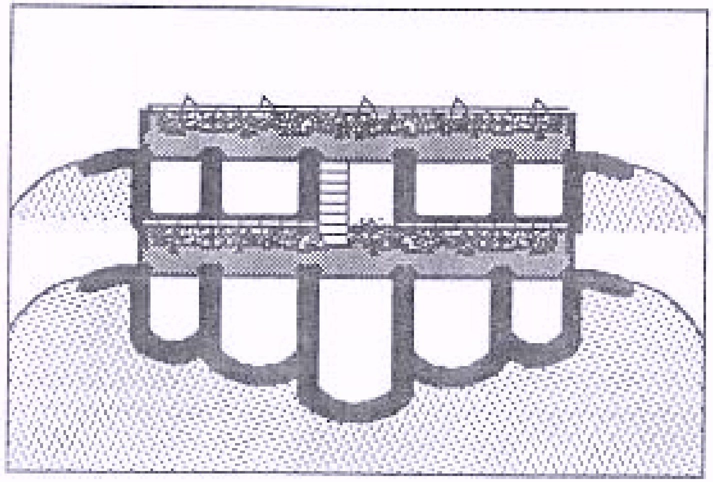


Combined Step and Row

When stepping patterns are multiplied, they are actually combined steps and rows. The resulting set of U's can accommodate almost any spatial plan relationship. Any single-level house plan can be designed and superimposed on a sloping site in steps.

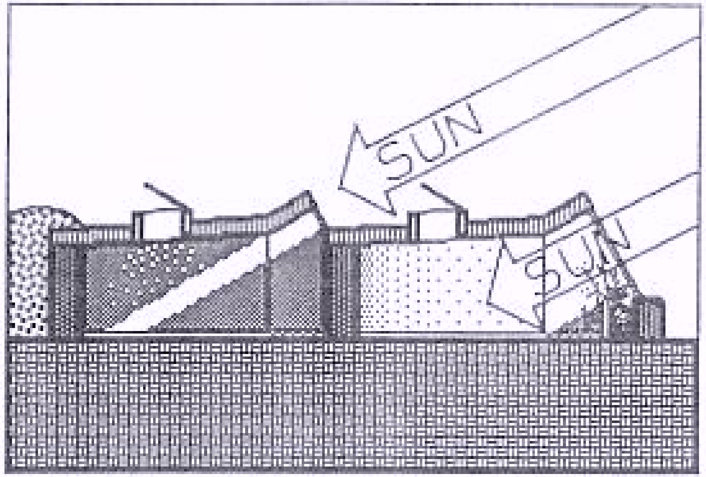
There can be any number of U' or steps in a row. A house can be 2 steps with 5 U's in each row or 5 steps with 2 U's in each row, or anything in between.



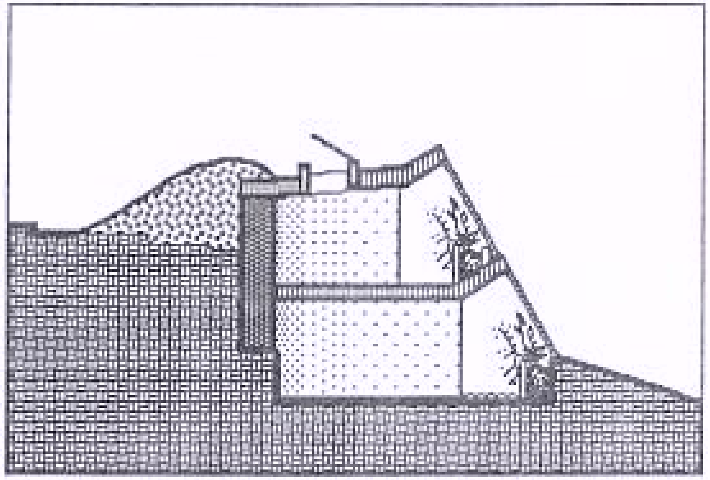


Combinations not Recommended

One U should not be put directly behind another on a flat site, unless heating is not required. This would put a room behind a room behind a greenhouse. The back room would not have any direct sun for light, heat, etc... It would be cooler and darker and difficult to heat without backup systems.

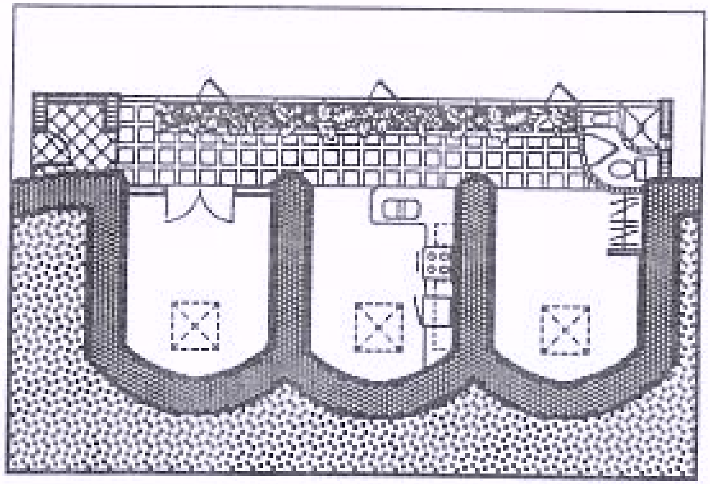


Two U's can be built one directly on top of the other, however in this situation an Architect should be consulted, This makes a more complex design in terms of structure and performance.



SIMPLICITY VS. COMPLEXITY
PERFORMANCE VS. AESTHETICS
ECONOMY VS. EXPENSE

The reason that the Earthship is so economical is that it can be so simple. In fact, a good sized, single family residence can be built with 3 to 5 nearly identical U's in a straight row. Because the U's are so similar in size, detail, construction, etc., it is the most effective use of time and materials possible for an Earthship of its size. In fact, this is the recommended design for most situations. It can fit on a flat or sloping site. It is simply the easiest and the most economical approach.



In any situation, the simplest design is usually the best. The rules of combination are the rules of design. Any time that they are broken, there will be extra expense, and usually cause the performance of the Earthship to suffer. When economy and efficiency are the primary goals (as in nature), performance determines the looks of the final design. Some people may find that they have a preconceived idea about what their house should be like, and use this notion as the starting point for their design. An Earthship cannot be designed this way. The layout must initiate from the characteristics of the U module, and then be adapted for the needs of the inhabitants.

POSSIBLE VARIATIONS AND MODIFICATIONS

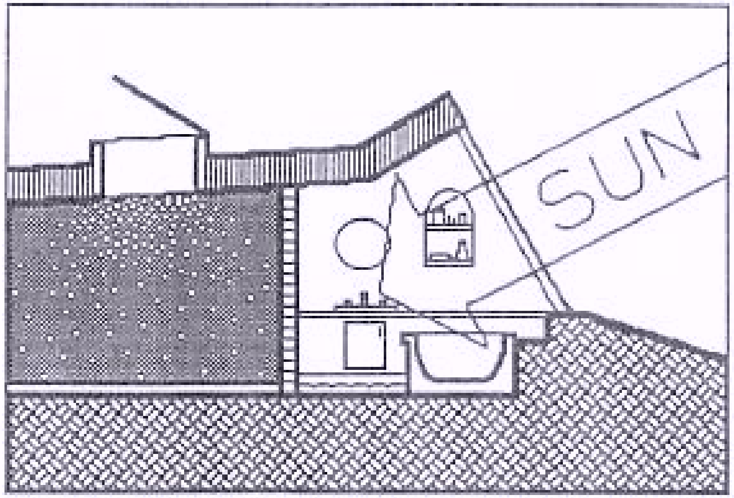
With this concern for simplicity in mind, we can now review the possible variations that can be made to the basic layout. Every variation will affect the performance of the Earthship, so it is definitely not recommended to stray too far from the basic design. Each variation also takes more time, materials, energy and money, and therefore will affect the performance of the builder / resident as well. This is why one or two changes may be okay if really necessary, but any more will begin to alter the Earthship beyond recognition. It would be possible to change the Earthship, bit by bit, into an English Colonial house with a heating system. This obviously would no longer be an Earthship.

Once an initial basic layout is designed, there are a few necessary variations that will only slightly affect the performance of the Earthship. They will now be discussed.

