ART 2640, Building Systems of Interior Environments

Fall Semester 2020

Tuesdays & Thursdays 10:30-11:50

Online

Matthew Ziff, Associate Professor, Area Chair

M. Arch, Architect, NCIDQ

E-mail: ziff@ohio.edu

Heating and Cooling Buildings: Sun, Wind, Earth

Design with the Sun:
Solar Design

How much energy comes from the Sun?

- The sun provides about **1000 watts per square meter** at the Earth's surface in direct sunlight (this reference intensity is often called "one sun" by solar energy scientists).

- This is enough power to power ten 100 watt light bulbs, or 50 twenty watt compact fluorescent light bulbs!

Solar Power:
Capturing sunlight for:

- **Photovoltaics** (solar electricity),
- **Passive Solar Design** (solar heating, natural cooling, and can incorporate hot water systems very nicely)
- **Active solar thermal** (Solar Hot Water/Air collectors)
- **Solar thermal electricity** (large and small scale electricity generation from solar heat)
- **Solar cooking**
- **Solar distillation**
- **Solar water pumping**

Renewable energy sources include:

- **Solar energy**

- **Hydropower** - Channeling falling water to drive turbines (generators) to generate electricity. This is renewable because the Earth's hydrological cycle, *which is driven by the Sun*, continuously replenishes lakes and rivers through rain. Hydropower is an *indirect* form of solar power.

- **Wind Power** - Using the wind to turn propellers connected to turbines.

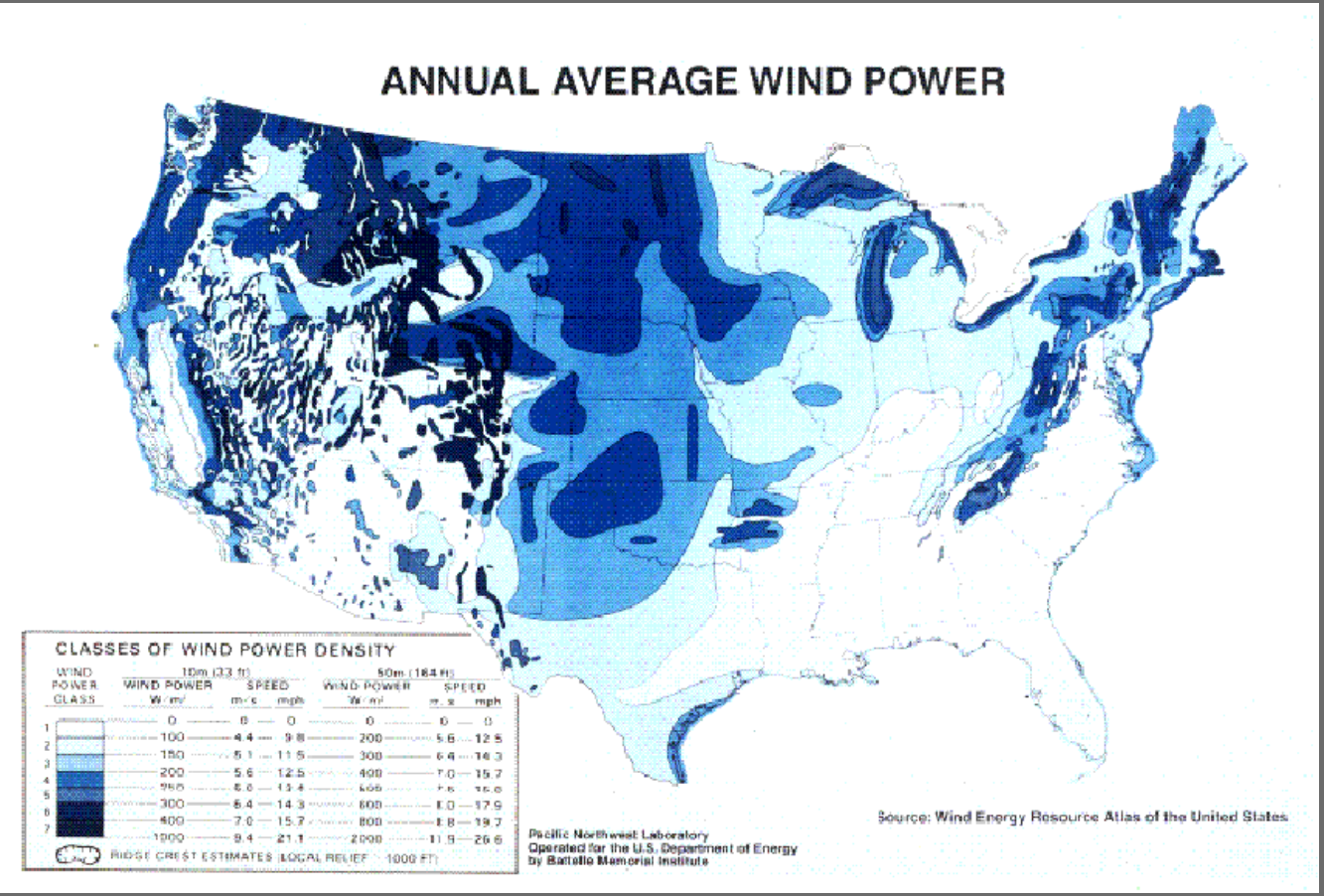
- Wind power is considered renewable because the Sun and the Earth's rotation are always generating more winds.

- Wind power, like hydropower, is really another form of *indirect* solar power.

How Wind Turbines Work

- The wind power resource of the United States, like its solar power resource, is huge.
- The dark blue areas in the map below show the areas where "class 6" winds exist.
- Wind power is presently the fastest growing energy source in the world!

Wind can be used to make electricity



Windmills


ontario place
2003
Season Pass
Only $49
ontario place

Using Solar energy

- in the design of architectural environments there are two broad ways of using the sun's energy:

- *Passive solar design*
- *Active solar design*

- Passive solar design means that the sun's energy is being used, or controlled, through the physical makeup of the spaces.

- Active solar design means that some type of mechanical system is collecting, transforming, or moving the energy of the sun in the interior environment.

Natural Bridges National Monument, Utah
Active Solar: photo voltaic panels

- The Natural Bridges PV System was dedicated in June 1980.
- Before switching to PV power, the Monument consumed up to 200,000 kilowatt hours of electricity annually.
- With installation of the PV system and the implementation of energy-efficient measures, the Monument now consumes about 70,000 kWh annually with over 90 percent of that coming from the sun.

Active solar:
rooftop photo voltaic 'shingles'

PV = photo voltaic

- The PV shingle shown here won Popular Science Magazine's grand award for What's new in Environmental Technology.

- The rooftop array of PV roof shingles was developed by United Solar Systems and Energy Conversion Devices under the DOE PV:BONUS program.

PV = photo voltaic

- The PV shingles installed on this residential-type building replace common roofing shingles.
- The PV shingles look much like ordinary roofing shingles, but they generate electricity.
- The PV shingles cover the inner portion of the lower roof section.

PV shingles

- They were laid out and nailed to the roof using the same methods as are used to lay conventional shingles.

- Like their non-PV counterparts, these shingles overlap providing for water shedding capability.

