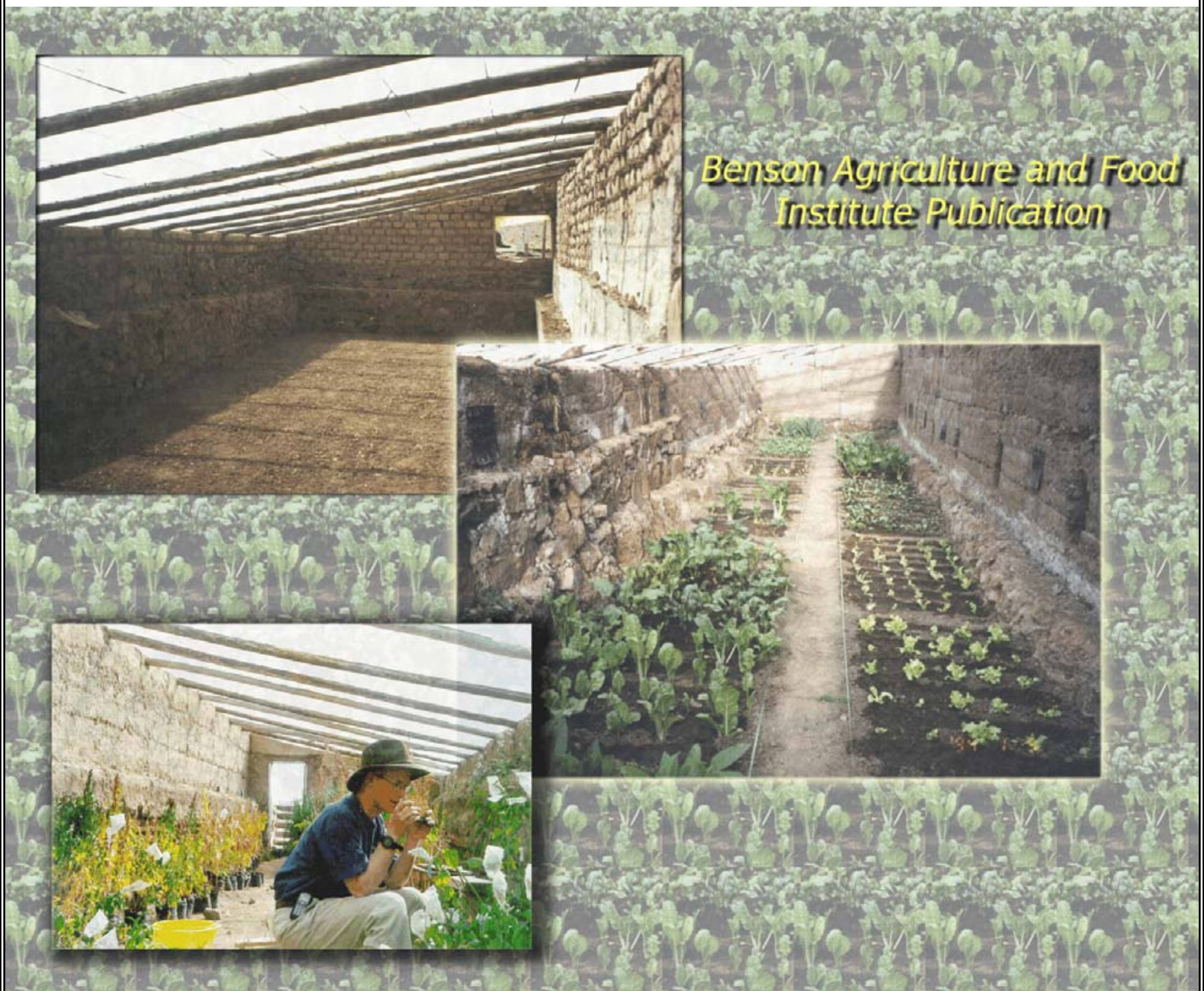
Walipini Construction (The Underground Greenhouse)



Revised Version

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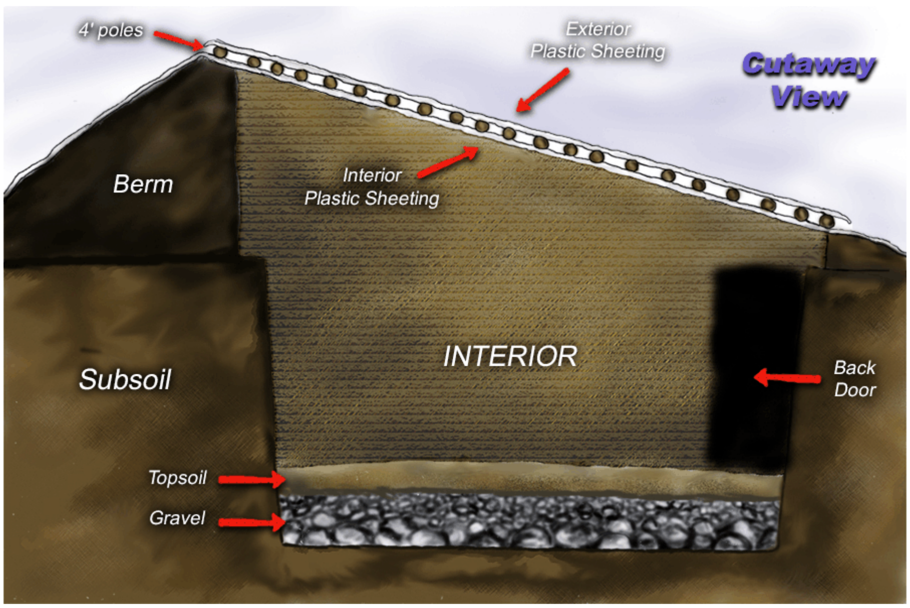
Introduction: The Walipini *(underground or pit greenhouse)* in this bulletin is designed specifically for the area of La Paz, Bolivia. However, the principles explained in the bulletin make it possible to build the Walipini in a wide variety of other geographic and climatic conditions. The word "Walipini" comes from the Aymara Indian language of this area of the world and means "place of warmth". The *Walipini utilizes nature's resources to provide a warm, stable, well-lit environment for year-round vegetable production*. Locating the growing area *6'- 8' underground* and capturing and storing daytime solar radiation are the most important principles in building a successful Walipini.