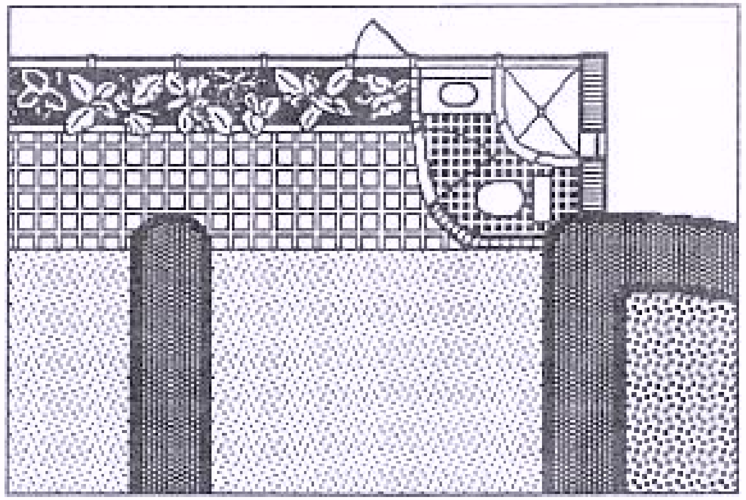
Bathroom

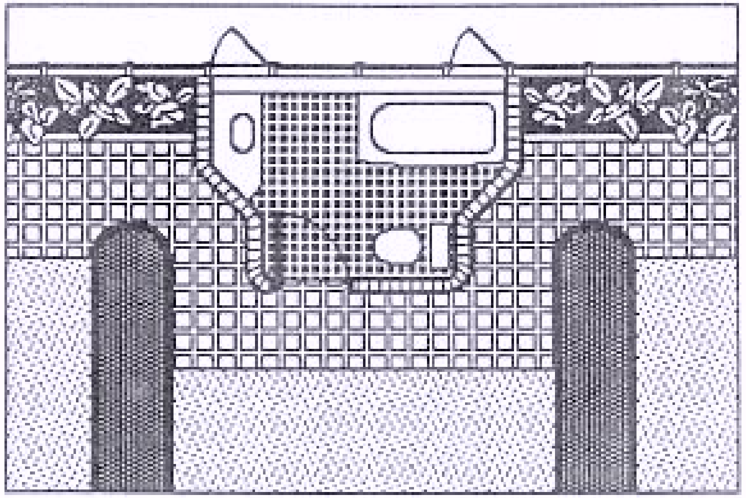
A bathroom is a small, self-enclosed room, and therefore can fit about anywhere in the design. But bathrooms need to be warm places because people wet from baths or showers tend to be colder than normal. Therefore, if a bathroom is located deep in an Earthship, away from the warm greenhouse, a unit heater should be installed in it. However, the best thing to do is to locate the bathroom right up against the southern glass to maximize the solar heat gain that will go directly into the small room. Bathrooms on the south face need no unit heaters.

Because it is right up against the glass, it will get some of the most intense direct heat in the house. This heat is then intensified because it is such a small room, compared to the rest of the U's.



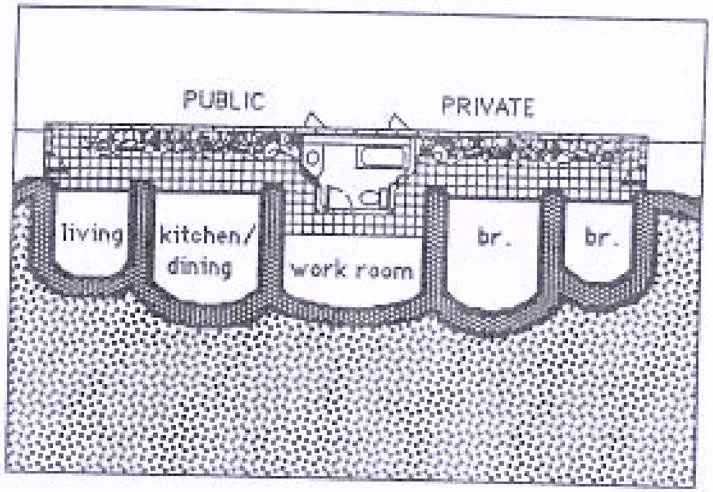
The bathroom can be in this position against the glass anywhere along the front face. Some common positions are at either end, or directly in the middle.





In either position, the bathroom creates a shaded space directly behind it. When on the ends, this shaded space may be slightly cooler than the other rooms. When in the middle of an Earthship, the shaded space is so well surrounded by other warm U's that it is as warm as any other space in the Earthship (except the bathroom itself).

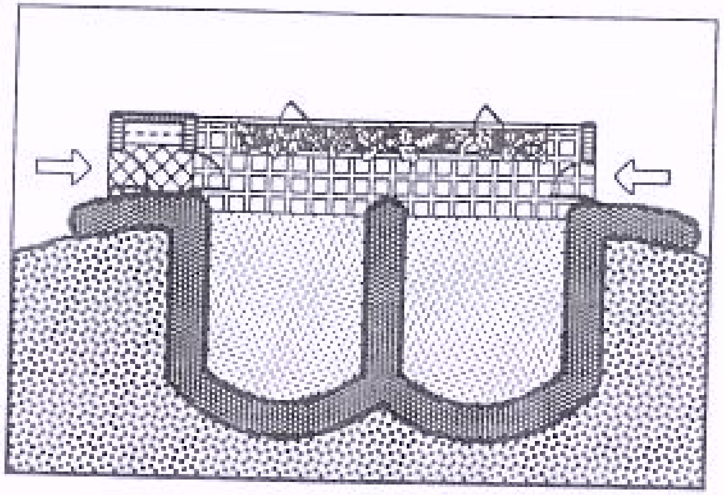
The bathroom can be used to divide the Earthship into segments. In a 3 U design, a central bathroom allows each end room to have a little more privacy. In longer designs, it can separate bedrooms from each other, or from the main living spaces of the house.



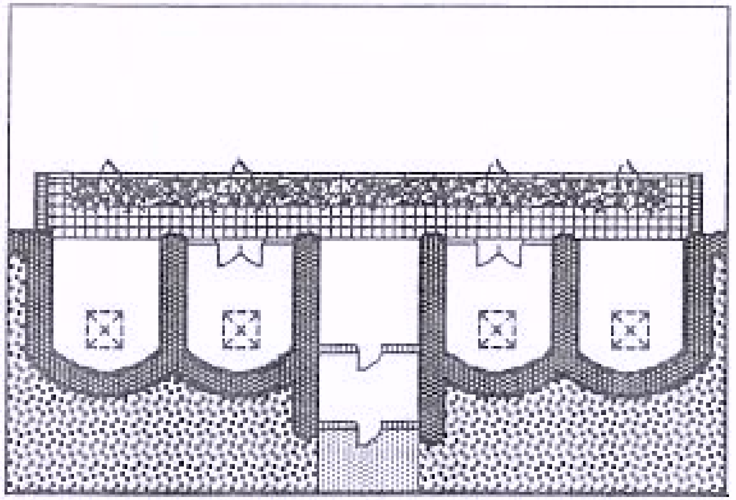
Entry

The entry is best on the East or West end wall, and with an airlock / vestibule / mudroom.

The airlock helps to prevent heated air from escaping whenever the door is opened. It can also be a storage room, utility room, closet, etc... The East and West greenhouse end walls are not structural or solar, and they already are linked to the circulation. This is the best location for entries.

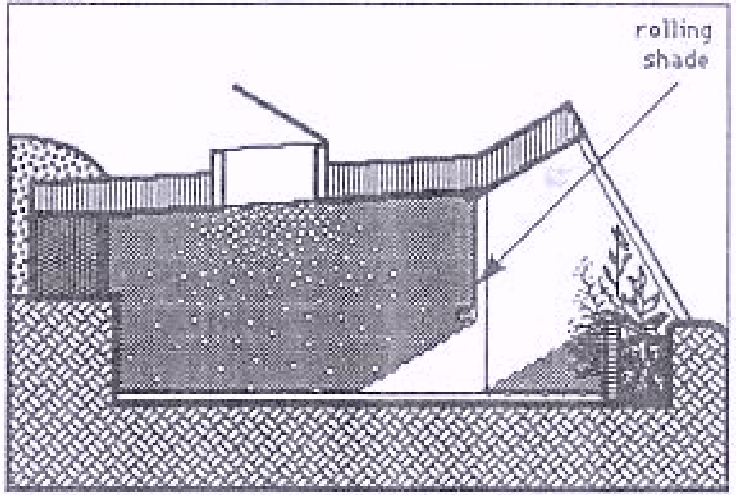


The entry can be made in the south glass wall. This is not recommended when serious heating is required, as it will create shadows and block some of the heat gain. It would also be possible to enter the Earthship from the North side, but this would require the elimination of a substantial part of the berm, which is both mass and insulation. An entry on the north side will affect the performance and the cost of the Earthship significantly but it can and has been done.