PV shingles

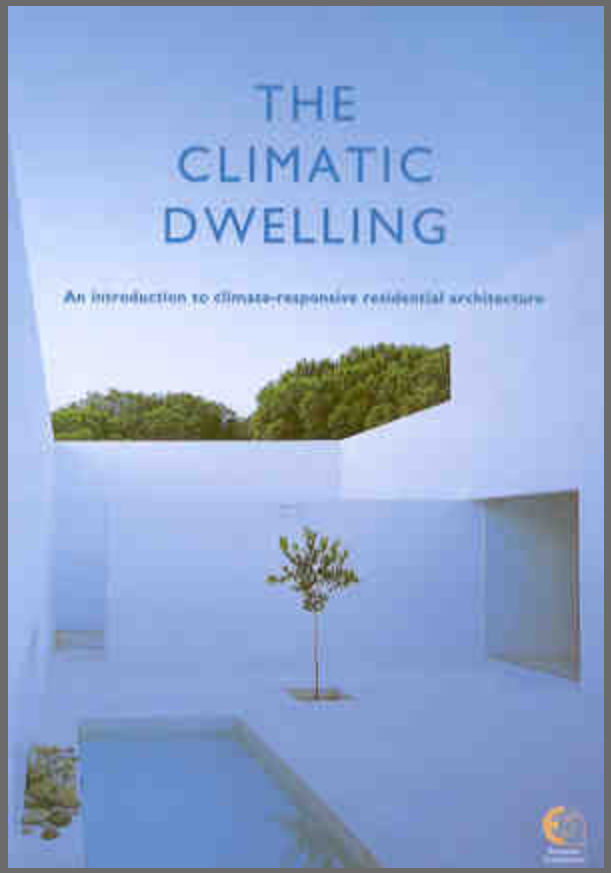
- The modules are multi-junction amorphous silicon (a-Si) PV.
- The a-Si is deposited on a thin, flexible, and lightweight stainless steel substrate and laminated in a polymer.
- The modules are approximately
  0.3 m x 3 m (1 foot x 10 feet).

This PV curtain wall incorporates solar cells into a window mullion

Building-Integrated panels

Outdoor Test Facility at NREL (National Renewable Energy Laboratory), Golden, Colorado

design with climate
(not against it)



Passive Solar Heating

Where the sun shines impacts the effectiveness of solar design.

The three principles of passive solar design are:

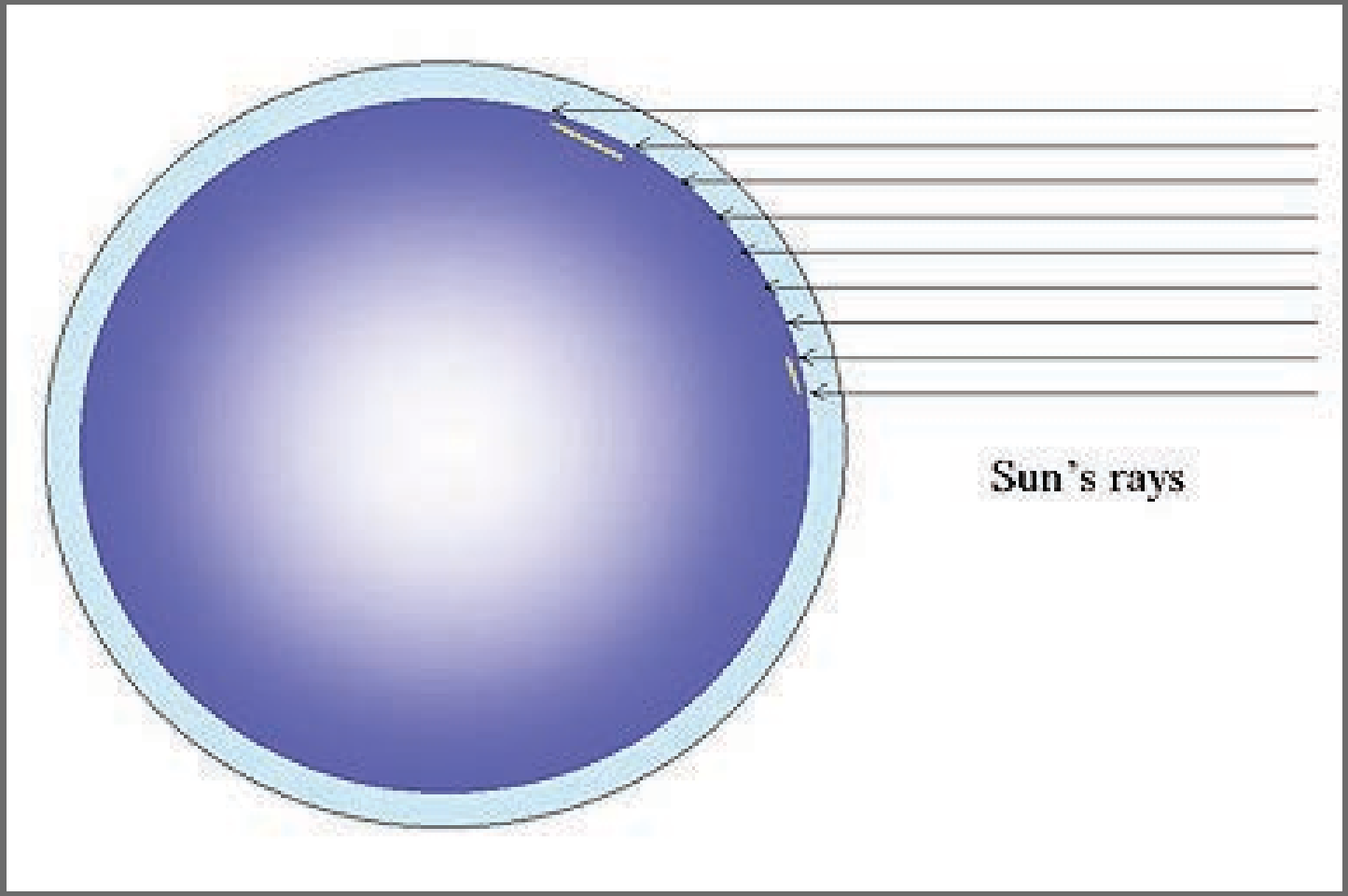
- **Gain:** Getting enough sunlight in at the right time (and blocking it at the right time as well).

- **Thermal Mass:** Having enough thick masonry surfaces to store the energy from sunlight to keep the home warm at night, and from overheating during the day.