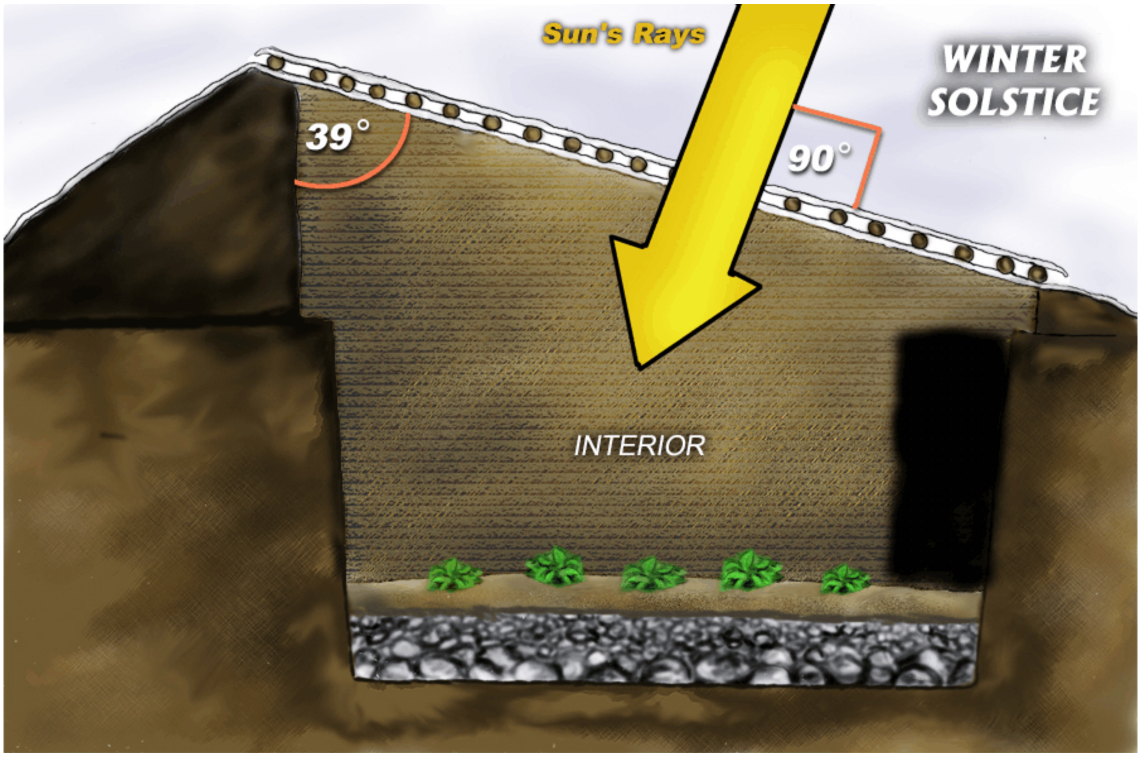


I. How the Walipini Works

The Walipini, in simplest terms, is a *rectangular hole in the ground 6 ' to 8' deep covered by plastic sheeting*. The *longest area of the rectangle faces the winter sun* -- to the north in the Southern Hemisphere and to the south in the Northern Hemisphere. A thick wall of rammed earth at the back of the building and a much lower wall at the front provide the needed angle for the plastic sheet roof. This *roof seals the hole, provides an insulating airspace* between the two layers of plastic (a sheet on the top and another on the bottom of the roof/poles) and allows the *suns rays to penetrate creating a warm, stable environment for plant growth*.

The Earth's Natural Heat -- Why dig in?

The *earth's center is a molten core of magma which heats the entire sphere*. At approximately 4' from the surface this heating process becomes apparent as the *temperature on most of the planet at 4' deep stays between 50 and 60º F*. When the temperature above ground is cold, say 10º F with a cold wind, the soil temperature at 4' deep in the earth will be at least fifty degrees in most places. *By digging the Walipini into the ground, the tremendous flywheel of stable temperature called the "thermal constant" is tapped.* Thus, the *additional heat needed from the sun's rays as they pass through the plastic and provide interior heat is much less* in the Walipini than in the above ground greenhouse. Example: An underground temperature of 50º requires heating the Walipini's interior only 30º to reach an ambient temperature of 80º. An above ground temperature of 10º requires heating a greenhouse 70º for an ambient temperature of 80º.



More Free Energy -- The Sun

Energy and light from the sun enter the Walipini through the plastic covered roof and are reflected and absorbed throughout the underground structure. By using translucent material, plastic instead of glass, plant growth is improved as certain rays of the light spectrum that inhibit plant growth are filtered out. The sun's rays provide both heat and light needed by plants. Heat is not only immediately provided as the light enters and heats the air, but heat is also stored as the mass of the entire building absorbs heat from the sun's rays.

Heat Storage -- Mass and the Flywheel Effect

As mass, (earth, stone, water -- dense matter) comes in contact with sunlight, it absorbs and stores heat. The more dense the mass (water is more dense than rock and rock is more dense than soil) the more energy can be stored in a given area. *Mass of a darker color such as flat brown, green or black absorbs heat best*. Light colors, such as white, reflect heat best. As the *earthen walls of the Walipini absorb this heat* they charge with heat much like a battery charges with electricity. This storing of the heat in the mass of the soil is often referred to as the *"flywheel effect"*, with the flywheel being charged in the day (storing heat/energy) and spinning down or discharging at night as heat/energy flows from the earthen walls out of the greenhouse up through the plastic glazing to the colder night air. *The amount of heat stored in the mass is a critical factor in keeping crops from being frost bitten or frozen during the coldest nights of the winte*r. These critical nights are usually encountered around the time of the winter equinox (June 21 in the Southern Hemisphere and December 21 in the Northern Hemisphere). The Walipini is usually designed to absorb more of the sun's rays/heat during the three coldest months of the winter than during any other time of the year. The key here is to have enough energy stored in the mass so that on the coldest nights, the plants are not damaged. *In general, nighttime temperatures should not be allowed to drop below 45º.* This minimum temperature is also dependent upon the types of crops being grown, as some are hardier than others and may require colder nighttime temperatures. An easy way to *increase the mass is to put a few 55 gallon drums filled with water and painted flat black* along the back wall of the Walipini. Some growing space will be lost, but the heated water will greatly enhance mass heat/energy storage and will provide preheated water for plant irrigation. Preheated water reduces plant shock, thus, assisting plant growth.

Cutting Down Heat Loss -- Insulation

A *double layer of plastic sheeting* (glazing) should be used on the roof. This provides a form of insulation and slows down the escaping of heat during the nighttime. This sealed dead-air space between the plastic sheeting should be between 3/4" to 4" thick. Poles used to span the roof that are 3.5" to 4" in diameter provide the indicated thickness of dead air space when plastic sheeting is affixed to the outside and the inside of the roof's structure. The inside sheeting also keeps the inside humidity from penetrating and rotting the wooden poles spanning the roof.

All above-ground walls should be bermed with as much soil as possible. This provides some extra mass, but provides much more insulation against above-ground cold temperature, winds and moisture penetration.

When nighttime temperatures are continuously well below freezing, insulated shutters made from foam insulation board or canvas sheets filled with straw or grass can be placed over the glazing. This requires more work and storage, and in many environments is unnecessary, such as is the case in the area of La Paz, Bolivia.

II. Location of the Walipini:

The Danger of Water Penetration

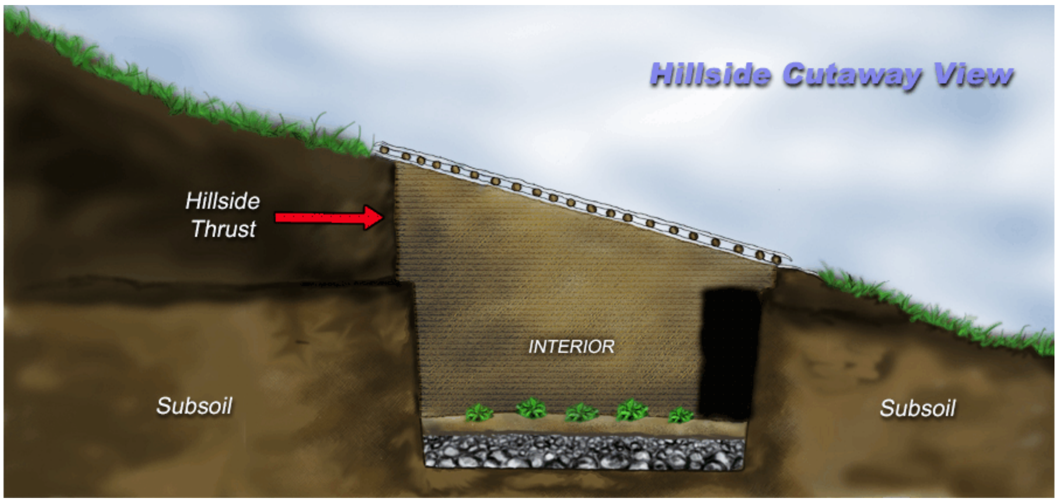
Water penetration of the walls and/or floor of the Walipini is destructive. If water seeps through the walls, they will collapse. If water comes up through the floor, it will adversely affect plant growth and promote plant disease. Dig the Walipini in an area where its *bottom is at least 5' above the water table.* When all of the above ground walls are bermed, a layer of *water-proof clay,* such as bentonite, or *plastic sheeting, should be buried* approximately 6" to 1' under the berm surface. It should be slanted so that the *water drains away from the Walipini* to the drainage ditches. In some cases where the soil has a low permeability rate, the clay or plastic may not be necessary. Be sure to dig a shallow *drainage ditch around the perimeter* of the Walipini which leads run off water well away from the structure.

Digging into the Hillside

Walipinis can be dug into a hillside providing the soil is stable and not under downward pressure. Since the Walipini has no footing or foundation, a wall in unstable soil or under pressure will eventually collapse.