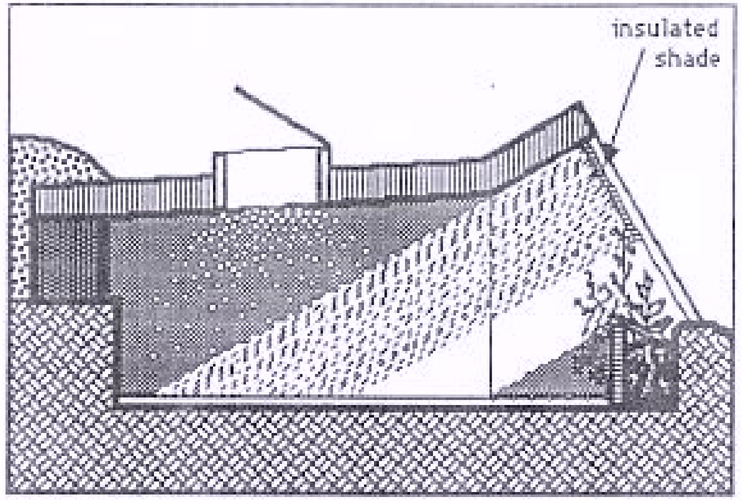


Shading

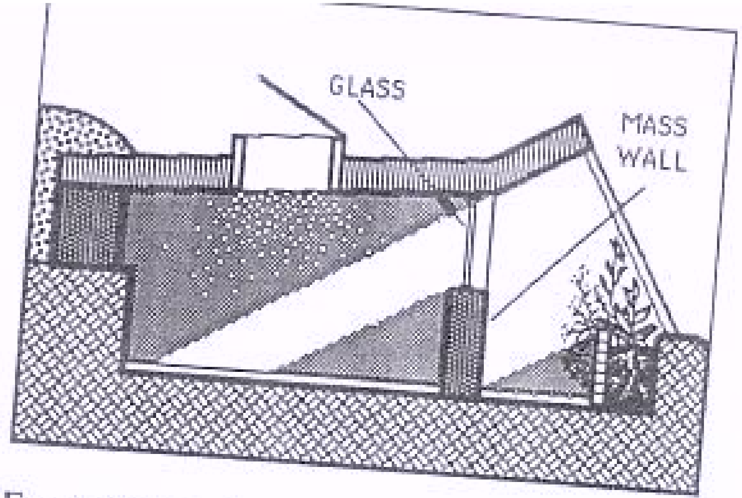
The living space of each U can be separated from the heating duct / greenhouse / hallway by the following means. Simple cloth or paper rolling shades can be hung, shading the space behind.



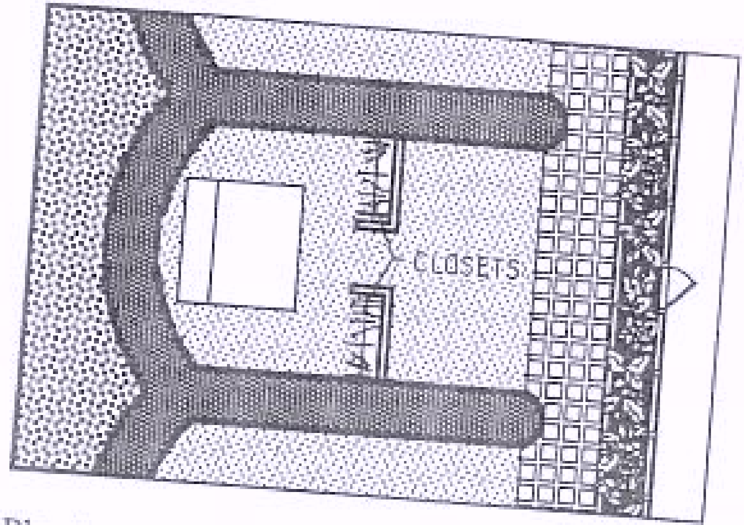
Insulated shades can also be hung directly behind the greenhouse glass to shade the living space and cut down on heat loss at night.



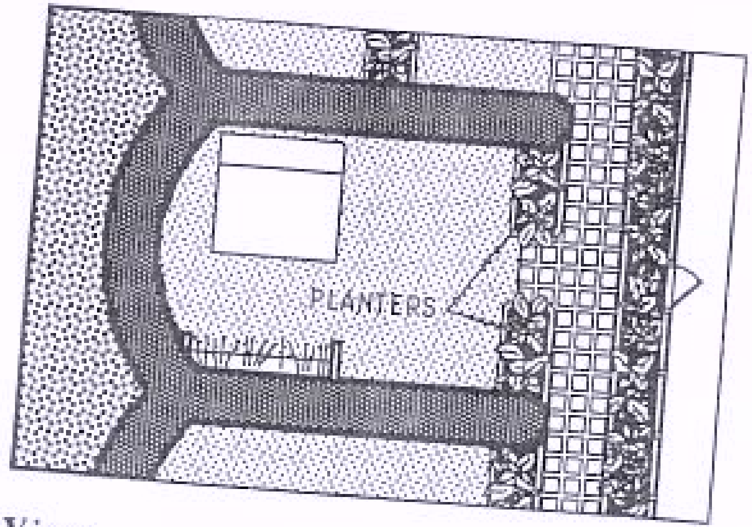
A dividing mass wall can be built between the mass U and the greenhouse. This can give more shade and privacy, but is not always necessary and is an added expense. It does, however, improve the performance by holding heat in the "U" and cutting down on heat loss at night. This mass wall usually has glass above it to allow "borrowed light" to come through the green house to the "U". Privacy and sun control in the "U" can be achieved via drapes or curtains over this glass(diagram next page).



Free-standing closets can give shade and also subdivide space, even within a single U, to have areas of added privacy.



Planters are sometimes used to subdivide space, providing some shade and privacy.

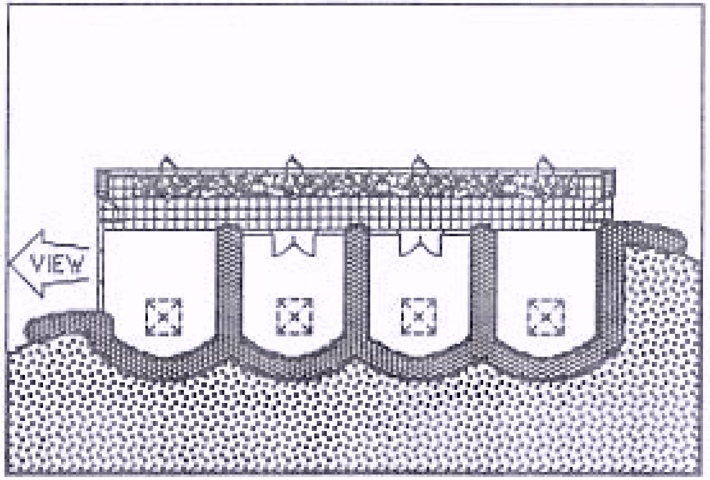


View

It is best if the view from the Earthship is limited to what is shown though the expansive greenhouse windows. If there is an incredible view in another direction, however, it is possible to open up a mass wall, but this eliminates mass and insulation, and obviously reduces the thermal ability of the walls, as well as escalates the cost.

The least disruptive direction for such an opening is to the East. Although mass and insulation are cut down, there is a little amount of early morning solar heat that is gained. It is not enough to make up the loss of mass, but helps a little.

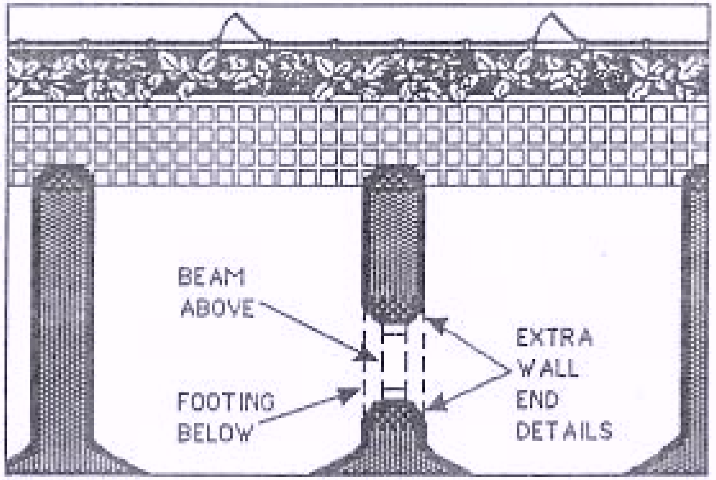
If the opening is to the West, there will be a very small amount of afternoon solar heat that is gained, but not at all as much as that which is lost



If the opening is to the north, obviously a lot of the berm will be eliminated, greatly reducing the thermal ability of the walls. There is no solar gain from the North (in the Northern Hemisphere), and a lot of heat will be lost through any north windows at night. Northern views are *not* recommended.

