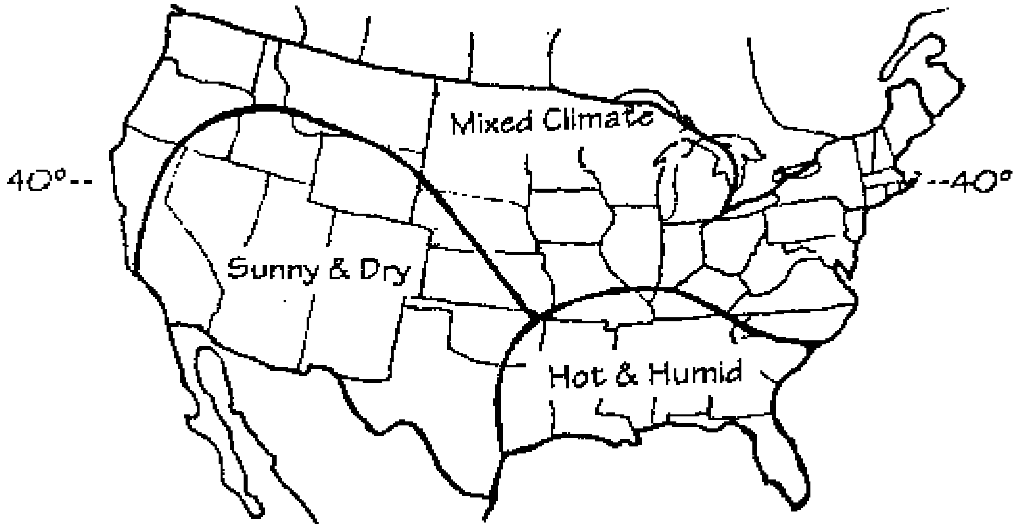
Solar Design

By Stephen Heckeroth **1992**

View from the South/East

Solar energy can provide health and comfort without compromising the quality of life for future generations. Unchecked fossil fuel consumption, however, denies future generations the ability to meet their energy needs and causes life threatening pollution. The concepts and systems in passive solar design are simple and include orientation to the sun and wind, earth coupling to take advantage of the earth's more constant temperature, thermal mass to absorb, store and radiate heat, and an insulating envelope to keep heat in or out.

Naturally heated and cooled buildings do not require any compromise in comfort or architectural aesthetics. The passive solar house pictured above requires no fuel for space heating or cooling. The interior is silently heated by the sun and cooled by prevailing winds. Despite its location on a rugged coastal point in Northern California, a site with over 4,000 heating degree days, the house has maintained indoor temperatures above 65 degrees Fahrenheit, day and night, since its completion in October of 1991. The annual utility costs for the 3,000 square foot luxury home are less than $300. Compared with conventional homes in the same area with up to 10 times the annual energy bill, a solar home can save as much as $750,000 in energy costs over a 30 year period. This solar home is built to last at least 100 years and cost less per square foot to construct than other custom homes in the area. With the installation of a 2 kW photovoltaic array the Point House would be a Zero Energy Home.