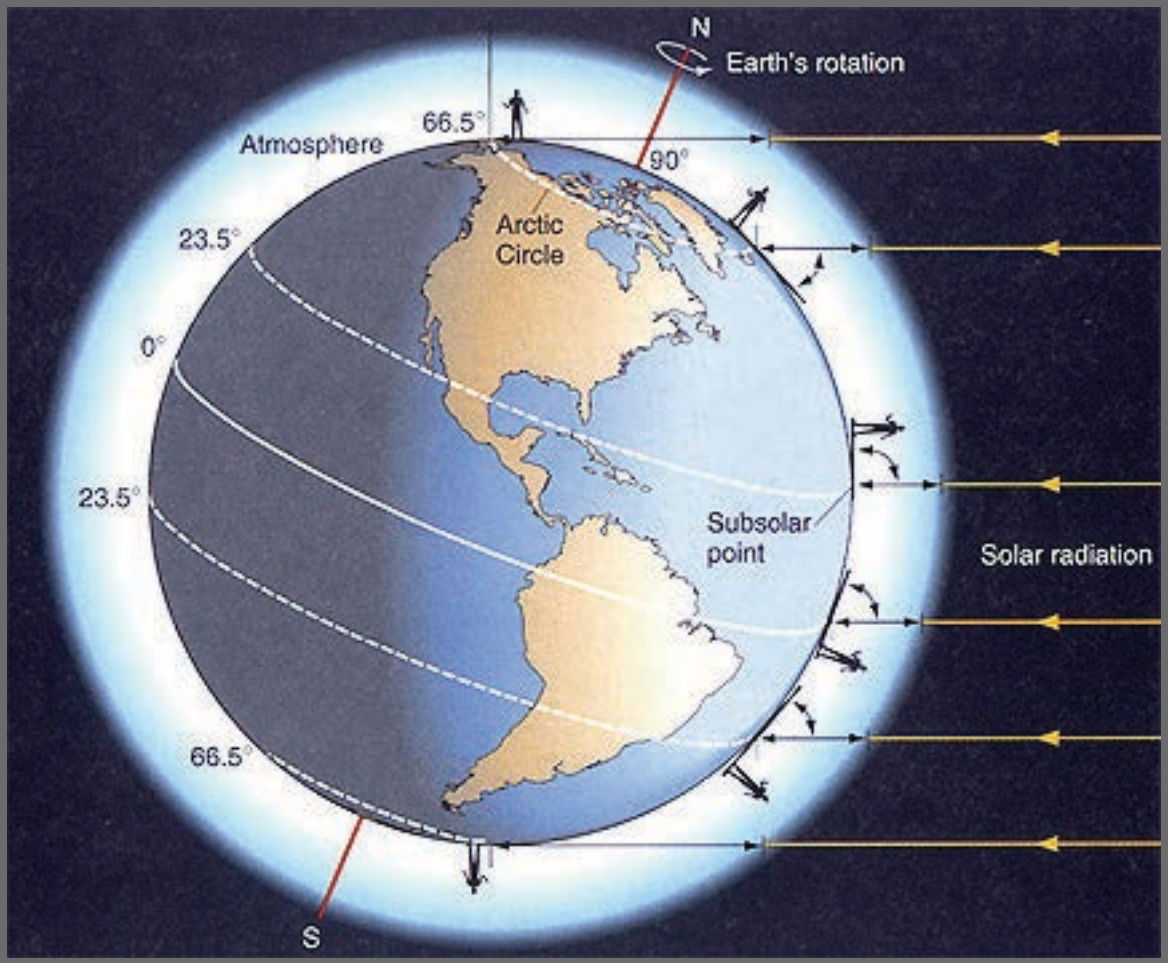
- **Insulation:** Having good insulation (and low air leakage) to keep the heat in during the winter, and heat out during the summer.

What causes winter & summer?

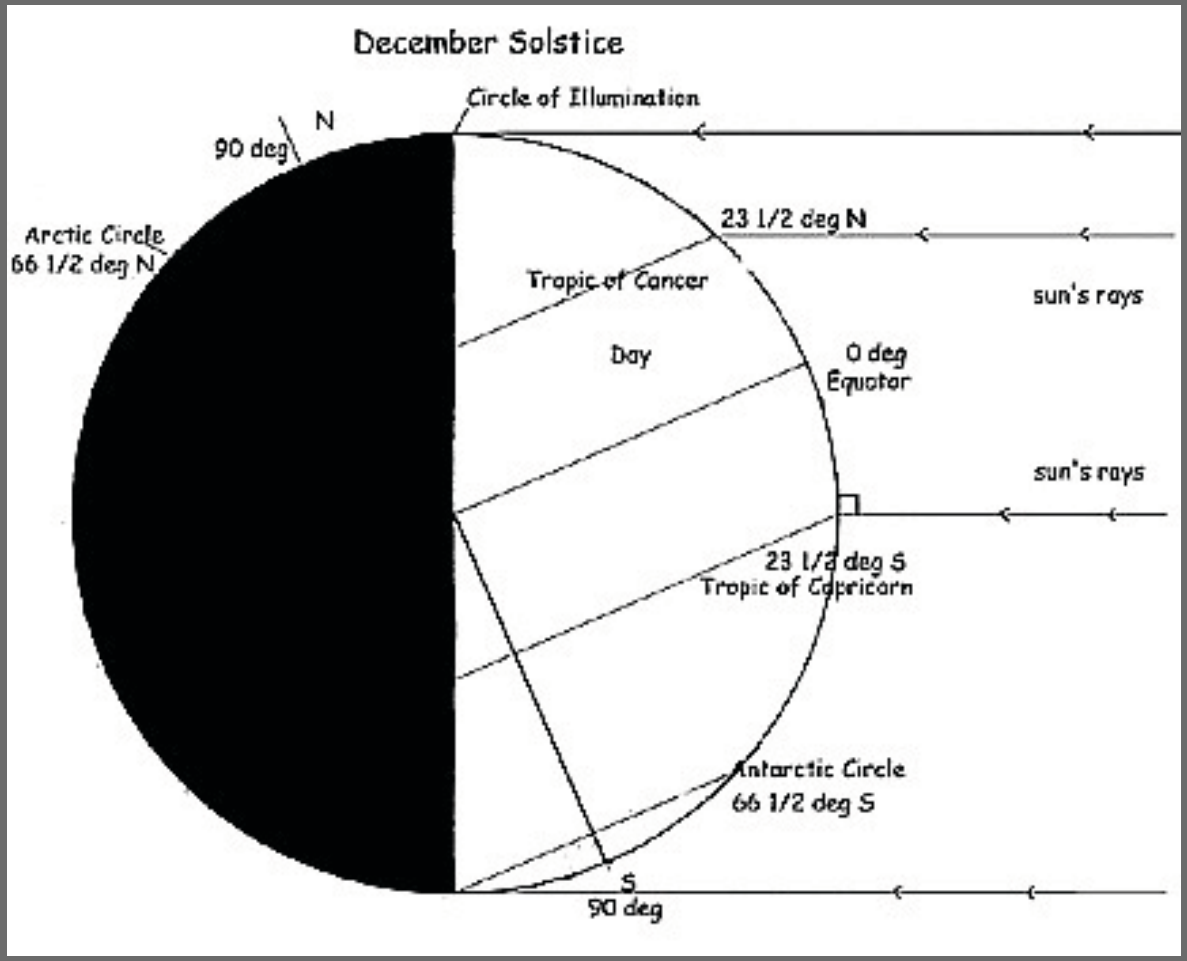
The relationship of sunlight to the earth's atmosphere.



North America tilting 23.5 degrees toward the sun = summer for North America (and winter for Australia)



North America tilting 23.5 degrees away from the sun = winter for North America (and summer for Australia)



The Earth makes a complete revolution around the sun once every 365 days, with an orbit that is elliptical in shape.