Maximizing the Sun's Energy

The sun is

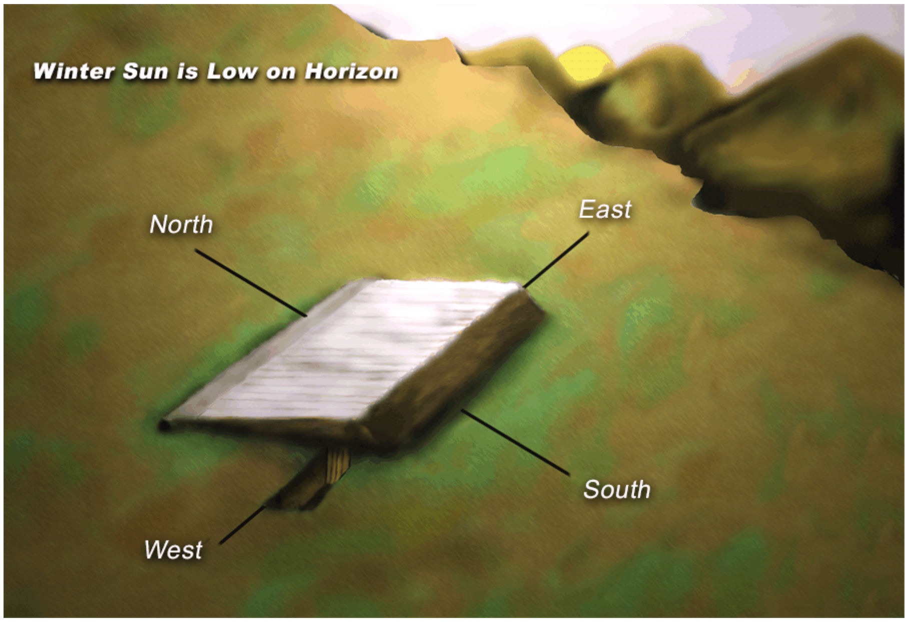


orbited by the earth once a year in an elliptical (oval) path at an average distance of 93M miles. The earth spins on its own axis creating the rising and setting of the sun. The *earth is tilted at 23 1/2° from the plane of its solar orbit, which is why the sun appears lower in the sky in the winter and higher in the sky in the summer*.

These variables in movement make the *location of the sun, both in height and plane, different each and every day of the year.* However, since the daily difference is minimal, *the Walipini can be located to maximize heat in any given season.* For vegetable production, this maximized location is for *winter heating of its interior* as this will be the most crucial time of the year for plant survival.

Alignment of the Walipini to the Winter Sun

Since the sun will come up in the East and go down in the West, the length of the rectangular *Walipini will stretch from east to west with the tilt angle of the roof facing north towards the winter sun in the Southern Hemisphere or towards the south in the Northern Hemisphere.*

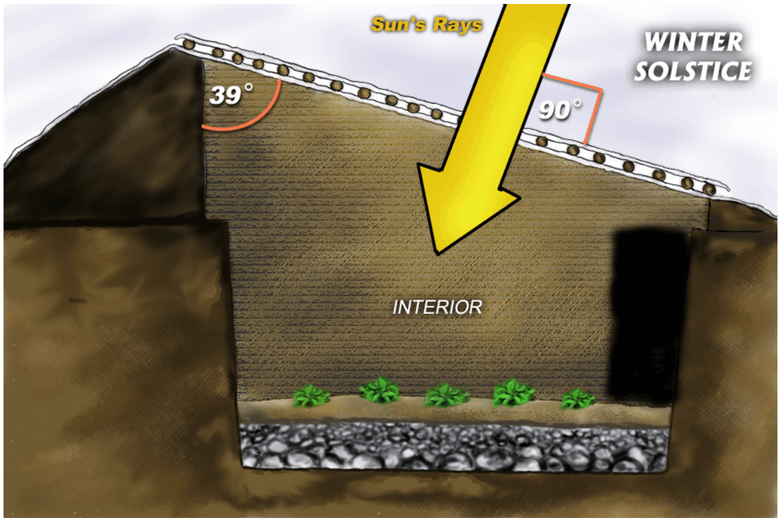


This allows the largest mass, the inside back (the highest) wall, to be exposed to the sun the longest as the sun moves across the horizon. *Some adjustments can be made for local conditions.* If winter conditions frequently produce hazy or cloudy mornings or high mountains in the east make for a late sunrise, it may be best to locate the Walipini 10-15º to the north west of true east in order keep the afternoon sun in the Walipini for a longer period of time. If winter mornings are generally clear, it can be located at 10 to 15 º north east of true east to maximize the early morning rays for a longer period. *Maximum heating will usually take place between 10:00 a.m. and 3:00 p.m.*

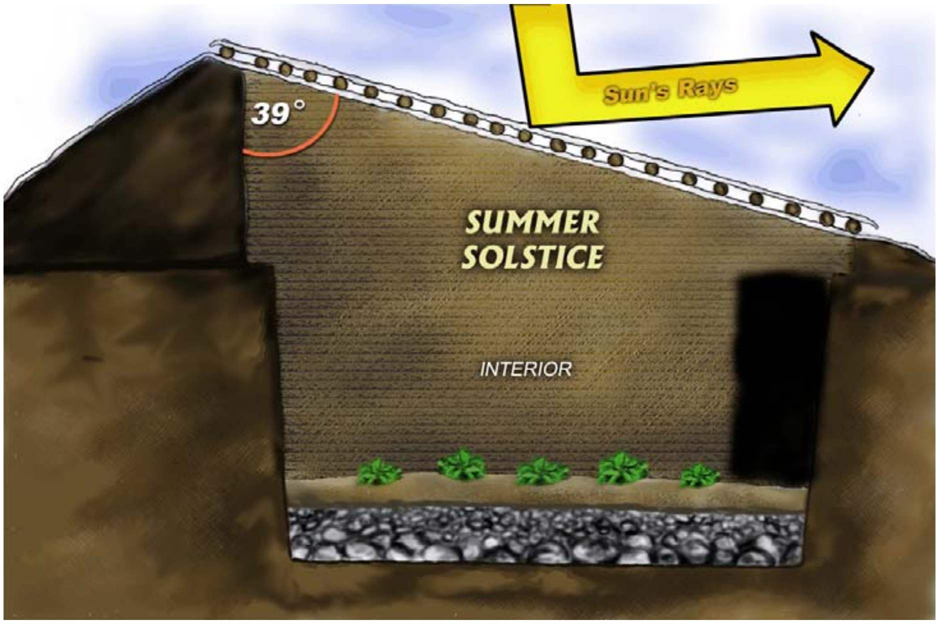
Angle of the Roof to the Sun

In order to make *the simple calculation for the best angle of the roof* (the plastic glazing) for maximum sun penetration at the winter solstice (the shortest day of the year), use the following rule of thumb: *1) Obtain a good map and determine the latitude on the globe.* La Paz is located at 16.4º south of the equator.

2) Add approximately 23º which will make a tilt angle of 39 - 40º for the La Paz area. *This will* *set the glazing of the roof perpendicular to the sun on the winter solstice*, which will maximize sun penetration and minimize reflection.

At the summer 

solstice this angle will have the opposite effect and maximize reflection and minimize penetration.