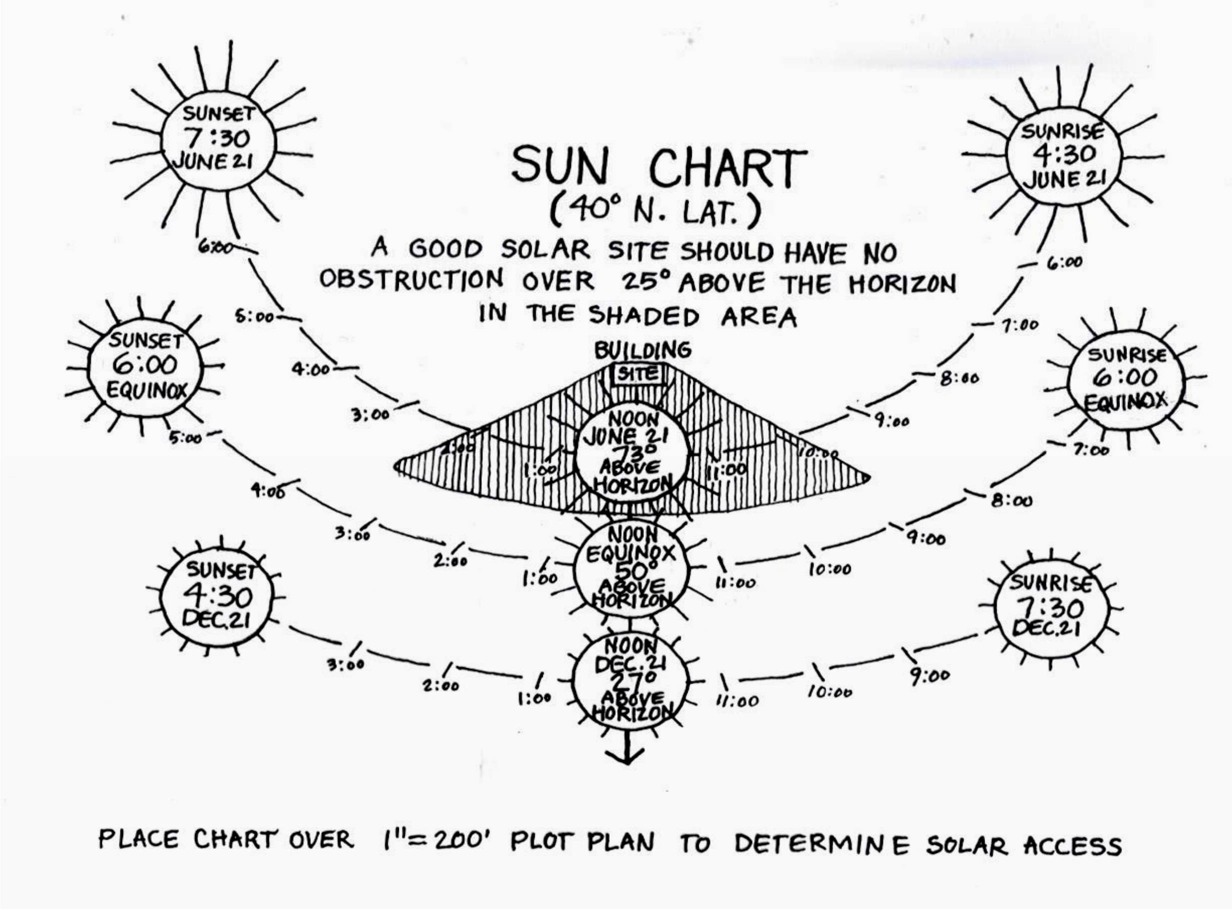
Climate Determinants

Different climates require emphasis on different passive solar systems. In a sunny, dry climate, special attention must be paid to summer shading and ventilation. Also, because underground temperatures tend to approximate the comfort range, earth coupling is very important. Maximizing Roof and overhang area oriented to support solar electric systems and solar water heaters should always be a top priority regardless of climate. In hot and humid areas natural ventilation becomes a main concern. And finally, all passive systems are equally important in areas with mixed climates, with additional emphasis on southern exposure the insulating envelope in colder areas.

Coastal Areas

During the day the land heats up faster than large bodies of water creating a cool moist on-shore breeze in the afternoon. The land cools at night causing off-shore breezes in the morning. The greater the difference between the temperature of the land and water, the stronger the breeze, and the more likely that fog will occur in low lying areas. Small windows on the North West side of building can be counted on to maintain comfortable temperatures on hot afternoons.

View from North



Orientation

Passively heated and cooled buildings rely on the sun, wind and the surrounding earth to maintain comfortable interior temperatures. Knowing how the sun's energy will intercept a building's exposed surfaces throughout the year is the most important consideration in successful passive solar design. For this reason the ideal building site will have both the sun and the view in the same direction. An understanding of local wind patterns enables the designer to shelter the home and also provide ventilation.

A sun chart can he used to determine a site's solar resource throughout the year. Fig. 2 depicts an example of a sun chart that pertains to those sites located near 40 degrees north latitude.