Connections Between Rooms

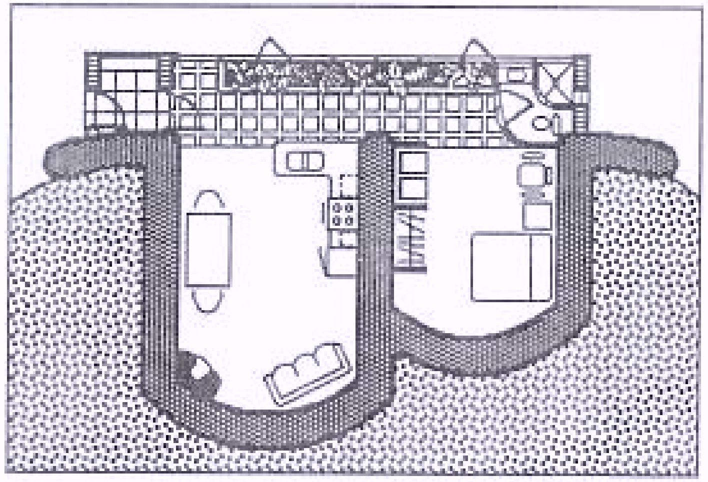
The best way to connect rooms is by means of the common greenhouse hallway. A small opening, such as a window between a kitchen and dining room, can be made through interior mass walls without affecting performance greatly, although this is more expensive. If a larger opening, such as a doorway, is made between interior rooms through a mass wall, it is even more expensive, because a footing and lintel beam are then needed. It also means that the mass wall must be ended, and then started again three feet away, resulting in three "mass wall end details" instead of just one.

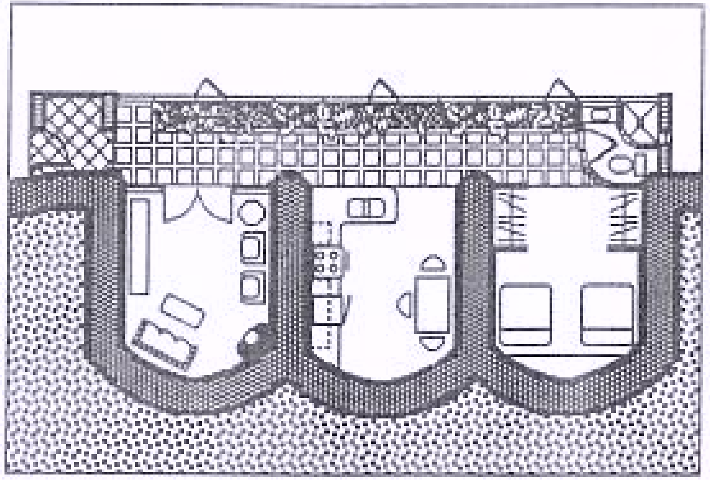


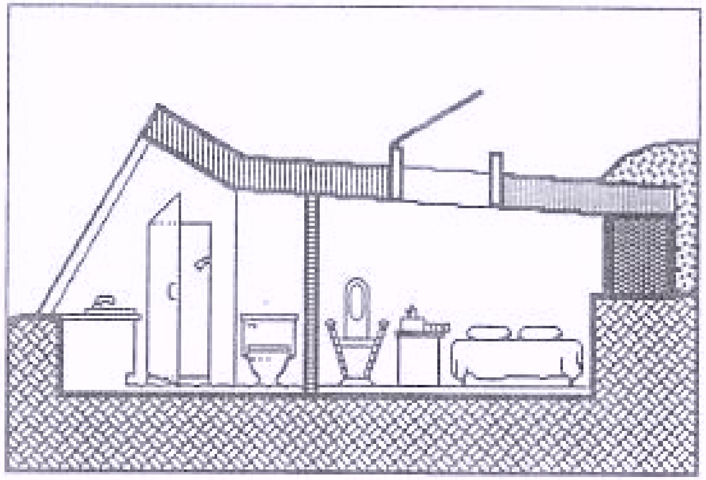
If the width of this doorway increases more, the amount of weight concentrated to either side will be great enough to require columns and beams and footings and reinforced concrete and much more time, energy, materials and overall *expense*. The technology involved in such an adventure is conventional for building contractors, but difficult for the average layperson. The loss of mass also limits performance, so it is really not recommended very often.

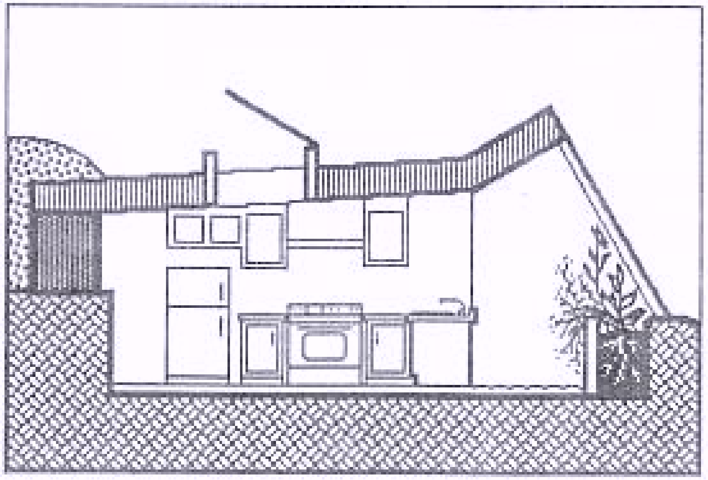
Because of the loss of mass and the difficulty of construction, **interior mass walls should never be eliminated!**

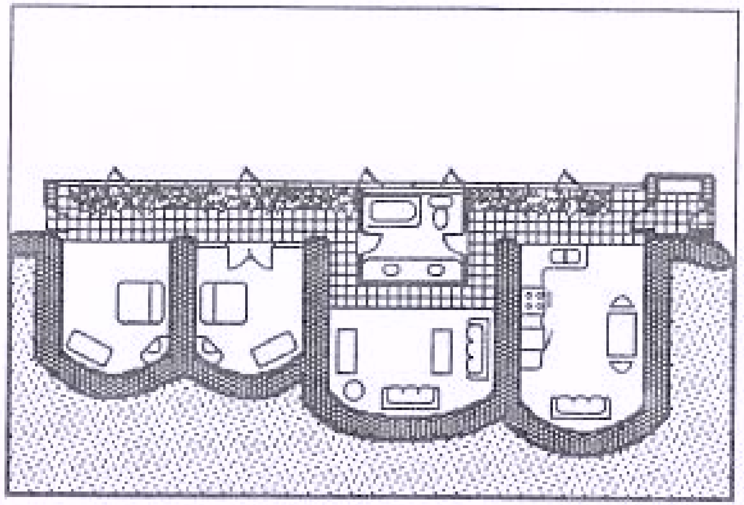
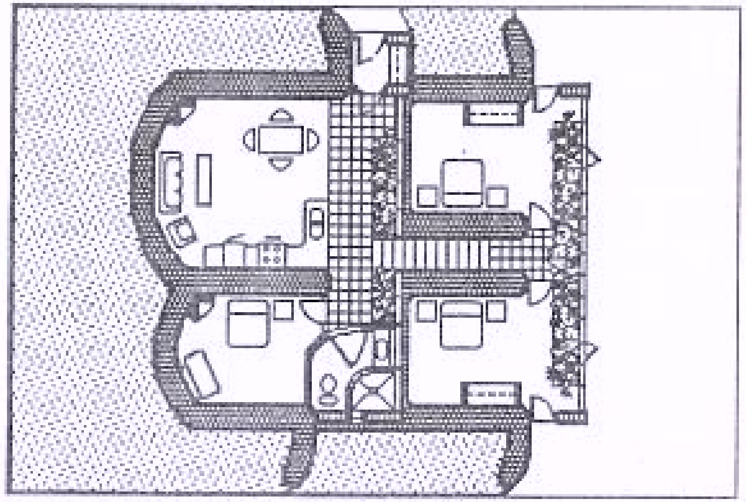
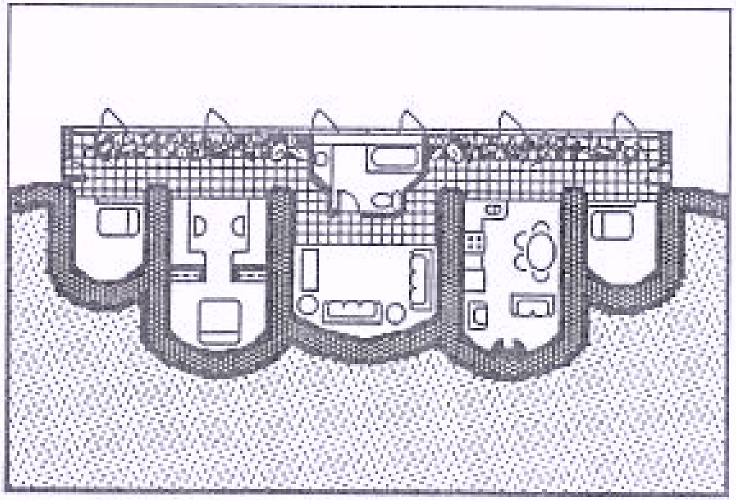
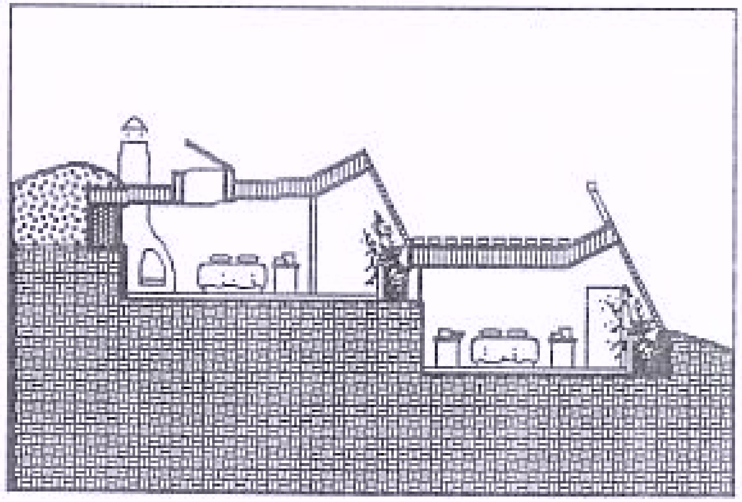
EXAMPLE DESIGNS