Explanation of Cause of Seasons

- This means that the distance between the Earth and Sun, which is 93 million miles on average, varies throughout the year.
- During the first week in January, the Earth is about 1.6 million miles closer to the sun. This is referred to as the perihelion.
- The aphelion, or the point at which the Earth is about 1.6 million miles farther away from the sun, occurs during the first week in July.
- This fact may sound counter to what we know about seasons in the Northern Hemisphere, but actually the difference is not significant in terms of climate and is NOT the reason why we have seasons. **Seasons are caused by the fact that the Earth is tilted on its axis by 23.5°.**

Explanation of Earth's Life Cycles (a 3 minute, excellent, video)

What does a passive solar house look like? Anything from this…

to this…

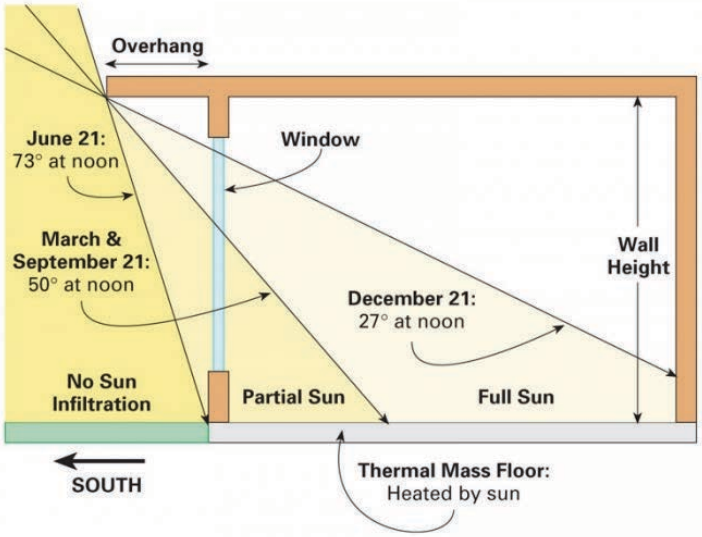
to this..

to this..

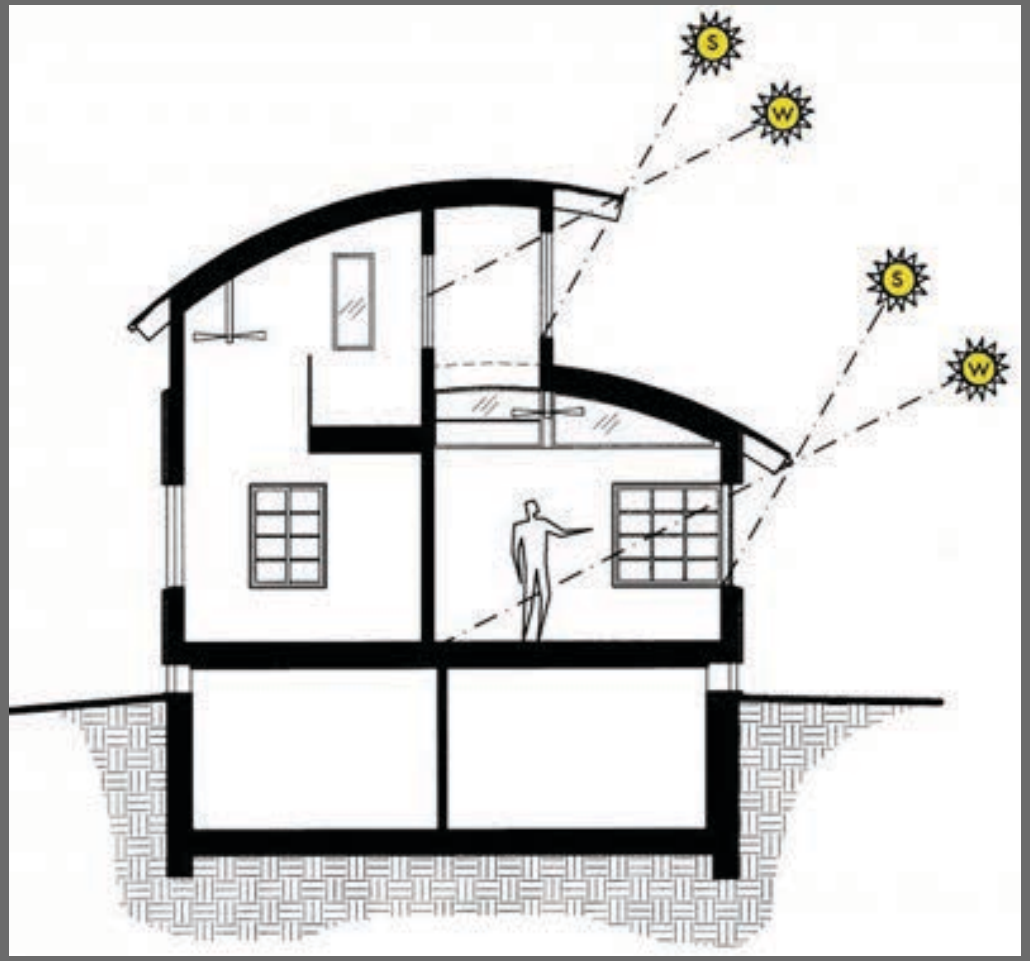
A more modest, lower cost, house, employing a rainwater collection cistern

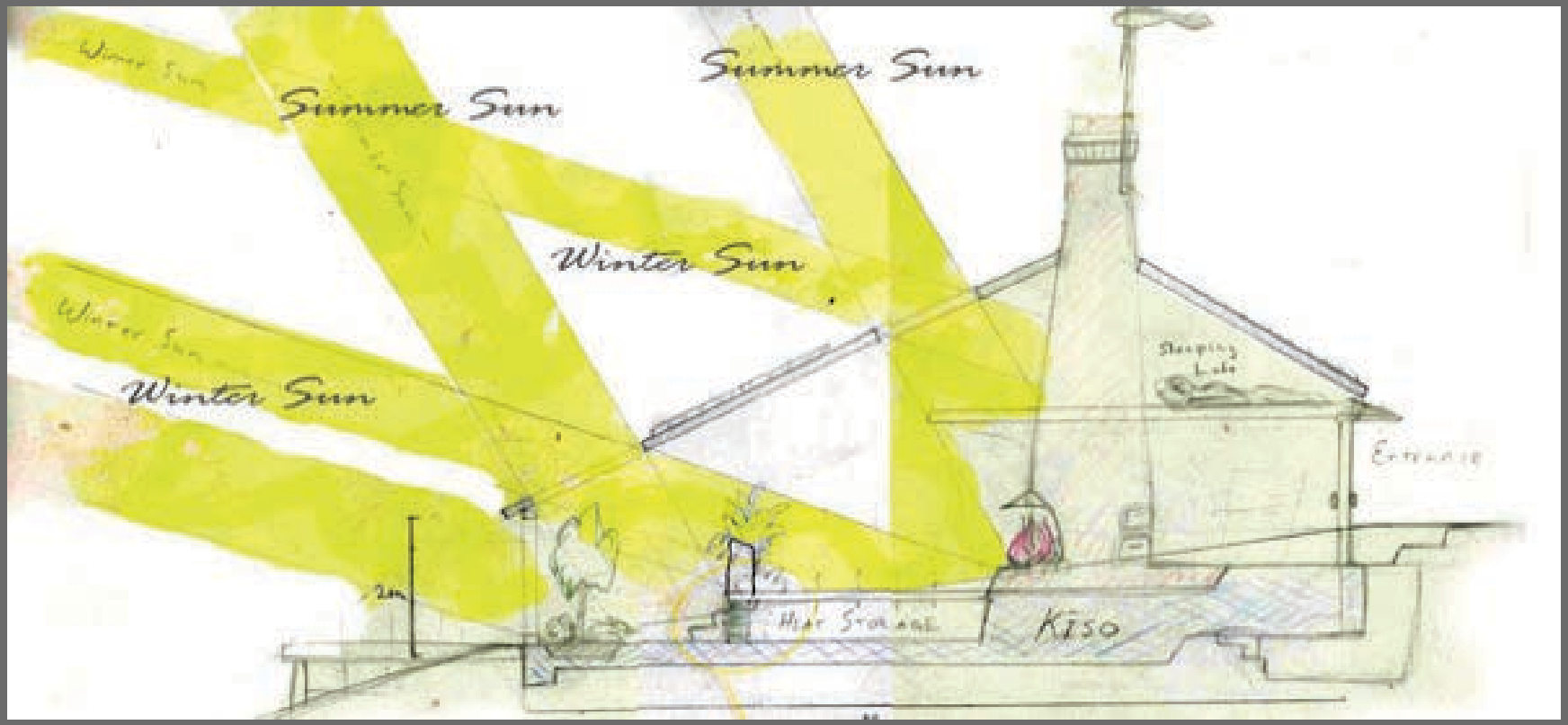
Rainwater flows off the roof, into the cistern