Thermal Mass

Thermal mass within a building regulates interior temperatures. During sunny periods thermal mass absorbs heat and prevents the interior from overheating. At night or during cloudy periods, the heat stored in the mass reradiates into the interior spaces to maintain comfortable temperatures.

Buildings built on a concrete slab with masonry retaining walls will usually have ample mass to use as heat storage. Exterior insulation is added to integrate a foundation's structural function with its ability to store heat.

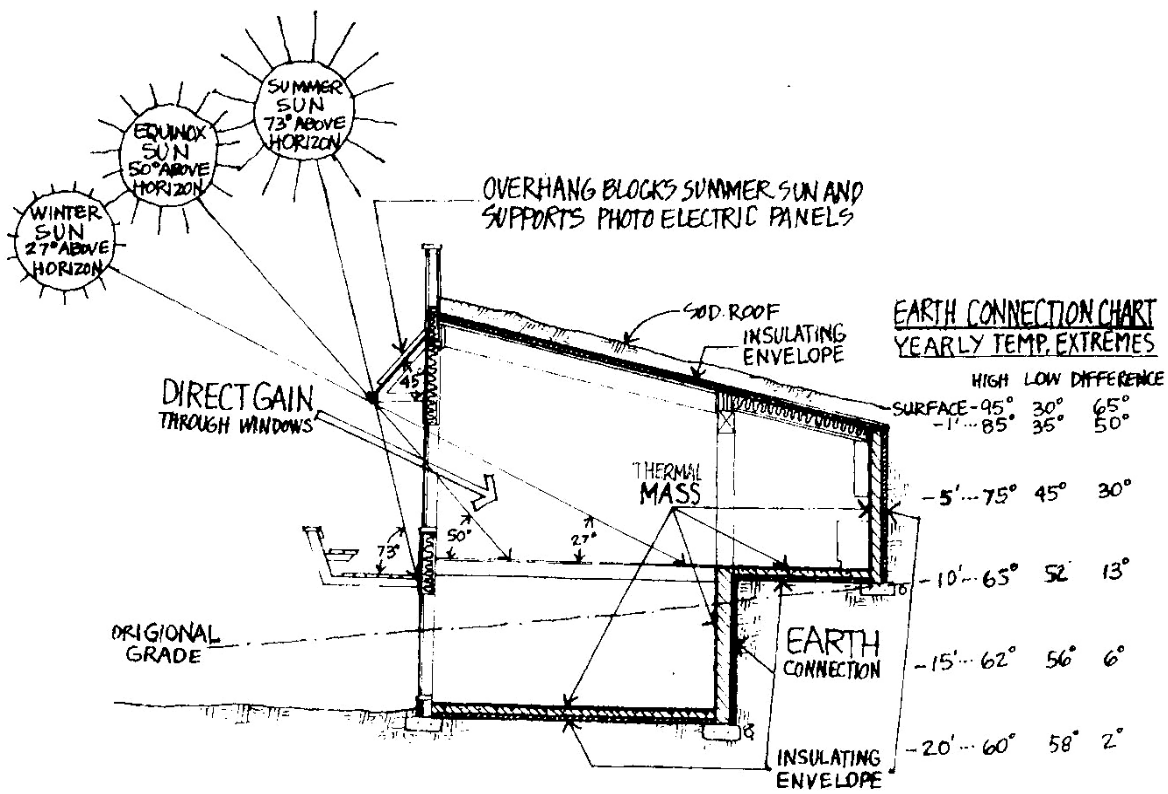
In the Point House there are 100 yards of structural concrete inside the insulating envelope which carries the building through long periods of overcast weather.

SOLAR SPACE HEATING

The basic principle of solar space heating is to maximize the glazing that is perpendicular to the sun's rays. Passive solar design techniques include direct gain, earth coupling, thermal storage wall, sun spaces, convection loops and radiant floors.