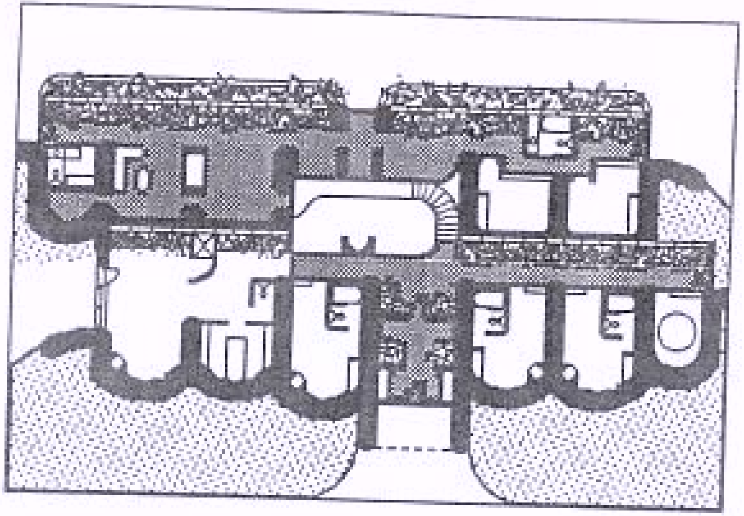


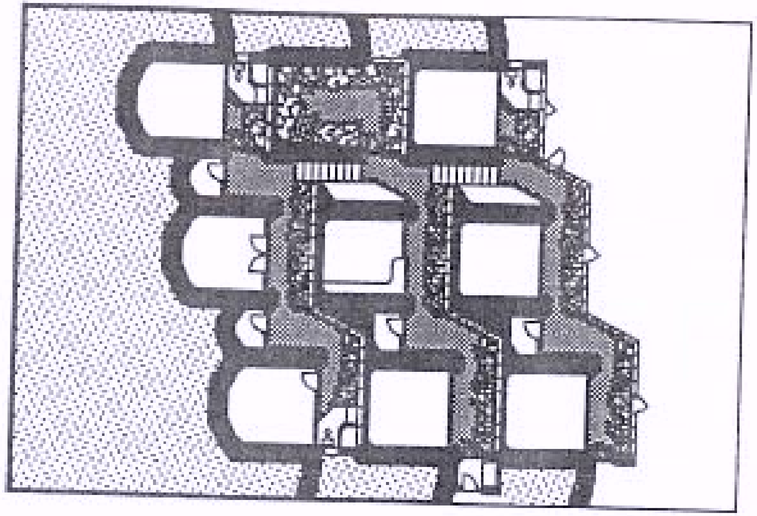


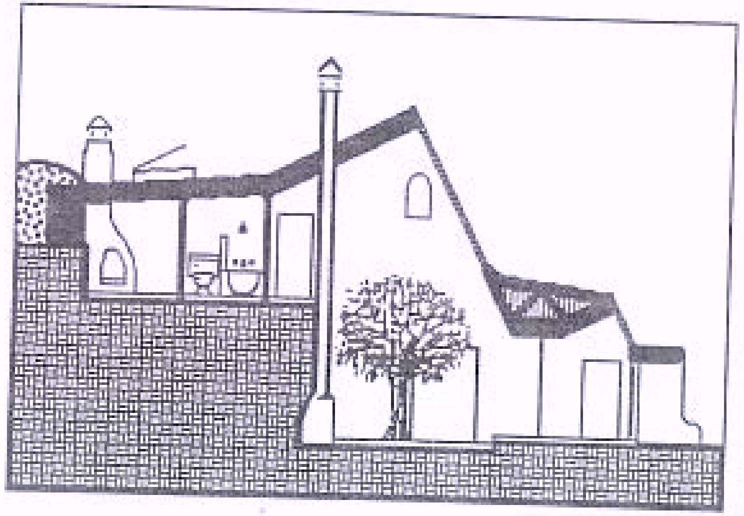


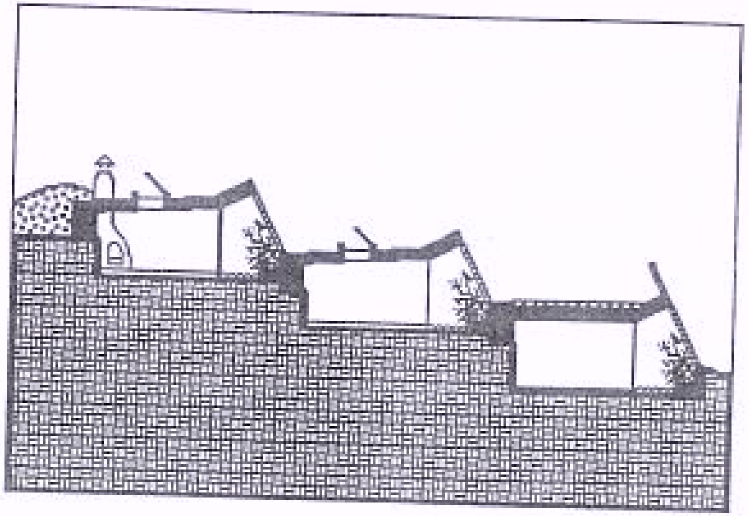










4. STRUCTURE

THE SKELETON OF THE VESSEL

Economy and availability to non-professional builders are important determinants of an Earthship structure. This chapter presents the simple structural integrity of existing prototype Earthships via conceptual diagrams, photographs and three dimensional drawings. This structural system is both designed and explained in terms to which the non-professional builder can relate.

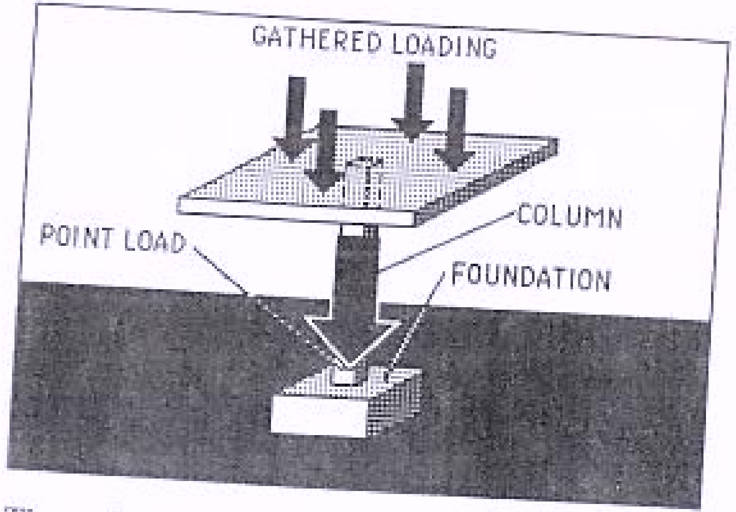
THE STRUCTURE OF BUILDINGS

In order to understand the structure of the Earthship, a general understanding of the concept of structuring buildings is necessary.