Roof Overhang for 40° North Latitude



Controlling where sunlight goes in a building is the essence of passive solar design.




Summer Sun
Summer Sun
Winter Sun
Winter Sun
Winter Sun
Sleeping Loft
Heat Storage
Kitchen

Passive solar heating uses the free energy from sunlight to warm the home.

- South facing windows allow maximum sunlight to enter and heat the house, while the well insulated structure lowers energy costs by retaining heat in the evenings and maintaining a comfortable interior temperature in both hot and cold weather.

- Interior stone walls and floors provide mass to absorb warmth during the day and then release-radiate that heat to warm the rooms at night.

- To prevent over heating in the summer, the outdoor verandas will be covered with deciduous trees that provide shade in summer and lose their leaves in winter to allow sunlight to enter and heat the home.

Orientation, Shading, Insulation, Thermal Mass, Windows, Ventilation

Characteristics of a Passive Solar Building

- In the northern hemisphere most of its windows are facing the south .
- Ideally, the interior surfaces that the light strikes are high density materials, such as concrete, brick, or stone.
- West windows are a source of high heat gain during the summer, and should be shaded. Generally, a plan with a long east-west axis and optimized south-facing wall will be the best passive solar design.

Passive Solar Design

- Passive solar buildings often have "open floor plans" to facilitate the movement of heat from the south side through the rest of the spaces.
-
- Sometimes small fans are used to aid in warm air distribution in spaces with "closed floor plans".

Passive Solar Techniques
1: Direct Gain

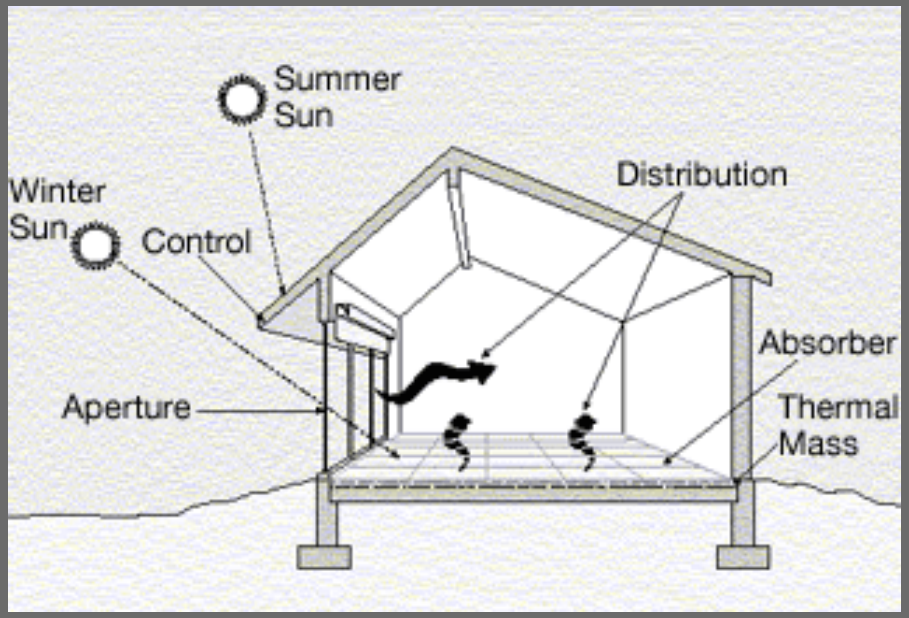
- There are two basic ways passive solar spaces gain solar energy, direct and indirect gain.

- Direct gain spaces, considered to be the simplest type, rely on south-facing windows, called solar windows.

- These can be conventionally manufactured operable or fixed windows on the south wall of the spaces.

Direct Gain

Solar energy, (sun light) strikes the surfaces of the space and warms those surfaces.



- While some of the heat is used immediately, walls, floors, ceilings, and furniture store the excess heat, which radiates into the space throughout the day and night.

- In all cases the performance and comfort of the direct gain space will increase if the thermal mass (concrete, concrete block, brick, or adobe) within the space is increased.

Passive Solar Techniques
2: Indirect Gain

- The second passive solar house type, indirect gain, collects and stores energy in one part of the house and uses natural heat movement to warm the rest of the house.

- One of the more ingenious indirect gain designs employs the thermal storage wall, or Trombe wall placed three or four inches inside an expanse of south facing glass.