Direct Gain

A building benefits from "direct gain" any time solar radiation passes through a window and warms a surface in a living space. Naturally, the more interior mass exposed to the sun the more direct gain is experienced by the building. Fig. 3 refers to the Point House building site which is located near 40 degrees north latitude. At this latitude the sun's highest position above the horizon is 73 degrees at noon in summer and its lowest position above the horizon is 27 degrees at noon in winter.



This information can be used to size an overhang to shade south facing windows in the summer and allow the low winter sun to penetrate deep into the living spaces when heat is needed the most.

For the best passive solar performance, the area of south facing glazing should be equal to between 7 and 12 percent of a building's floor area. Solar gain cannot be controlled by overhangs on the east and west sides and there is very little gain from the north side so glazing area should be minimized on these sides to prevent unwanted heat gain and loss.

The Point House has 12 percent window area on the south and between 2 and 3 percent on the east, west and north sides. In colder climates more East facing window area may be desirable for early morning warm up. In hot climates west facing windows will cause uncomfortable over heating in the afternoon.

Earth Coupling

Earth coupling refers to the percentage of a building's skin that is in contact with the earth. From season to season, air temperatures at a site can fluctuate greatly. Unlike ambient air, the earth maintains relatively constant temperatures throughout the year. The deeper one digs the more constant the temperature. The earth connection chart shows how yearly temperature extremes are affected by excavation depth. Because unwanted heat loss and gain through insulation is proportional to the temperature difference between the interior space and the exterior, insulation efficiency increases with the depth of the earth connection.

Establishing earth connection requires excavation at the site. Care should be taken to separate and protect top soil during excavations, so that this valuable resource can be used to heal the site. Excavated subsoil can be bermed against exterior walls to help deflect prevailing winds, reduce air infiltration and increase the depth of earth coupling.

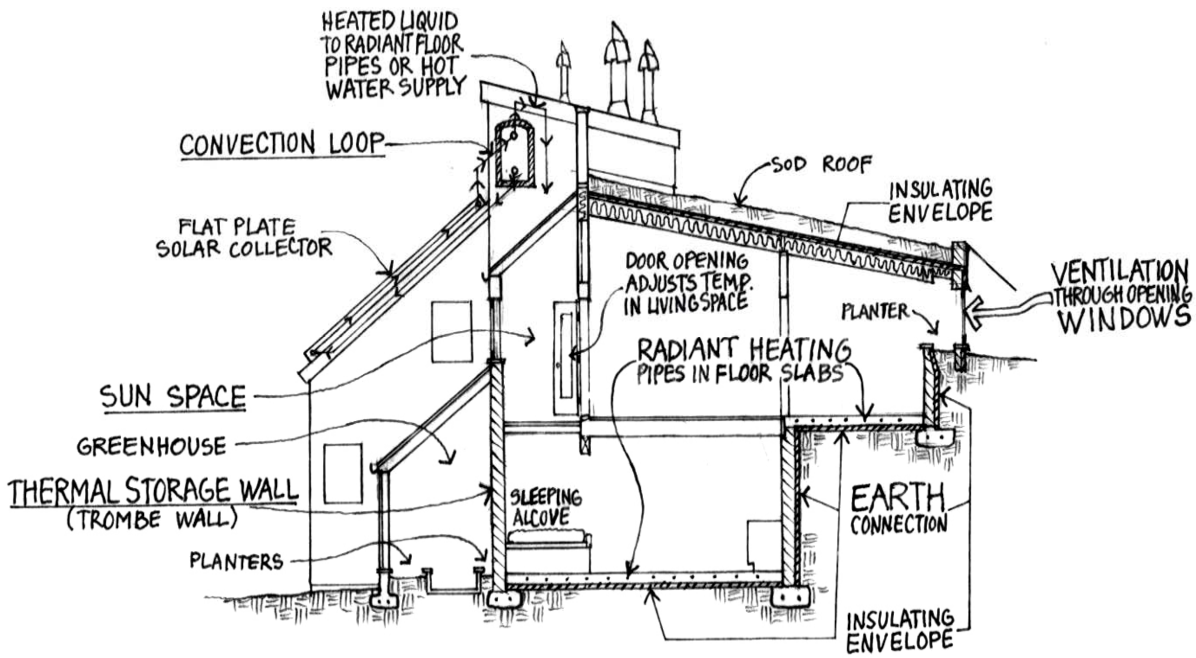
Insulating Envelope

The term "insulating envelope" refers to the ability of a building's skin to hold heat in or out. Passively heated solar homes require that the structural foundation be insulated from the earth. The addition of insulation on the outside of below-grade walls and floors incorporates the structural mass into the house. Consequently heat absorbed by floors and walls is available for space heating and not lost to the surrounding earth.