Buildings must be able to carry weight, or *loads*. There are two kinds of loads, *dead loads* and *live loads*. The dead load is the weight of the building itself, which is caused by gravity. Just as our skeletons must be able to support the weight of our bodies, the structure of the building must be able to support the weight of its roof. The live load is the weight of more transient and varying things, such as snow, people, and furniture. This is similar to our skeletons also being able to support the clothes we wear and the things we carry.

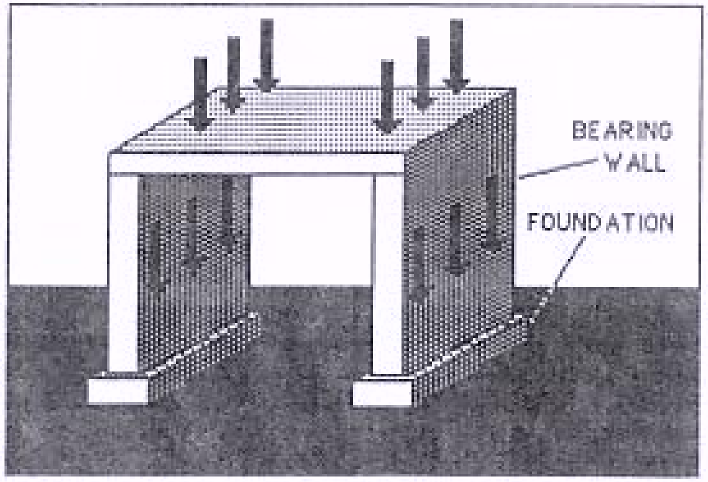
The combination of these two kinds of loads is the *total load* on the structure, and it is usually expressed in pounds per square foot. The purpose of the structure of the building is to organize, transfer and distribute these loads to the Earth.

Basically, this can be done in two different ways. The loads over an area can be gathered to one point, or a *column*. They will then be transfered down the column, to a *foundation*. The foundation is much wider than the column; it serves to spread the load out to the surrounding earth.



These loads are called point loads, because they bring down intense loads on a few points. There is more chance of movement and settlement where point loads occur. Usually point loads must be analyzed by an architect or engineer. They are avoided in Earthship designs.

The second method is to distribute the loads in a linear fashion, ie. a *bearing wall*. Similar to the column, the loads are then transferred down the wall, to a foundation. The difference is that the load on any part of the wall will be much smaller than the load on the column. Bearing walls are structural walls which act as a continuous unit, distributing loads over an entire wall.

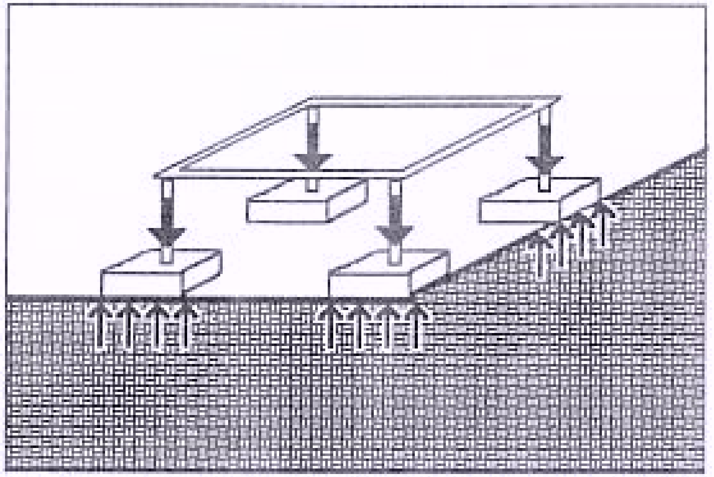


The load on the wall is more evenly distributed to the foundation, thereby spreading the loads over a larger area as they meet the earth. This results in less strain on the structural element and overall reduction of stress on the foundation, since the job of distributing the load has already been partially completed by the wall itself.

THE STRUCTURAL CONCEPT OF THE EARTHSHIP

The structural concept is again based on the "U" module, just as the thermal design concept is. One "U" could be structured independently, and then repeated over and over again.

Most conventional building materials and methods do little to recognize the natural phenomena of the relatively fluid Earth. Structures are designed in and of themselves and then are placed on the earth. In most cases there are a few large loads, and massive foundations are needed to distribute these loads to the earth.



Often the Earth, being rather fluid relative to concrete, has been known to shift, settle, or otherwise move slightly. This can result in major structural cracks in concrete work where intense loads are concentrated and brought to the Earth in great magnitude. To avoid this, much expense is required, plus the employment of an engineer, to build structures with expansion joints and steel reinforcements to resist the tendency of the Earth to move. This is further complicated by the tendency of the materials themselves to expand and contract - see thermal dynamics, Chapter 2.

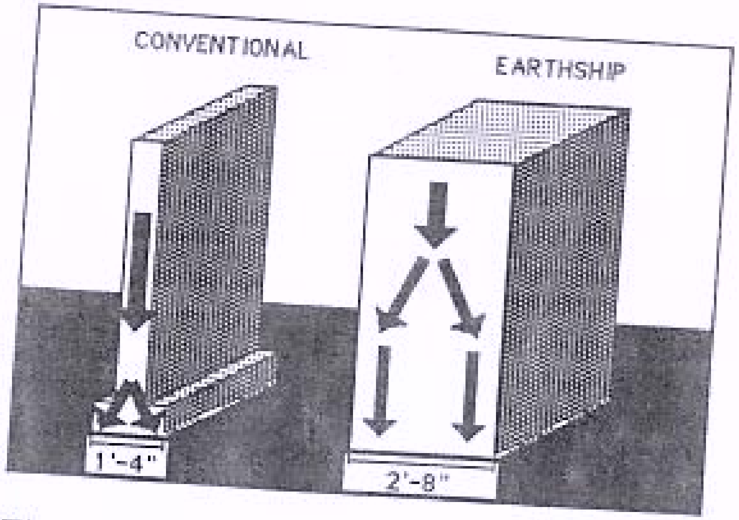
In contrast, the Earthships are designed to join the Earth, rather than to resist it. The structure (mostly earth itself) is based on a very wide distribution of loads so that by the time all loads reach the earth, they are insignificant in magnitude. An Earthship actually "floats" on the earth. This results in a very forgiving structure that has the potential to move with the Earth.

Conventional buildings set <u>on</u> the earth, Earthships are <u>of</u> the earth.

<u>U-shaped Mass bearing walls are their own foundations</u>

We have already discussed the fact that rooms must be wrapped in mass walls in order for them to store heat. Since we already have these massive walls, we will use them to hold up the roof of the module as well. <u>*They will act as bearing walls as well as mass walls.*</u>

Conventional bearing walls for a room the size of an Earthship module are usually 8" thick, and require a foundation 1'-4" wide to distribute the loads over the earth upon which it sets. The massive walls of the Earthship are 2'-8" thick, and are already wide enough to evenly distribute this load much more than conventional methods require. The Earthship walls themselves are *wider* than the required footing for such a wall.

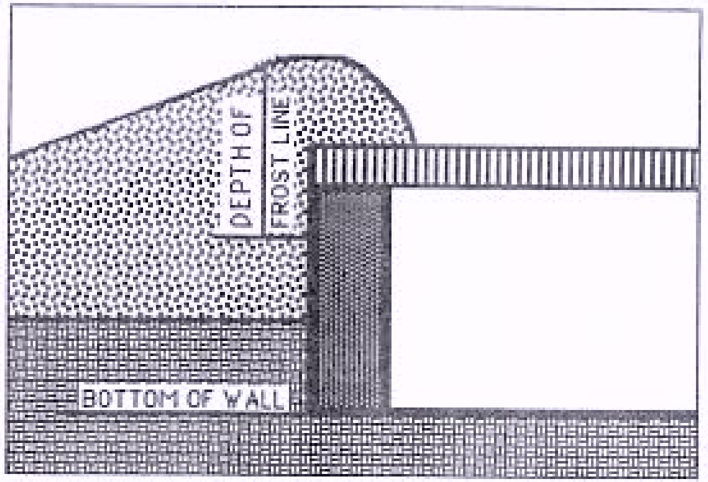


<u>*Therefore, the mass bearing walls of the Earthship are also the foundations.*</u> So the module is in effect floating with the Earth.