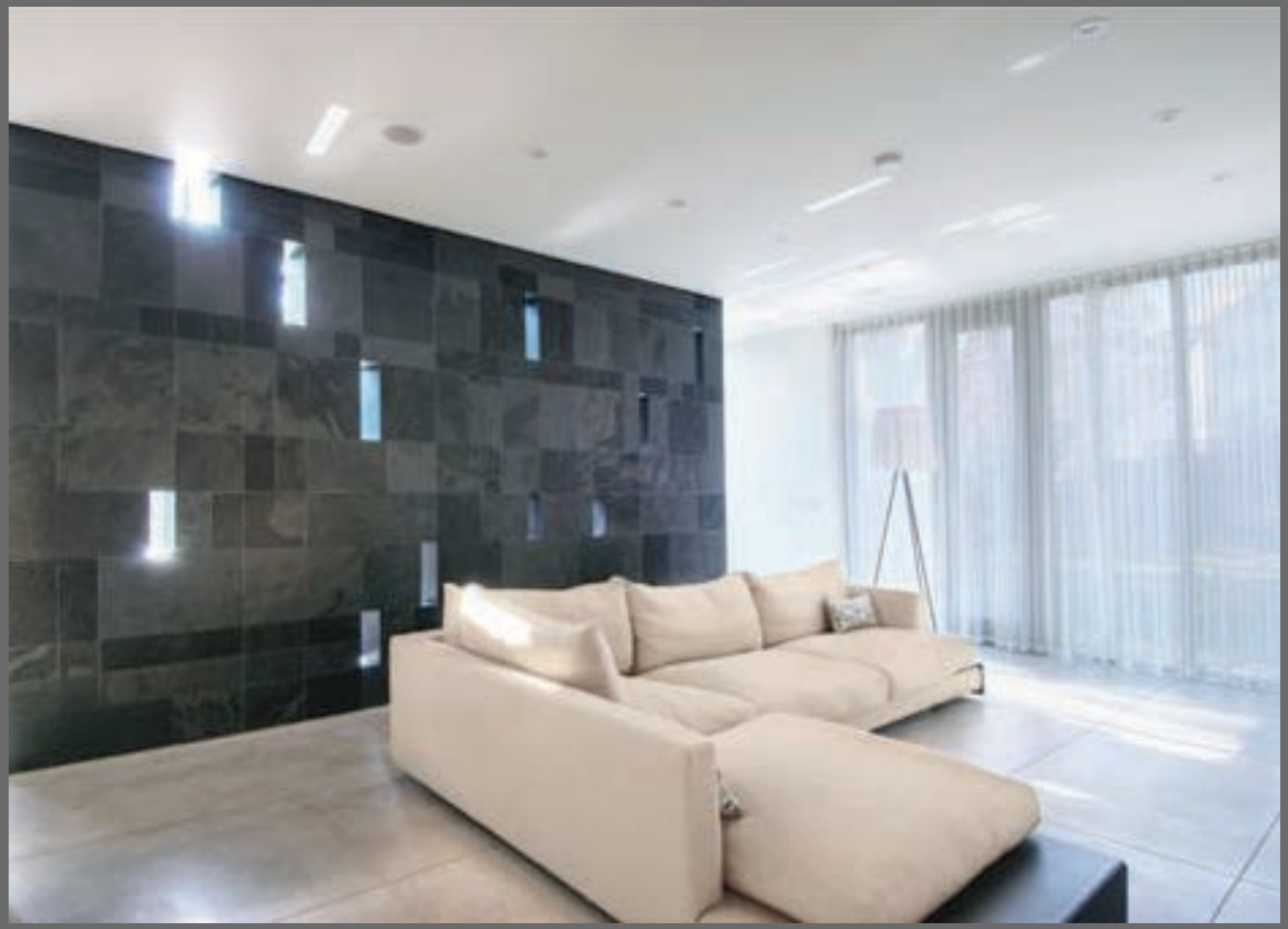
Trombe wall

- Named after its French inventor, Felix Trombe.

- The wall is constructed of high density materials--masonry, stone, brick, adobe, or water-filled containers--and is painted a dark color (like black, deep red, brown, purple or green) to more efficiently absorb the solar radiation.

A Trombe wall can look like this..

(it’s the black granite wall with small openings)



behind the large glass wall

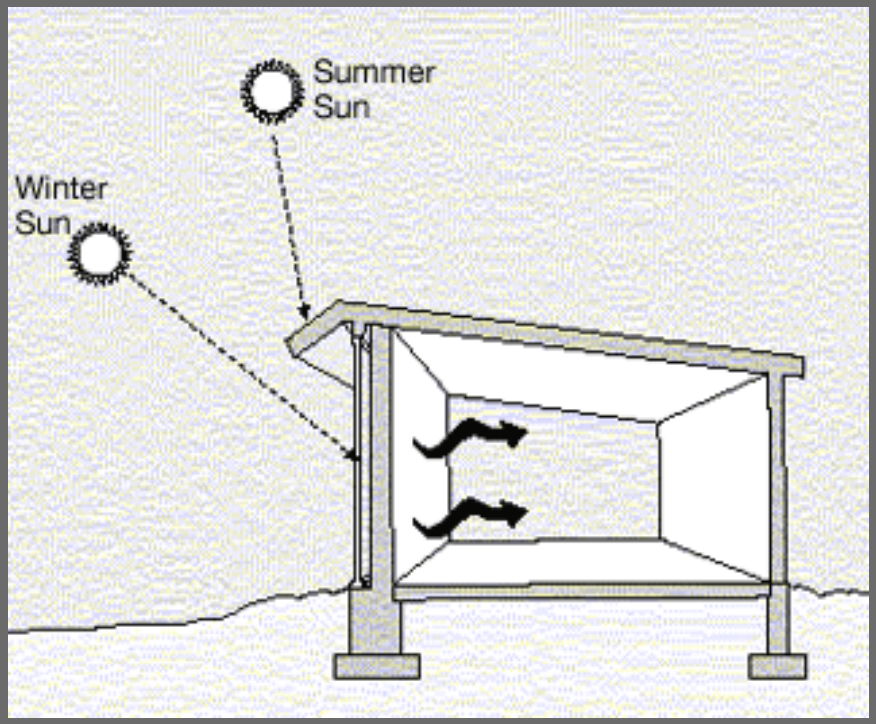
Or this…
a wire cage with stones inside

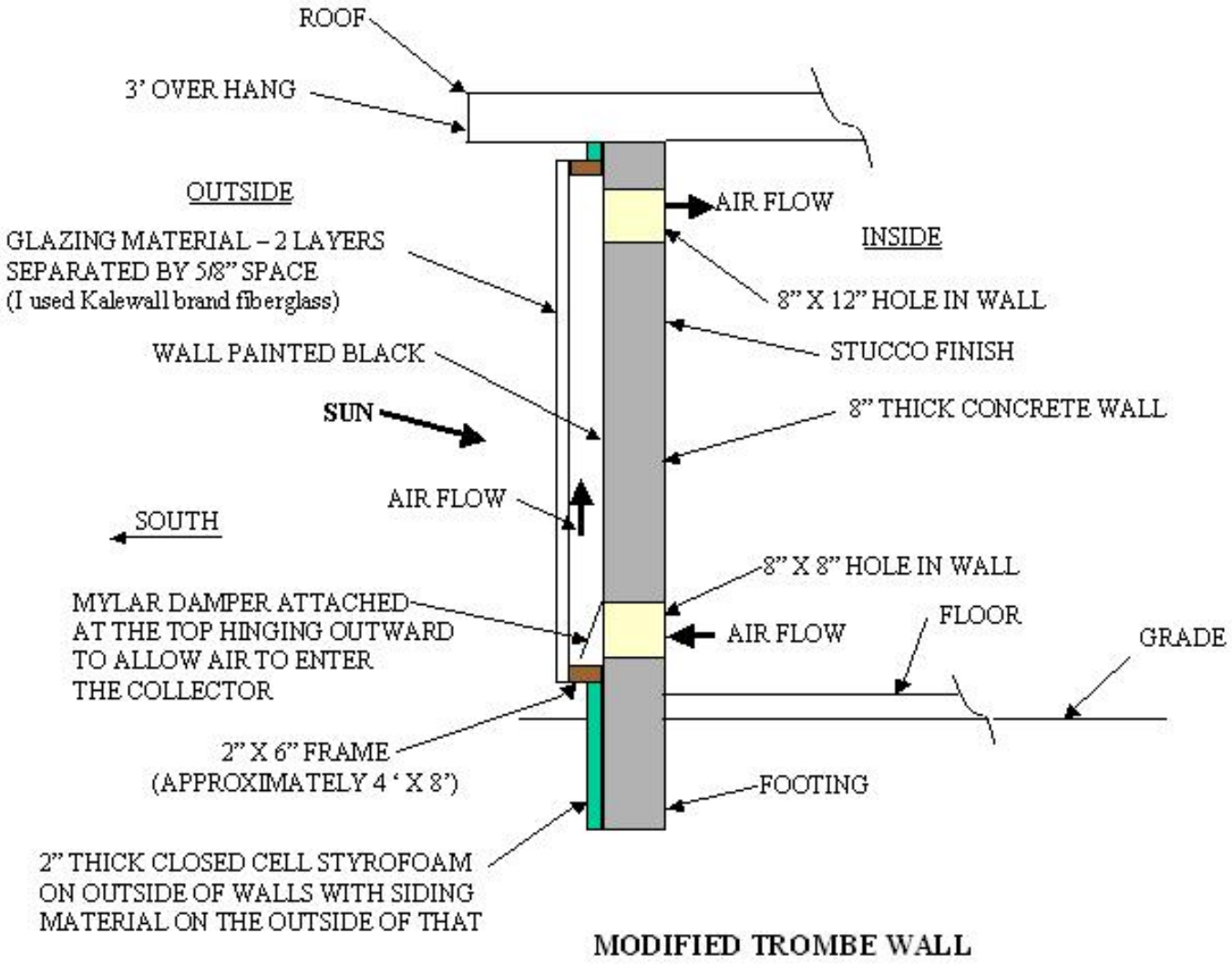
to this..
a brick wall behind obscure glass windows