State Energy Offices can usually recommend the appropriate amount of insulation for a specific area. It is important to keep in mind that R-values apply to only the insulating materials and not to a wall or ceiling taken as a whole. With the addition of plumbing, wiring, electrical boxes, and framing members, the overall R-value for a wall will be significantly lower than that of the insulating materials. To increase a building's resistance to heat flow, the installation of an additional continuous layer of rigid insulation on the outside of the entire building is recommended.

Windows and doors are penetrations into the building envelope and require careful planning to prevent heat loss.

Use of windows with high R-values will minimize heat loss. Main entries of Point House are located on the leeward side of the building and prevent unwanted air infiltration. Exterior doors do not open directly into heated living spaces and the greenhouse serves as an intermediate space which buffers the interior from direct exposure to outside air.



Thermal Storage Walls

Thermal storage walls are typically dark masonry walls positioned between exterior glazing and the living space. These walls absorb the sun's heat during the day and radiate heat to the living spaces during the evening when it is cooler. As shown in Fig. 4, the north wall of the greenhouse is a thermal storage wall. The heat absorbed during the day is radiated into sleeping alcoves on the other side of the wall at night. Thermal storage walls occupy little space and are particularly effective in the winter when low sun angles strike them most directly.

Sun Spaces

Sun Spaces are glass rooms built onto the south side of a building to collect heat. These rooms are thermally isolated from the rest of the building so that their interiors heat quickly. Hot air from sun spaces is released directly to the building's interior by means of windows, doors, or vents. The bedroom wing of Point House is angled 30 degrees to the east. The bedrooms have sun-spaces to speed early morning warm up. The attached Greenhouse Entry is a sun space that also provides a good environment for gardening.

Convection Loops or Thermalsiphon Systems

A convection loop uses the sun's energy to move heated air or water without mechanical systems. As the suns energy heats air or fluid it rises naturally and the rising molecules are replaced by surrounding cooler air or fluid. This process can used to create more comfortable temperatures in a building or to heat water for domestic use or fluid for home heating needs. A typical installation includes a flat plate collector ideally oriented due south and perpendicular to the sun's equinox angle or to favor the winter sun collectors should be angled 10° to 15° more than the latitude of the site (40° -55° for the Point House site) and a tank mounted at least two feet above the top of the collector. When the liquid is heated in the thermal collectors it rises into the top of the tank and cooler, heavier liquid from the bottom of the tank siphons into the bottom of collector where it is heated. This passive circulation or thermo siphon is nature's free pump. Thermolsiphon solar water heating system must be protected in areas freezing temperatures could rupture pipes.

The Point House a convection loop is used to heat the domestic hot water and a glycol solution, which is then pumped through pipes in the floor slab. The pump is a small active component in an otherwise passive system.

Radiant Floors

Installing pipes in the floor slab puts heat where it does the most good. Because heat rises, a floor is the ideal place for heat storage. This system of floor heat, called radiant heat, can be installed in conjunction with a back-up boiler fired by wood or gas to maintain comfort during extended overcast periods.

In the Point House radiant heating pipes were installed in all floor slabs. A wood fired water heater was installed as a back-up but has rarely been used.

PASSIVE COOLING

The main strategies for passive cooling are; deflecting the sun's hot summer rays, and providing operable windows to channel the prevailing summer winds through the building.

Shading

Controlling solar radiation is the least costly and most effective means of passive cooling. By knowing the sun's angle above the horizon at noon, overhangs can be designed to totally shade south facing windows during the cooling season. West facing windows should be minimized in cooling climates to eliminate the hot afternoon sun. Fig. 3 shows how overhangs work at the Point House.