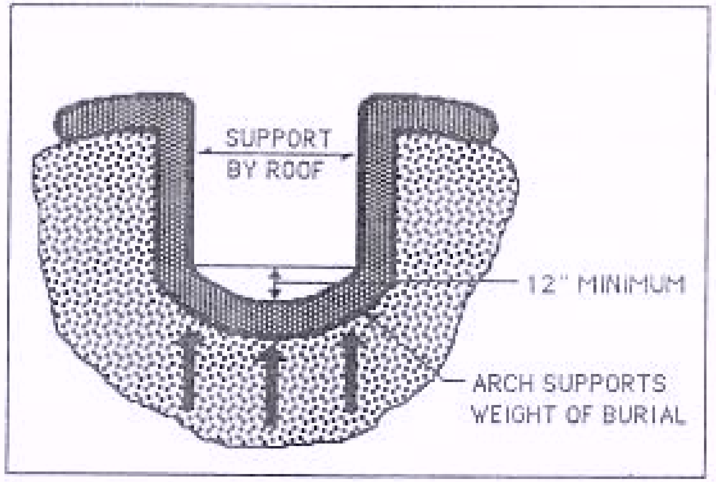
We are achieving thermal mass, structural bearing and foundations all in one shape. The shape is mostly earth itself which is contained in rubber (as later chapters will describe). This results in a massive, durable, resilient structure equipped to handle the seismic loads created by earthquakes. **Brittle, intensely loaded structures are much more vulnerable to earthquakes than resilient, widely distributed structural designs.**

Since most buildings are not surrounded by earth, the foundations need to be well below the rest of the structure to get below the frost line.

This is necessary to protect the foundations from the freeze- thaw movements of the earth. This means that the bottom of the foundation must be below the deepest point where the ground will freeze. These depths vary from region to region. Because Earthships are buried at the perimeter. The bottom of the mass wall will be well below the frost line, and there is no danger of thermal movement.

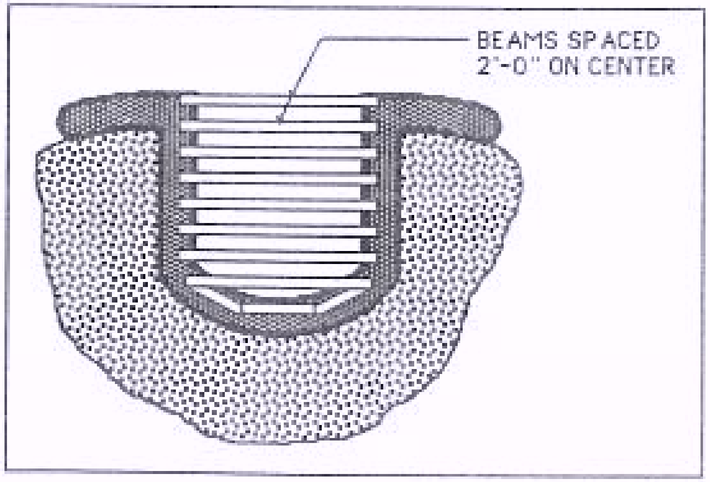


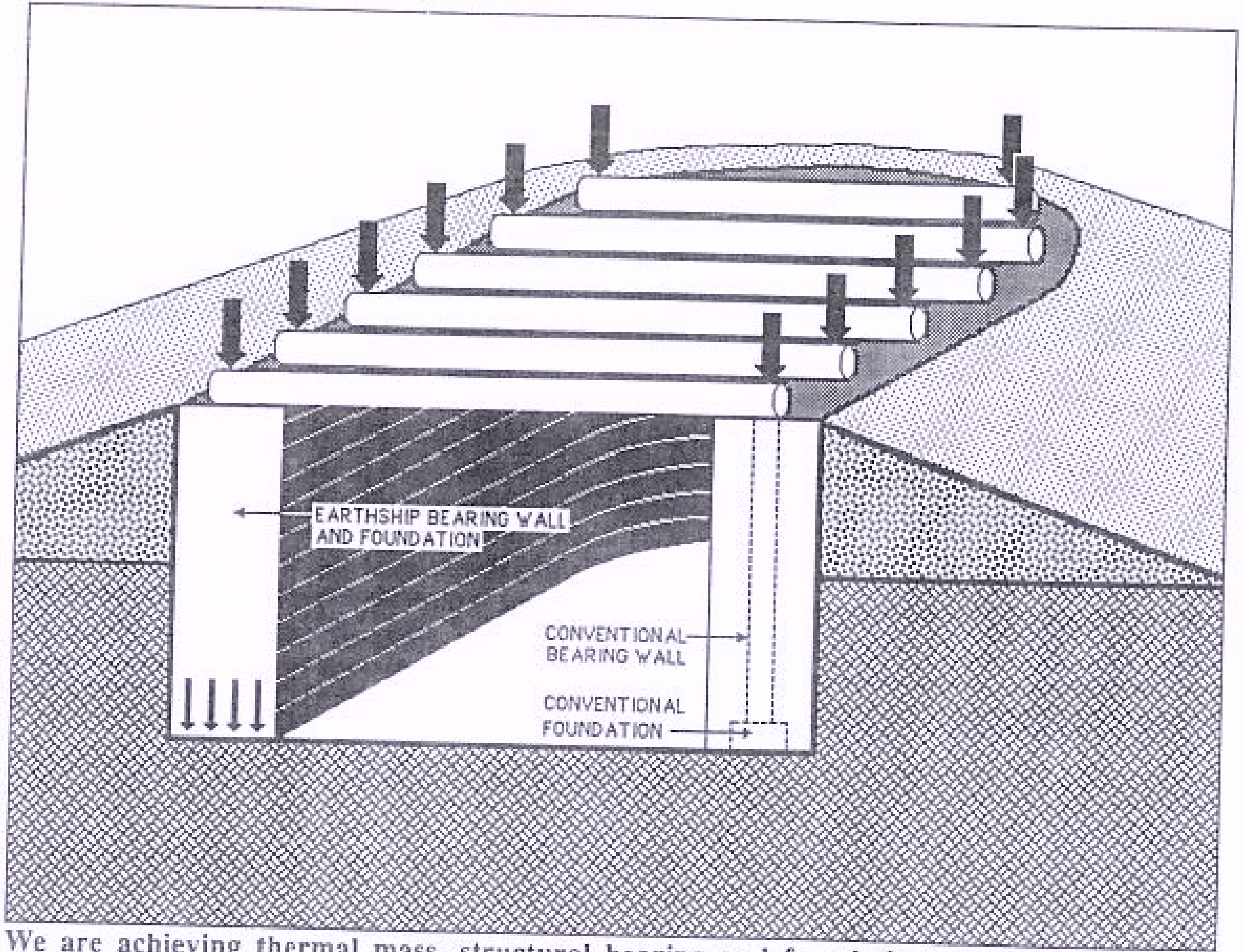
Although the north wall, or rear of the "U" is not necessary to support the roof, it is needed to retain the weight of the burying up against the building. The ability of this wall to retain the earth is strengthened if the wall is arched. This arch should be a minimum of 12" deep and can be as rounded as a semi-circle.



Framing the Roof

The roof structure is framed with beams running in the east-west direction, so that the loads are transferred directly to the mass bearing walls. This distributes the loads in many small increments along the wide, massive walls.





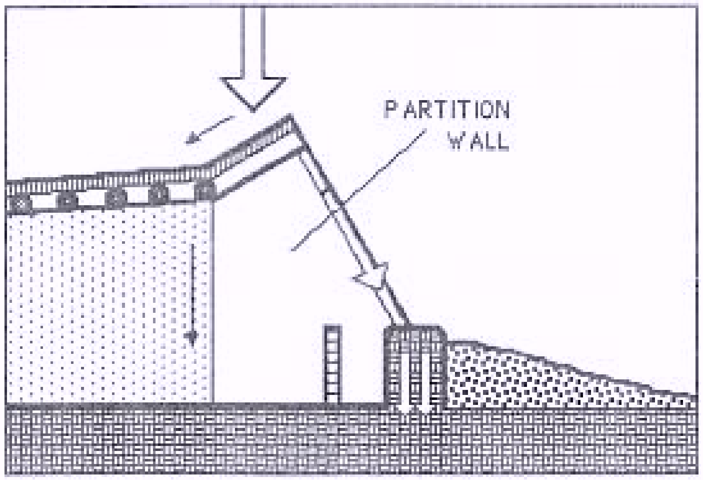
We are achieving thermal mass, structural bearing and foundations all in one shape.