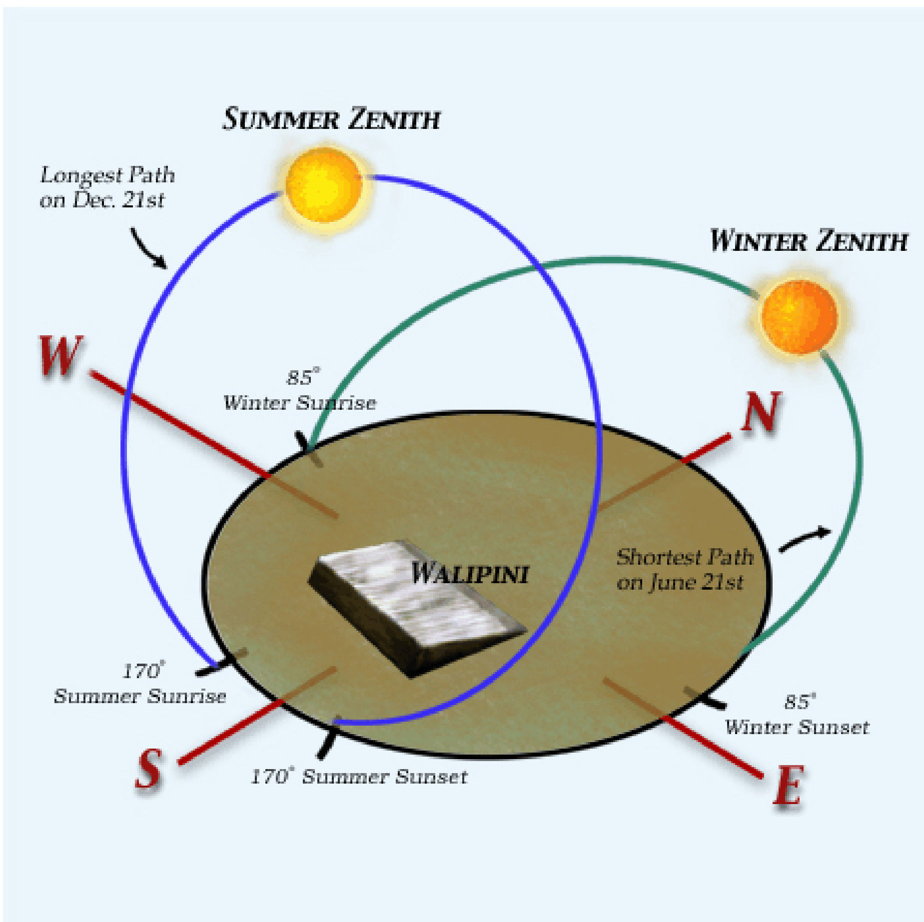
This angle 

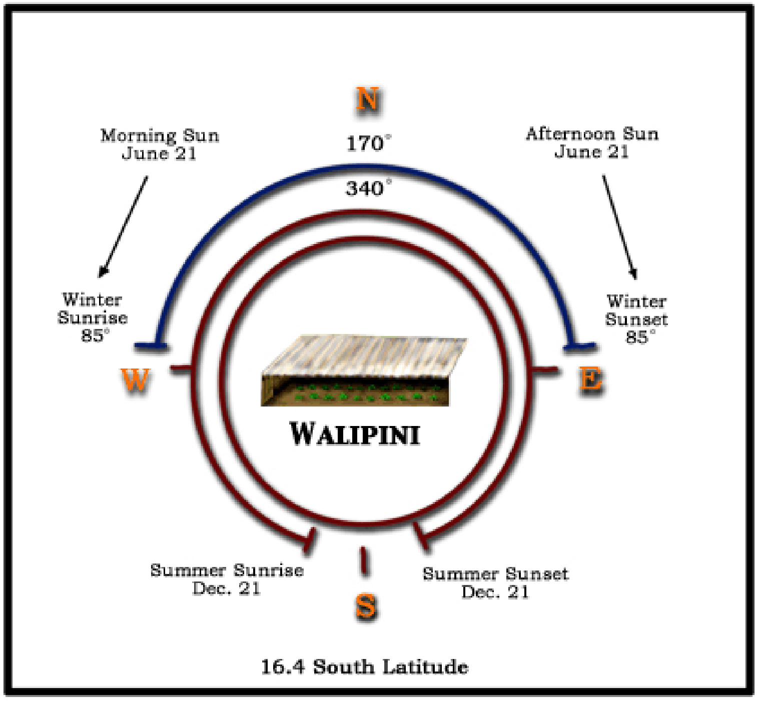
can be varied, but will change the basic design of maximizing heat during a winter solstice and minimizing it during the summer solstice.

Azimuth

The change in the length of daylight from summer to winter is the result of the azimuth. The sun is higher in the sky in the summer and also goes through a much wider plan arc, or azimuth, thus making the days longer.

At 16.4º south latitude, in (La Paz) the summer azimuth is approximately 340º while the winter azimuth angle is about 170º. This means that the winter sun rises at 85º east of north and sets at 85º west of north. Since we are seeking maximum heating in the Walipini on the winter solstice (June 21 in the Southern Hemisphere and Dec 21), the orientation of the Walipini and the angle of its glazing are designed to facilitate maximum sun penetration at the winter solstice.





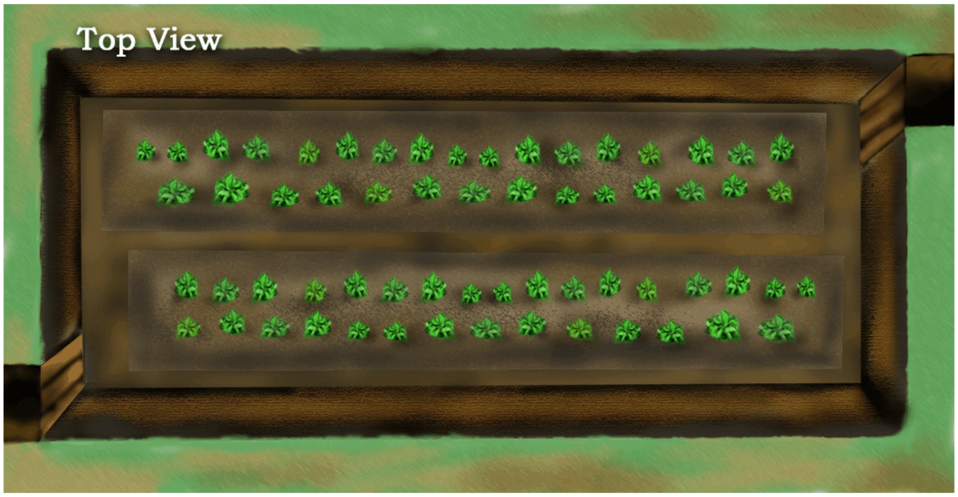
Obstructions

Make sure that the Walipini is located so that its face (the roof angle facing the sun) has no obstructions such as trees, other buildings, etc. which will obstruct the sun. This is also true of the east and west sides of the structure. The only exception to this rule would be a few deciduous trees which lose their leaves in the winter. They can provide limited shading in the hot summer, but little shade in the winter.

III. Walipini Design

Size and Cost Considerations

The primary considerations in designing the Walipini are cost and year-round food production for the family. The *minimum recommended size is 8' x 12'*. However, generally speaking, the larger the Walipini, the more cost effective per square foot the construction will be. A *minimum of 94 sq. ft. of growing space per person is recommended for a year-round vegetable supply*. Thus, for a family of seven people a 12' x 66' area = 792 sq. ft. Less 16% for access = 665 sq. ft. of growing space divided by 7 people = 94 sq. ft. per person in the La Paz model. Keeping the size of the Walipini manageable and its cost as low as possible are important design considerations.

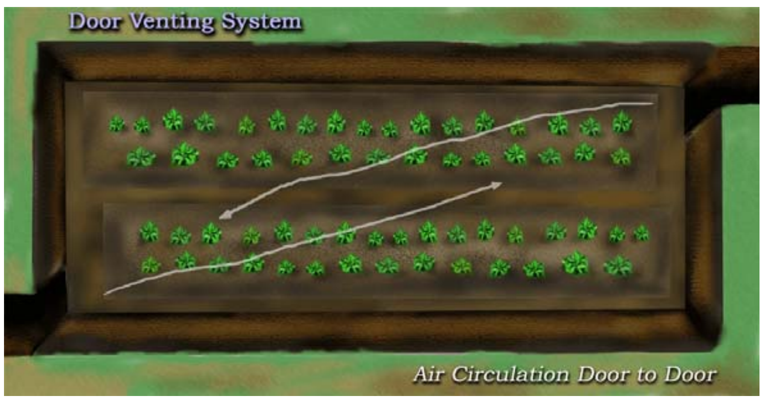


The Walipini is designed to *keep costs as low as possible* using the following: 1) Free labor -- the builder's and that of friend's and neighbor's; 2) Only unlined, inclined, interior earthen walls; 3) Traditional concrete footings and foundations are excluded because they are unnecessary, when the perimeter of the building is protected from water penetration; 4) Plastic ultraviolet (UV) protective sheeting on the top and underside of the roof instead of glass or corrugated fiberglass panels; 5) The most economical, durable materials found thus far for spanning the roof are 4" eucalyptus poles or PVC pipe;   6) The top soil from the dig is used at the bottom for the planting soil; 7) The rest of the soil from the dig is used for the rammed earth walls, berms and adobes; 8) Stones and any gravel from the dig are used in the planting area drainage system and sump-wells; and 9) Used materials are utilized where possible and practical such as used, cleaned 55 gallon oil drums, used doors, etc. It is assumed that only some of the materials will have a monetary cost and that labor will have none. The cost of materials will vary from location to location and will also vary according to what is available free of cost. Materials for the current La Paz models (20' x 74') are $250 to $300.