Ventilation

Knowing the direction of the prevailing winds is as important to cooling as the direction of the sun is to heating. Small opening windows should be located on the side of the building that receives afternoon breezes. High opening windows should be located on the opposite side to create cross ventilation and allow hot rising air to escape. In very hot climates night ventilation can be used to draw heat from the thermal mass. Then the cooled mass will act as a heat sink during the day.

Vegetation

Trees can be used as wind breaks in cold climates or shade on the west side in warm climates. Deciduous trees and vines can be used in mixed climates for shade in the summer and allow the sun to shine through the winter.

SUMMARY

Planning for the integration of the ideas outlined in this solar design manual will make it possible to reduce dependency on finite energy sources. New solar technologies, materials, and access laws can help create a built environment that will make a sustainable lifestyle accessible to everyone.

Sustainable Aesthetics

Aesthetics based on the enduring laws of nature prevail over those based on the fads and whims of people. The fate of life on the planet depends on pacing human consumption with nature's production.

Climate Determinants

Different climates require emphasis on different passive solar systems. In a sunny, dry climate, special attention must be paid to summer shading and ventilation. Also, because underground temperatures tend to approximate the comfort range, earth coupling is very important. Maximizing Roof and overhang area oriented to support solar electric systems and solar water heaters should always be a top priority regardless of climate. In hot and humid areas natural ventilation becomes a main concern. And finally, all passive systems are equally important in areas with mixed climates (hot summers and cold winters), with additional emphasis on southern exposure the insulating envelope in colder areas.

Solar Access

Solar access should be the primary concern in the schools where land use planning is taught and in the government agencies charged with guiding development. The idea of keeping the shadow cast by any development within the boundaries of the property on which the development takes place must assume at least as much importance as providing enough parking spaces. In addition, steep north slopes that do not receive any sun in the winter must be eliminated as building sites. As the cost of BIPV drops the only requirement for energy independence will be solar access.

Energy Efficiency

A good insulating envelope and the most energy efficient appliances and lighting are a prerequisite for the rest of the solar design strategies. Double glazed windows provide twice the R-value of single glazed units. New types of glazing with thin film suspended between the layers of glass can have R-values more than four times that of single glazed windows and filling the space between the layers of glass with argon gas can, again double the R-value.

Small is Beautiful

The true cost of a buildings size and energy use are measured in the diminished health of all who are living and are yet to be born. Good functional design can maximize comfort and minimize size. The Point House may seem excessively large until it is understood that it is designed for an extended family with places for 17 people to sleep.

Build Permanently

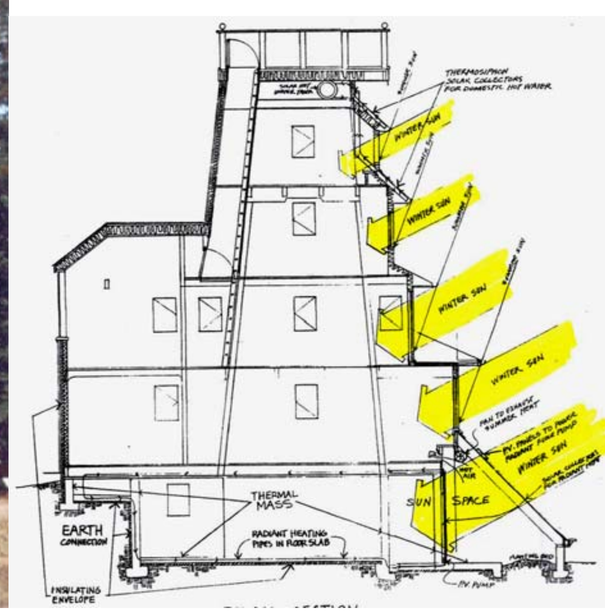
Use durable materials. The amount of energy used in construction should be balanced with the useful life of the building.