Point loads are avoided. An even distribution of loads throughout allows the structure to "float" with the earth.

Greenhouse Lean-to

The other major structural component is the greenhouse. The greenhouse is a relatively light piece of carpentry work, compared to the massiveness of the U structure. It is a lean-to element which rests on the southernmost beam.

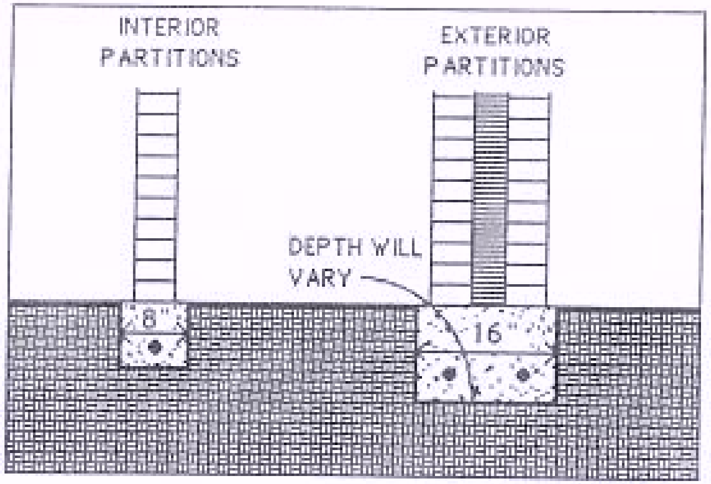
As the loads come down on the roof of the greenhouse, they are distributed in part to this beam, however, most of this relatively light stress will be transferred down to the mass wall which supports the greenhouse. All of these loads are minimal. This mass wall is also 2'-6" thick, thus continuing the "floating" concept of the Earthship.



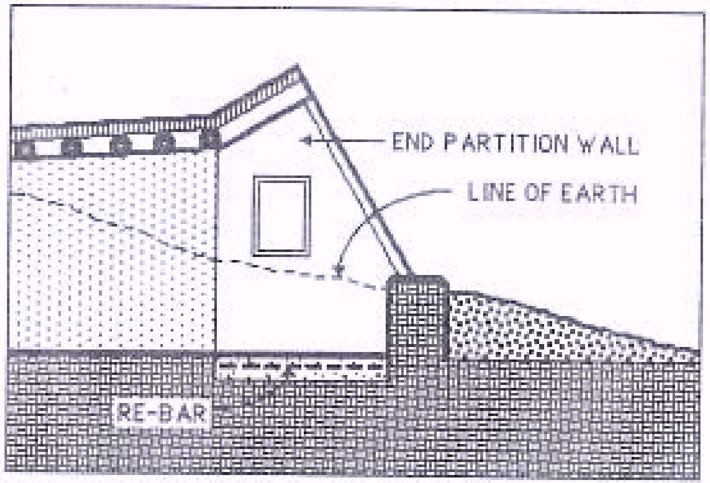
Partition walls

Partition walls are non-structural walls. They will be used to fill in the space between the greenhouse face and the mass walls as well as to enclose bathrooms, etc. Since they do not need to carry any loads additional to their own weight, they simply set on foundations which are about the same width as the walls themselves.

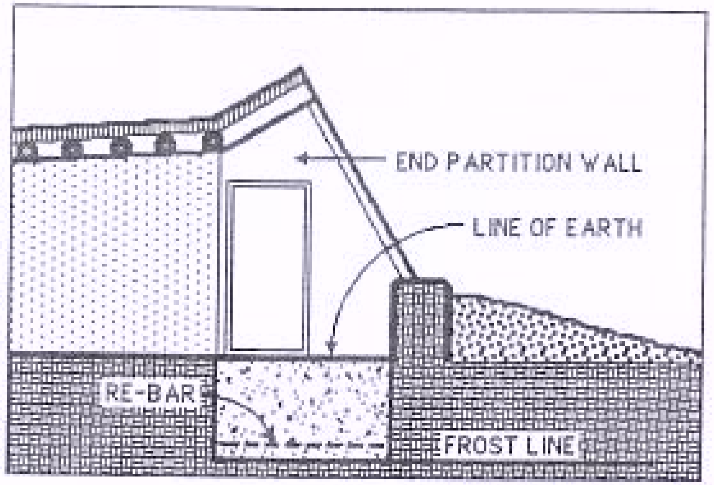
There are two types of partition walls in the Earthship - interior walls and exterior walls. (The method of building these walls out of aluminum cans will be discussed in Chapter 6 & 7). Interior partition walls are 6" thick and require an 8" wide by 8" deep footing with one piece of 1/2" steel reinforcement bars (rebar) to hold it together. Exterior partition walls are insulated which makes them 14" thick and they require a 16" wide footing with two pieces of rebar.



The depth of the footing will vary, relative to different conditions. If the bottom of the wall will be *below* the frost line after berming, a concrete pad 12" deep will be needed.



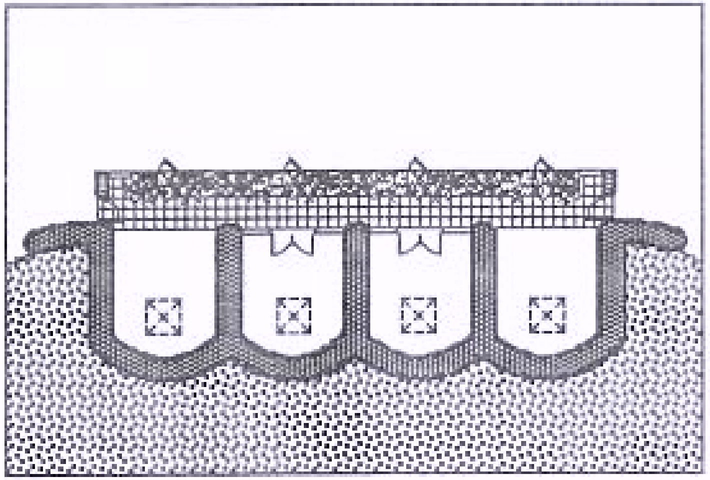
If the bottom of the wall is *above* the frost line, the foundation will need to go as deep as the frost line.



This will insure there will be no thermal movement.These foundations will have (2) 1/2" pieces of steel rebar.

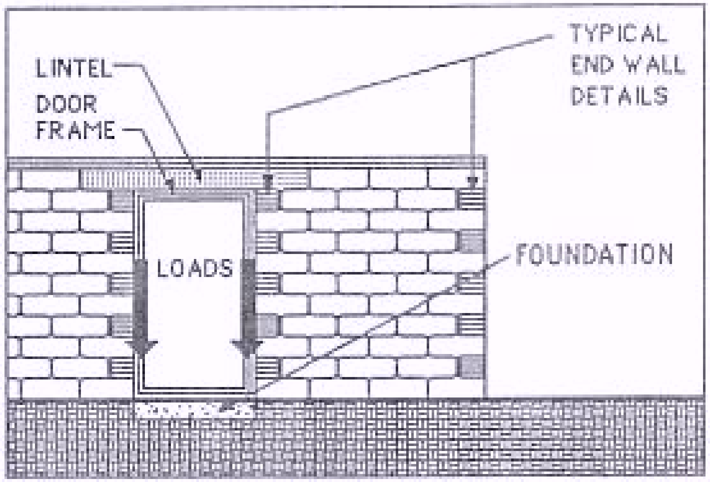
STRUCTURAL ECONOMY

As was discussed in Chapter 3, Earthships are designed with performance and economy in mind. Building a house made up of several simple "U" modules is the easiest, cheapest way to go. The structure is simple and has very few variations. This is critical when cost is an issue.



Deviations from the simple structure of the "U" module are possible, but *they will add to the cost and subtract from the performance* of the building. For example, a doorway could be cut through a tire wall, providing a passageway from one room to the next.

However, as you will learn more about in Chapter 6, this would entail cutting many extra blocks which are used for half tires, making a lintel and a frame, pouring a concrete foundation in which to set the frame, securing the frame to the tire wall, etc...



This requires time, conventional materials, and additional skills and *all of these cost more money*. Also, this will reduce the mass of the room, and reduce the possibility of individually controlling the temperature of each room.

If you do want to deviate from the structural simplicity of the "U" module, consider the consequences, and make as few of these changes as you can. The extreme, replacing all interior tire walls with columns, will leave you with a house which costs as much, and performs almost as badly, as a conventional compartment.