<u>Venting System</u>

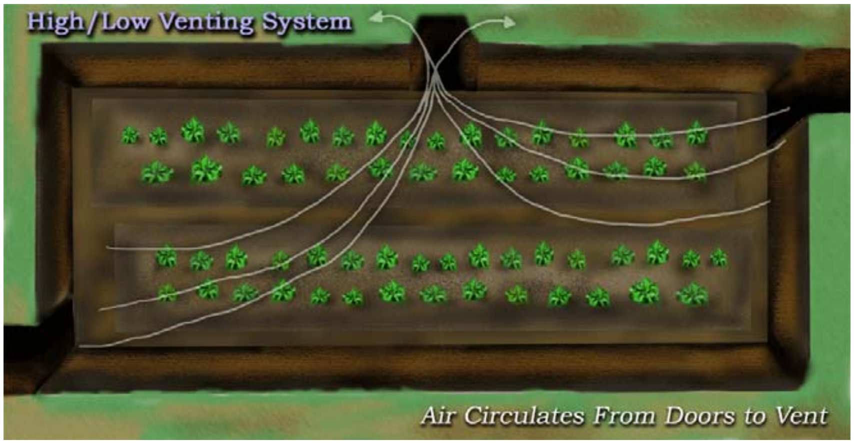
Venting can become a crucial factor in *controlling overheating and too much humidity in the Walipini*. Too much venting can also be a detriment and, thus, the proper balance must be maintained for optimum plant growth. This balance is dependent upon a combination of the factors discussed in the previous three sections. *Four methods of venting the Walipin*i will be discussed in ascending order of volume of air ventilation possible in each system. Each method has its advantages and disadvantages regarding labor, mass storage, cost, volume of air flow, etc.: 1) The first method, currently used in the La Paz model, is that of ventilating by using two doors at opposite ends of the building. It requires no additional vents, material, or labor, but it lacks the advantage of low to high convection ventilation which can move much greater volumes of air sometimes needed, if temperature and humidity climb too high.

Venting Method # 1

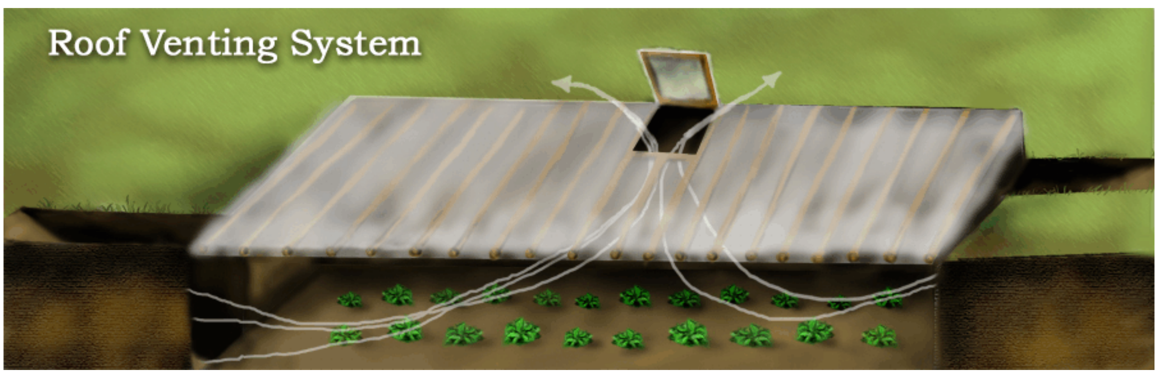


2) Method two uses the same doors with the addition of a vent of equal size as one of the doors when the vent is fully opened. This vent is centered at top of the back wall. It requires less rammed earth (labor) in the back wall (the vent area) and it provides a much greater volume of air exchange when needed. However, heat storage mass is lost in the back wall where most of the heat is collected, more interior surface area is exposed to the outside cold, a lintel must span the vent to support the roof poles and additional labor is required to contour and seal the berm at the vent on the exterior back wall.

Venting **Method # 2**

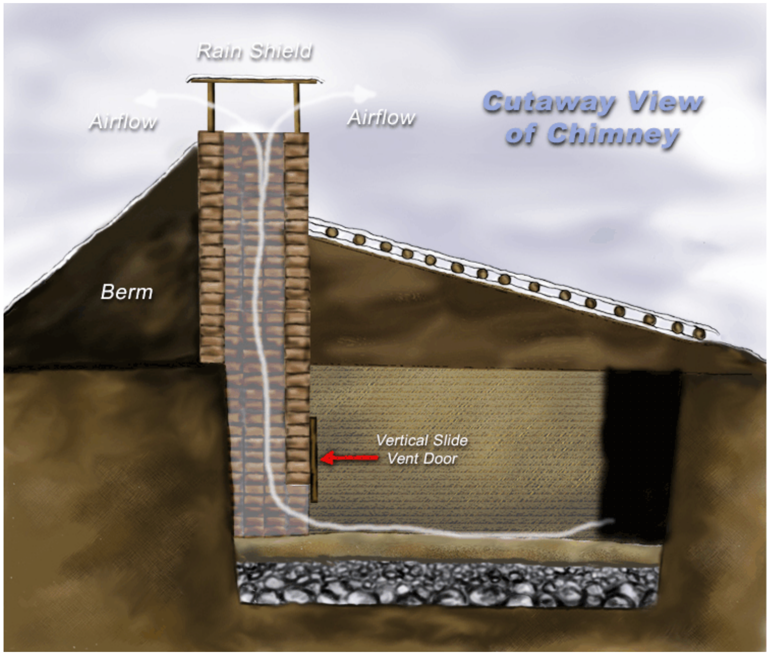


3) Method three uses the same doors with an additional trap door type vent of equal size in the roof.



Venting Method # 3

This vent is located in the roof at the center, back against the rear wall at the highest point. When needed, the highest volume of air exchange, thus far, can be obtained and no heat-storage mass is lost in the back wall. However, if the operable vent in the roof is not built correctly, even when in the closed position, it will leak rain water and will allow heated air to filter out when it is most needed. Only a few boards for the frame and two hinges are needed to build this 4' x 4' vent.



4) Method four uses the same doors in conjunction with the addition of a *chimney* located at the bottom center of the rear wall.

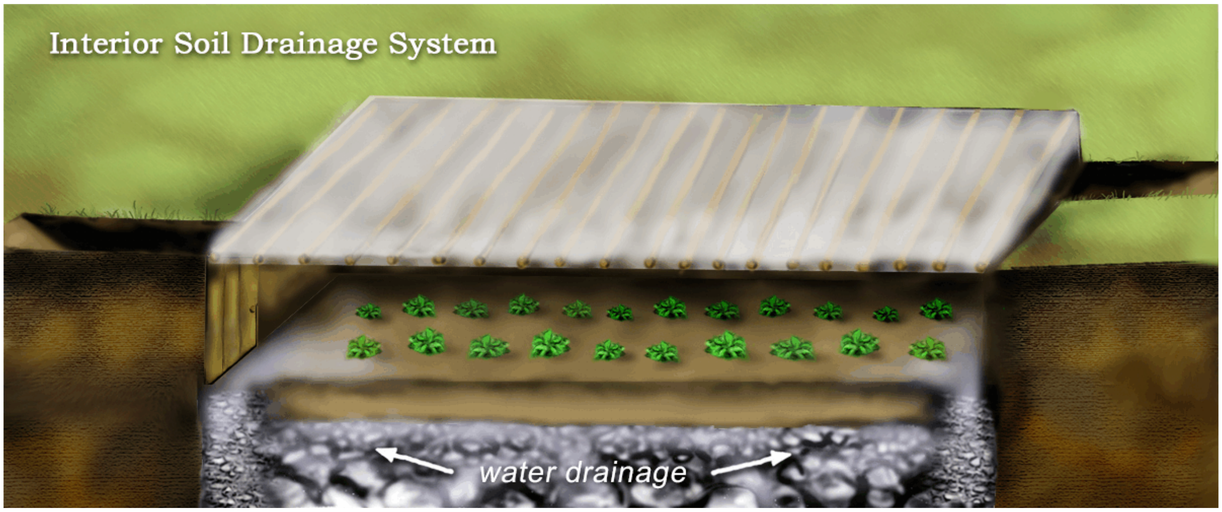
Venting Method # 4

This system provides the highest volume and best control of ventilation while retaining mass, but it requires more labor, a little more material in the adobes, 4 short vertical poles and a rain shield.