Use Recycled and Local Materials

Using recycled materials saves the energy and environmental costs of extraction and disposal and much of the cost of transportation, refining and milling. The use of local materials also requires less energy consumption both in their manufacture and distribution. Redwood timber savaged from the local mill were used as beams and resawn for trim around all doors and windows in Point House. During the excavation clay, sand, gravel and top soil were carefully separated and stored on site. The clay was used to berm the north and west wall, the sand was used as fill to level under the concrete slabs, the gravel was used on the driveway, and the top soil was put back on top of the berm and reseeded with native vegetation.

On Site Power Generation

Building Integrated Photovoltaics (BIPV) mounted on a south facing roof can usually provide enough power to satisfy all the electrical needs for an energy efficient building. Proper orientation to the sun is essential for effective performance. The overhangs at Point House have been designed to support a properly oriented PV array capable of satisfying the power needs for the house and to charge the batteries in a neighborhood electric vehicle.



A five story tower house with solar access in every room and a hot tub on the roof

Review of Solar Design Strategies

1. Orientation
To maximize solar exposure and protect from prevailing wind
2. Direct Gain
Through glass to trap heat in dark massive materials
3. Thermal Mass and Storage Walls
To act as a thermal flywheel to maintain more constant temperatures
4. Shading and Overhangs
To shade in the summer but not in the winter
5. Sun Spaces
To capture solar energy when needed and vent it when it is not
6. Daylighting
Insulated transparent panels & light shelves, eliminate daytime lights
7. Earth Connection
To take advantage of the earth's more constant temperature
8. Convection or Thermal-Siphon Loops
To naturally circulate air and liquids
9. Insulating Envelope
To hold heat in winter and exclude heat in summer
10. Wind Breaks and Berms
To channel cold weather around or over buildings
11. Deciduous Vegetation
To shade in summer and let in heat in winter
12. Building Integrated Photovoltaics
To provide on-site power for essential loads

Guidelines for Sustainable Living

Guiding Principles
- Sequester toxins.
- Maintain or improve the quality of essential resources (air, water and soil).
- Use resources equitably and efficiently.

Site Selection and Planning
- Pick a location close to employment, schools, housing, arable land and desired services.
- Pick a site with good solar access and water supply out of the flood plain.
- Minimize building coverage and soil compaction. Consider sod roofs and green pavers.

Building Design

- Build small and efficiently. (Every square foot of building has an environmental cost.)
- Minimize exterior surface area to maximize the efficient use of energy and building materials.
- Maximize south facing solar collection area. South facing glass should be 7% to 10% of the floor area. It should be fully shaded from the summer sun and fully exposed to the winter sun.
- Provide 10 to 40 square feet of south facing solar thermal collector area per person for domestic hot water and 10% of the floor area for south facing collectors for radiant space heating.
- Provide room for 1 kW of PV per person or 1 kW / 1000 $ft.^2$ of floor area, whichever is greater.
- Minimize north facing glazing to reduce heat loss.
- Minimize west facing glazing to prevent afternoon overheating.
- Allow 4% to 6% of the floor area to be east facing glazing for morning warm up.
- Insulation should be as seamless as possible and have equal or higher value than the code suggests, and should extend below grade in cold climates.
- Include structural mass inside the insulating envelope in creating links to the Earths constant temperature to moderate internal temperatures.
- Use the prevailing wind and operable windows to provide ventilation.
- Incorporate day lighting to reduce the need for electric lighting.
- Use energy efficient lights and appliances.

Building Materials and Construction

- Use materials with low embodied energy. (Use local materials to reduce energy spent in transportation and use materials that require minimal energy in their manufacture.)
- Use non-toxic materials.
- Use recycled or sustainably harvested materials.
- Use durable materials.

Water and Waste

- Conserve water. (Install low flush or compost toilets and low-flow showerheads.)
- Catch roof runoff to augment water supply and reduce erosion.
- Create wetlands for waste water treatment and use gray water on non-edible plants.
- Recycle and compost.

Permaculture

- Plant an edible landscape that can thrive with minimal care and watering.
- Encourage non-invasive diversity of flora and fauna.
- Plant deciduous vegetation to shade west facing windows