Trombe wall

The solid wall is placed between south facing windows and living spaces. The wall absorbs solar heat through radiation, stores it, and then releases it into the space when the indoor temperature falls

below that of the wall's surface.





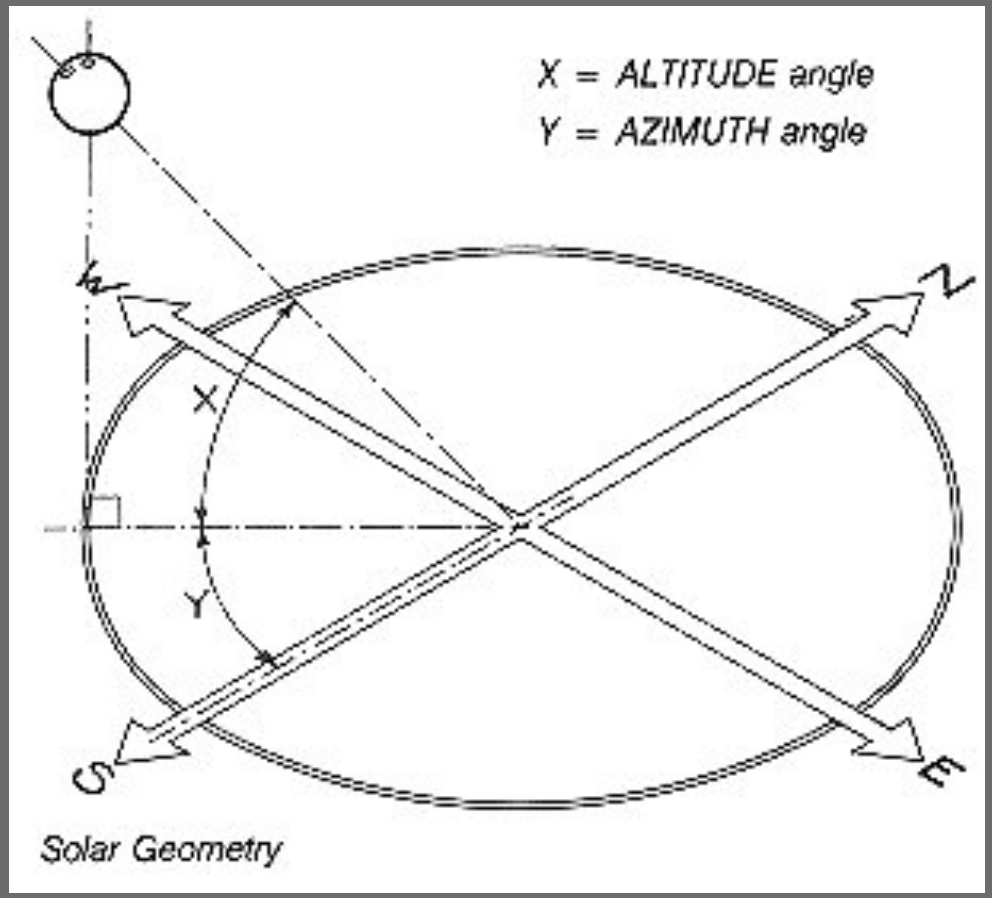
MODIFIED TROMBE WALL

Passive Solar Preliminary Design Rules of Thumb

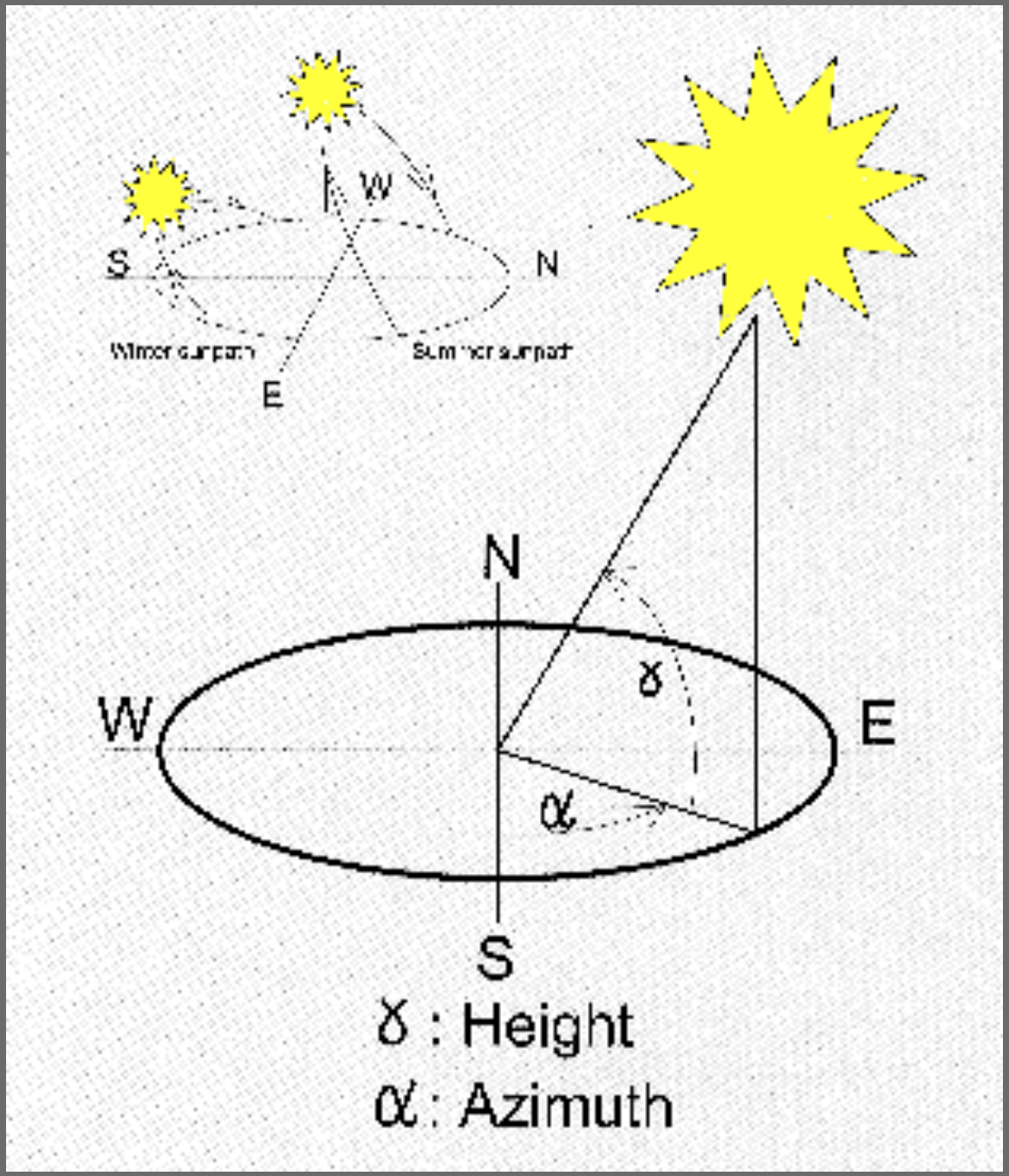
- The longest wall of the building should ideally be facing due (solar) south to receive the maximum winter and minimum summer heat gains.