Interior Drainage System

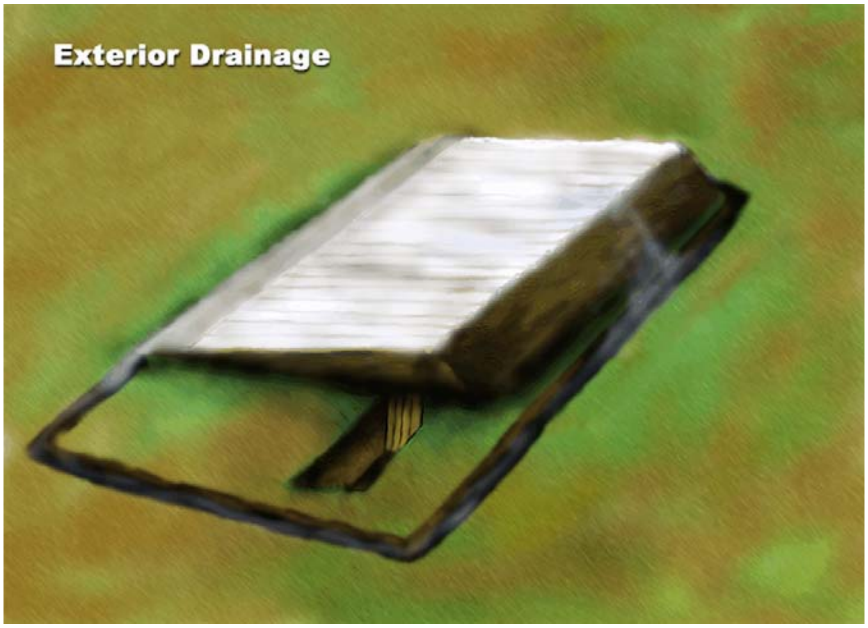
Keeping moisture from building up to such a degree that it adversely affects plant growth and contributes to plant disease is an important aspect of the interior drainage system.

As the hole for the Walipini is dug, it is excavated to an approximate depth of 1 - 2' deeper than it will be when in operation. This area (1 - 2' of depth) is filled with stone, gravel and 8" of top soil. The larger stones are placed at the bottom with the gravel becoming progressively smaller as it meets the layer of top soil. The bottom of the dig will be progressively sloped from the center to the ends with a drop of 1/4" per foot. In the La Paz model this means that from the center, the bottom of the dig to each end will have an over-all drop of 8.25" (The center to each end is 33' x .25 = 8.25".). This incline will allow excess water to flow to each end of the building. At each end of the building a 2' x 3' gravel-filled sump/well deep enough to absorb the runoff is found. The top of this sump should be covered with an openable lid so that water can be removed with a bucket when and if needed. *Moisture content inside of the Walipini can also be controlled by the amount and frequency of irrigation, and by venting.*



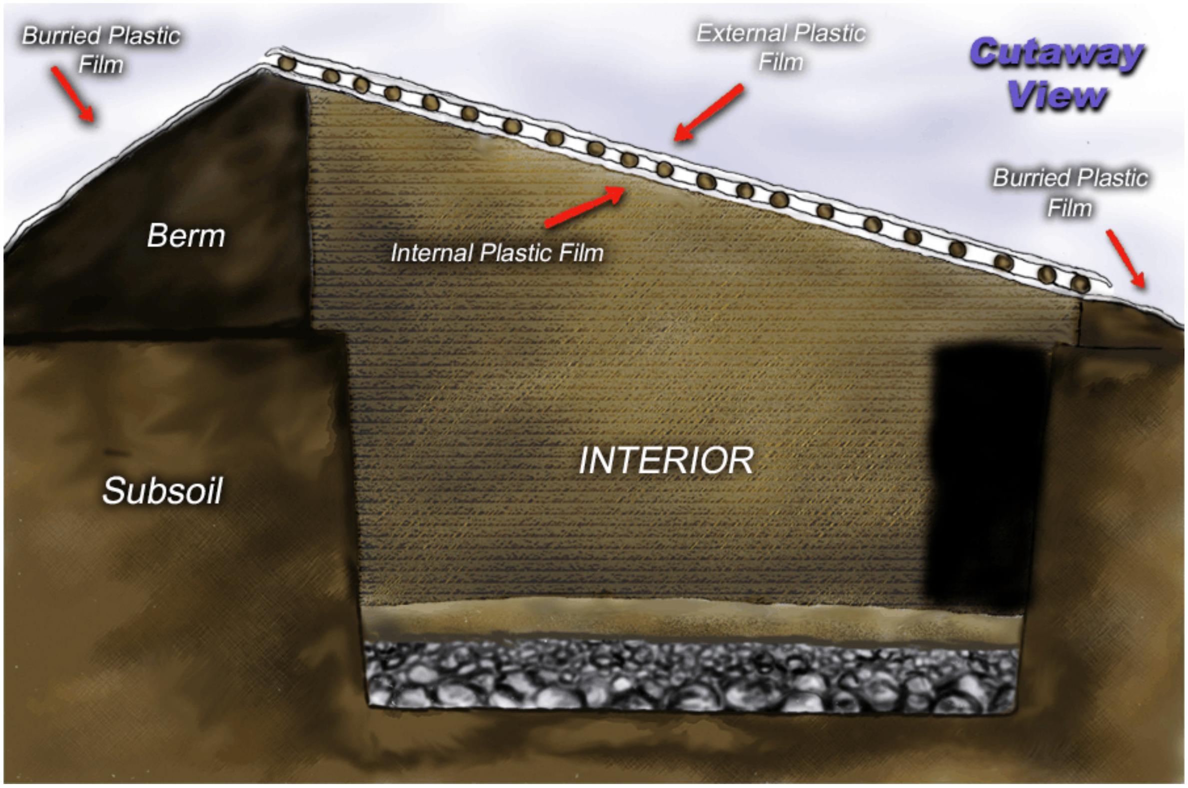
Exterior Drainage

Water is both friend and foe of the Walipini growing system and must be handled appropriately. *Exterior drainage of excess rainfall away from the Walipini is crucial*.



For this reason *berms must have sufficient incline away from the underground walls of the building to move water away quickly*. A minimum of a quarter inch drop per running foot is recommended.

Depending upon the porosity of the soil, *it may be necessary to bury a layer of clay such as* *bentonite or a layer of plastic sheeting from the rammed earth wall to the perimeter drainage ditch.*



How far the ditch is away from the interior wall of the building will depend upon how effectively one can seal the berms and/or move the water away from the building. Most currently-existing Walipinis which have had no wall moisture penetration have an average berm length on the high, back wall of about 10', on the front low wall of about 5' and on the side walls also about 5'. These Walipinis are located in heavy clay soil which helps to inhibit water penetration.

Water Collection Heating/Irrigation System

This system *collects runoff from the roof* at the front of the roof in a galvanized metal or PVC rain gutter. From the gutter water flows through a pipe into the 55-gallon barrel/drum system used for irrigation and mass heat storage.

Each of the barrels is connected by overflow piping at the top with the overflow pipe at the last barrel exiting at ground level under the back berm to the perimeter drainage ditch.
In case of a down-pour or continuous excessive rain, it would be wise to have a *T pipe/valve* at the bottom of the gutter so that the runoff can be diverted to an outside perimeter ditch instead of moving down to the already full barrel system. How much run off the system can handle in a given period of time will depend upon the size of the gutter and the diameter of the pipe used. The larger the diameter, the more volume of water can be handled. As previously indicated, this system *provides not only preheated irrigation water, but a dense solar mass (water) in which additional heat is stored for the cold winter nights*.

IV. Building the Walipini

Tool List

Hammers, shovels, picks, saws, wheelbarrows, crowbar, forms for rammed earth compaction (two 2 " x 12" x 6' planks held together by 2" x 4" or metal rods or many other type of forms can be made), 100' and 25' measuring tapes (If 100' tape is not available, measure out and mark 100' of string or rope), levels, clear hose for corner leveling, cutting knives, hose, nozzle, hand compactors, adobe forms, drill, bits, stakes, nylon string, etc.

Materials List for a 20' x 74' Walipini

Water

20 -- 4” x 16’ poles or PVC pipes to span the roof

3 -- 3’ x 6’ hinged doors (one is for the 3’ x 5’ vent cover)

3 -- 3’ x 5’ door frames (2 if rear wall vent is not used)

2 -- 3’ x 6’ door lintels

1 -- 6’ x 3’ vent lintel or roof frame for vent, if used

1700 sq.’ of 200 micron agrofilm (polyethylene UV plastic)

640’ of 1” wood stripping to secure plastic sheeting to the poles

Shovels, tractor or ox drawn fresno plow to dig hole

30 cubic. yds. of gravel for the floor drainage system

1 cubic yds of gravel or stone to fill the 2 drain sumps

233 cubic yds of soil will come from the excavation

22 cubic yds of top soil for planting (8” x 66’ x 12’)

94 cubic yds. for the rammed earth walls

This will leave a remainder of 109 cubic yds. for wall berms.

2700 sq’ of plastic sheeting to bury for drainage, if needed

74 ‘ of drain gutter for the lower end of roof

100’ of overthrow/drain pipe from gutter through barrel system to perimeter drainage ditch

Nails

116 8” x 4” x 12” adobes for the perimeter to seal plastic roof edge

Laying out the Building

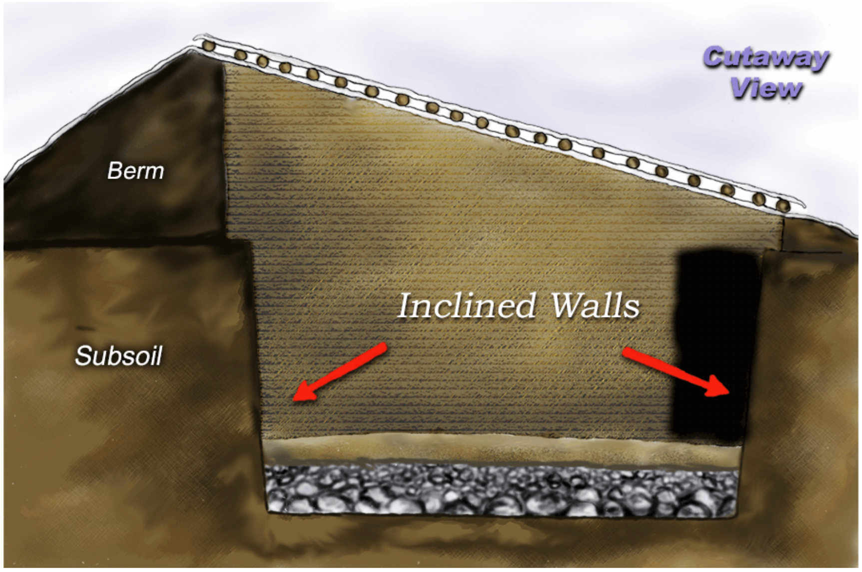
We will use the La Paz model. *Select the site location* as explained in section I and *measure out the 12.5’ x 66’ growing area* marking it by driving stakes and stretching string. Now "*square” the area* using the tape or the pre-marked rope. Next go along the string line and *mark the outline of the area to be dug with lime*. Set the batter boards and grade stakes using the clear hose level or a transit making sure they are all set at the same level. They are used to measure for uniform depth of the hole and for uniform level the ground upon which the walls will be rammed. If one or more walls are going to be rammed as the soil is removed, also lay out and mark them.

<u>The Excavation -- Digging the Hole</u>

The hole should be dug 1' - 2' deeper than the growing surface. This allows room for rock/gravel fill and then the top soil. *Separate the first 8" of top soil from the rest* of the soil as it will be used as the top soil for growing in the Walipini. The excavation can be *hand-dug* which is made easier by wetting the area first, by an *ox or horse-drawn fresno plow/scraper* used by the pioneers in the USA to dig canals, basements, earthen tanks, etc. or *by machine* (tractor or backhoe). The method used will depend primarily upon the availability of time and money.

As the soil is removed, *remember to pile the soil in areas where it will be used for berming and the rammed walls*. Moving it the least number of times will reduce labor. (Some of the rammed earth walls can be built at the same time the excavation is going on using the soil as it comes from the hole). Soil for rammed earth should contain approximately 10% moisture – just moist enough to hold its shape after being compresses in your hand.

Don't forget to *dig the two channels needed for the door entrances* at opposite ends of the building. It is important to note that *all four vertical walls of the dig need to be sloped from the bottom to the outside at the top*. A minimum of a 6" slope from bottom to top is suggested for a 6' high wall. This will greatly reduce soil caving in or crumbling off from the walls over time.

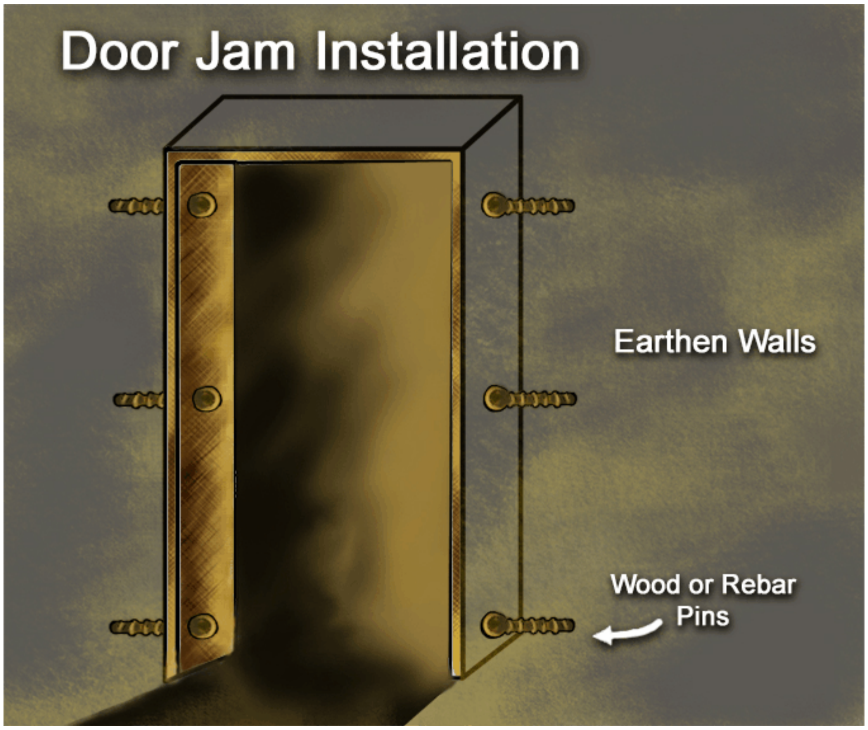


The *floor should be sloped for interior drainage* from the center to each end and *sump/wells dug at each end* before starting to back-fill with gravel and topsoil as explained in the previous section. Next *place the stones, then gravel at the bottom of the Walipini and in the sumps.*. Mix the top soil with organic matter and the appropriate fertilizer, as needed, and *spread the top soil at least 8" thick over the gravel drainage system*.

The *door jams (frames) and doors should now be installed* at the bottom level of the two ramps at the level of the growing surface. Door jams (frames) should be of 2" thick board stock, such as 2" x 8"s, with holes drilled at the top, middle and bottom of each side. Wooden stakes, dowels, or rebar are then driven through these six holes into the earthen wall in each jam to *set the doors in plum vertical position (use a level)*.

Install the doors making sure they fit as airtight as possible.

Fill in any air cracks found around the door frames with adobe mud (clay, sand and straw mix). This completes the underground portion of the Walipini.



The Walls

Lay out the walls all the way around by dropping back 6" from the edge of the excavation. Using the grade stakes as the reference, *make sure the soil foundation for the walls is level* and uniform all the way around the building. *Mark the layout of the walls with lime* and begin ramming them staring at a corner using the ramming form. *Mix the soil to approximately 10% moisture content* before shoveling it into the form. A good rule of thumb for the 10% moisture content is -- 1) If the soil holds its shape after being tightly-squeezed in the hand and 2) When it is dropped to the ground, if it cracks and crumbles somewhat instead of splatting into a plastic mass, the moisture content is about right. If it splats like a mud ball, it is too wet. Before starting to ram the soil into the form, wet (not soak to a muddy texture) the soil area at the bottom of the form for a better bond between the two surfaces. *Start ramming earth* into the form beginning at one of the corners. *When the doors are reached, pin (using rebar stakes) a lintel* (metal or wood) over each door to support the weight of the wall to be built on top of it. The lintel must be as wide as the wall (18" to 3'), a foot longer on each side than the width of the door (5' for the 3.0 door) and approximately 4" thick, if using wood. (The 4" poles used to span the roof, cut in to 5' lengths laid side by side and wired and/or nailed together on top of the door frame may be sufficient. *Continue moving the form and ramming the first course/level of earth until the first level is completed all the way around the building.* As the form is set for the next courses as the wall goes up, *always check with a level* to make sure that the walls are straight up and down (perpendicular to the ground) and not leaning to one side or the other.

Begin the second course of rammed earth on top of the first at the mid-point of the first form that was rammed. This will cause the vertical joints of each form length to be staggered and greatly increase the strength of the wall.

Be sure to *wet the exposed surface of the soil at the bottom of the form each time before beginning to ram*. This will increase the adhesion of the horizontal joints and strengthen the wall. *Continue until the proper height has been reached on each wall*. If the middle, top-of-the-back-wall *vent is used*, leave the appropriate 3' high by 6' long hole here by skipping this area during the last few courses of ramming. This will need to be spanned with a 2" thick wooden *lintel (with a vertical support post at the center)* for the roof poles to be nailed to. The *end walls will need to be cut with shovels at the appropriate 39-40º angle* for the perpendicular roof angle needed to the sun at the winter solstice. Also, *the high and low walls will need some shaping* to accommodate this same angle, as the poles spanning the roof glazing are laid into them at 39º - 40º. *This completes the walls*. If the walls are located correctly, a 6" shelf will exist around the entire inside of the building between the bottom of the rammed walls and the top of the dug out walls. This shelf can serve many purposes, but during the ramming of the walls it provides enough of a surface between the bottom of the wall being rammed and the top of the dug wall to prevent cave-ins along the dug out walls.

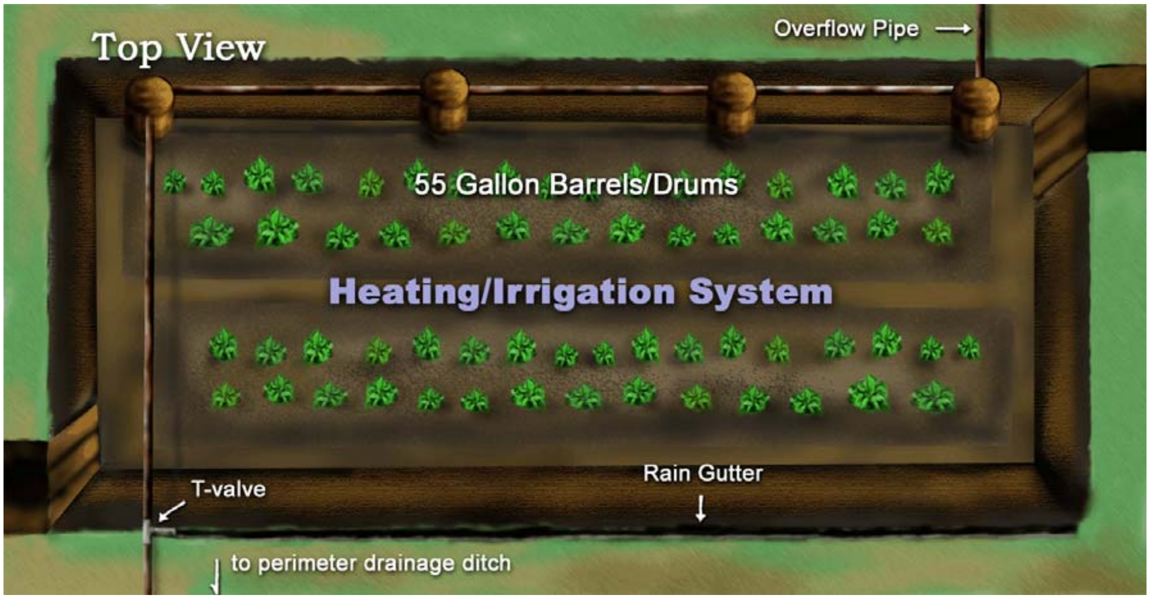
<u>Roof and Glazing</u>

Recheck and *make sure that the angle* of the roof is approximately *39º to 40º* so it will be perpendicular to the sun's rays on the winter solstice. Next *place the twenty 4" x 16' long poles on 4' centers spanning the roof* beginning at one end of the growing area which will place the 18th pole at the other end of the growing area. Poles 19 and 20 are placed at the ends 4' from poles 1 and 18 so that there is *minimum 1' overhang over the two doors on the ends of the building*.

Little overhang on the front and back walls is needed, if plastic sheeting is used to protect the immediate area from erosion and water penetration. Before pinning the poles into the tops of the back and front walls, *place a sheet of plastic running the full length of the interior of the building*, including the overhangs, at both the top and bottom so that this interior glazing will be staked down with the end of each pole. *Drill a hole in each pole and stake it* into the rammed earth with rebar, a wooden stake or dowel. *Fill the wall in between each pole with adobe mud the width of the wall following the angle of the poles.* This will seal the area between each of the poles to prevent outside air from coming in and inside heated air venting to the outside. Now *cover the entire exterior of the roof with the plastic sheeting* overlapping each joint at least 6" to minimize air leakage and securing each overlap with wood stripping and nails at one of the poles. *Nail stripping the full length of each pole* to secure the plastic and to prevent wind damage. Place a *single course of adobes* all the way around the perimeter of the roof with the exception of the bottom side where the water runs off into the gutter system. This will *secure the boarder of the plastic to the walls*. On the lower wall the plastic must run down to the gutter system unobstructed so the water freely follows this course.

Now go inside the Walipini and *finish lining the underside of the poles/roof with the plastic* securing it with nailed stripping as well. Make sure to seal the overlaps to prevent heated air and moisture in the growing area from entering the dead 4" insulation air space. Now check all areas where the poles and plastic join the roof for open spaces that will leak air and fill them with adobe mud from the inside and the outside.

Next return to the outside and install the rain gutter at the lower end of the roof so that it will catch all of the run off from the glazing. Make sure that the gutter is lower at the end where the distributions of the water will take place. At the gutter exit install a T-pipe so that water can be directed to the nearest surface drain ditch and/or inside to the barrel water storage/heating/overflow system.



Run a pipe from the T valve inside above the door and over to the first barrel in the corner. Then run additional pipe for overflow from the first to the last barrel and then an exit pipe from the last barrel through the back wall of the Walipini over to the nearest surface drainage ditch. The roofing system is now completed.

Berming and Exterior Drainage

We now berm the exterior walls. *The thicker and higher the berms the more mass and insulation*

we add to the above-ground portion of the structure which will improve its performance. At the same time, however, *we need to maintain a sufficient drop angle on the berm surface for drainage and/or bury plastic in the berm* to accomplish this. In some soils both may be necessary. Regardless of how long the berms are, *plastic should be placed all the way around the perimeter of the building at the top of the wall just under the poles (roof line) so that rain water flows away from the point where the wall and the berm meet*. Berming up to the doors can only go as close as dirt mounds permit unless retaining walls are built, which may or may not be necessary. The doors could also be insulated by attaching foam board to both the inside and outside of the doors, if, once the Walipini is functioning, more heat retention is needed. A *shallow drainage ditch* should be dug around the perimeter of the entire building where the berm reaches ground level. The primary purpose for the ditch is to *collect both exterior and interior excess run off and lead it well away from*
the Walipini.

Venting Systems

The first two venting systems have already been treated. The last two venting systems require additional construction. *The third* simply requires the making of a frame (approximately 4' x 4' x 4" thick in size which will allow the 4' on-center poles to be used for the roof side mounting of the vent roof hinges) covered with plastic sheeting both top and bottom. It should be located in the middle of the roof of the building at its highest point -- against the back wall. Make sure that the plastic on the top of the trap door overlaps the edges of the hole by at least 6 " all the way round for a better water/air seal. This trap door can be opened from below and set at different apertures according to venting needs. *The forth system* requires the building of a chimney with its highest point (not including the rain shield) at a minimum of 2' above the apex of the roof of the structure. Air flow is controlled by a vertical sliding cover at the chimney opening inside of the building and by the two doors.

Completion and Charging

The basic structure of the Walipini is now finished and it is almost ready for planting. Once the Walipini is finished, it should be *rechecked for air leaks* and any found should be properly sealed. Smoke generated inside the Walipini escaping to the outside will indicate where more sealing still needs to be done. Once it is confirmed that the building will seal properly, it should then be left with all doors and/or vents closed so that the *mass can begin to charge with heat*. Once interior temperatures are 45º and above at the coldest part of the night (3:00-4:00 a.m.), the Walipini is ready for planting the first crop. As experience is gained working with the system, learning how to fine-tune and balance the variables of heat, cold, mass, ventilation, humidity, water, drainage, etc., to maximize production will become more and more natural.