- However, the south wall can be as much as 30 degrees east or west of solar south with only a 15% decrease in efficiency from the optimum

the location of the sun (relative to us) is described in terms of its altitude, and azimuth



Solar Geometry


W
S
N
E
N
W
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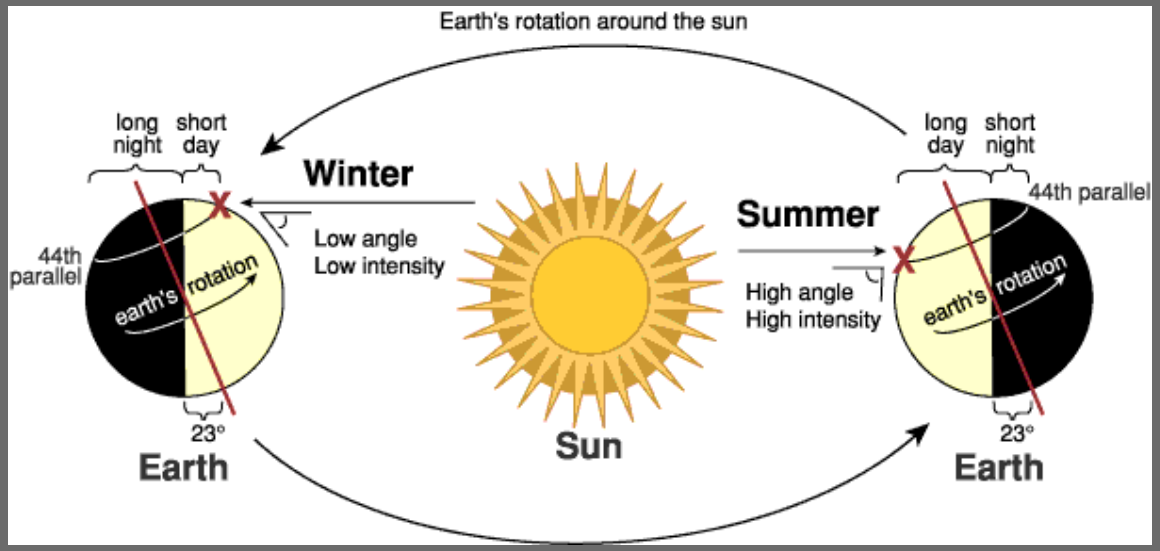
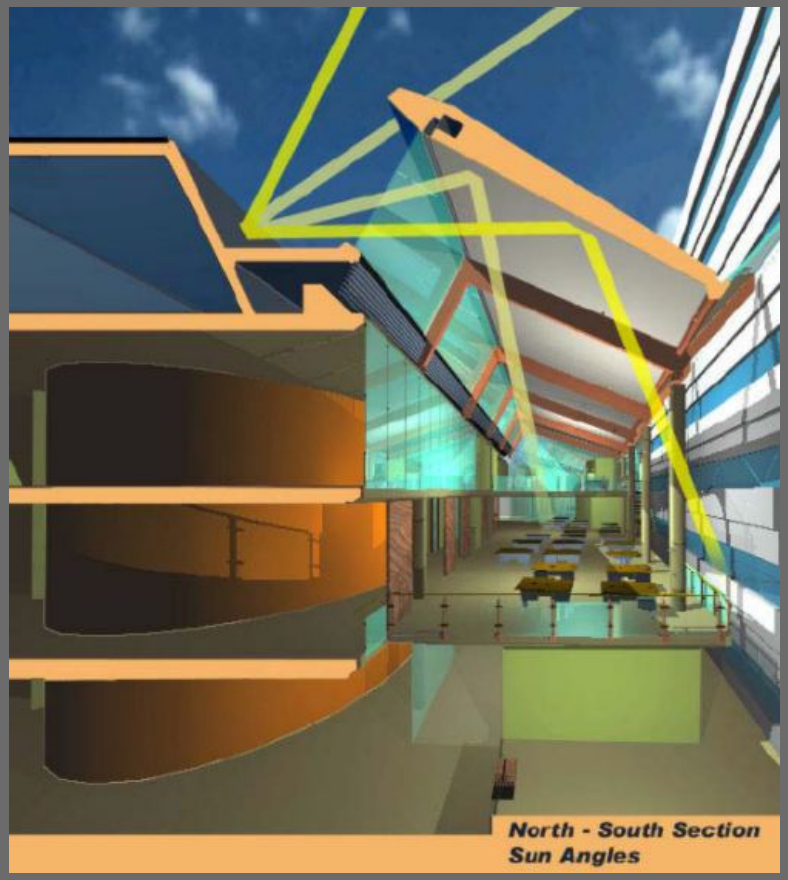
γ
α
γ : Height
α : Azimuth


Earth's rotation around the sun
long night
short day
Winter
Low angle
Low intensity
44th parallel
earth's rotation
23°
Earth
Sun
Summer
High angle
High intensity
long day
short night
44th parallel
earth's rotation
23°
Earth

Bringing sun/daylight inside built spaces



- Athens, Ohio is located at:

- 82 degrees West longitude
- 39.5 degrees North latitude


Arctic Circle
Tropic of Cancer
Equator


Equator
Tropic of Capricorn
Antarctic Circle

- The **Tropic of Cancer** (23 1/2°N) and the **Tropic of Capricorn** (23 1/2°S), mark the farthest points north and south of the equator where the sun's rays fall vertically, 90 degrees.

- The **Arctic Circle** (66 1/2°N) and the **Antarctic Circle** (66 1/2°S), mark the farthest points north and south of the equator where the sun appears above the horizon each day of the year. Inside the Arctic circle, the sun never rises for the winter months.

Section through classrooms showing winter and summer sun angles

N

Section through skylight- PV cells on south face, skylight from north face

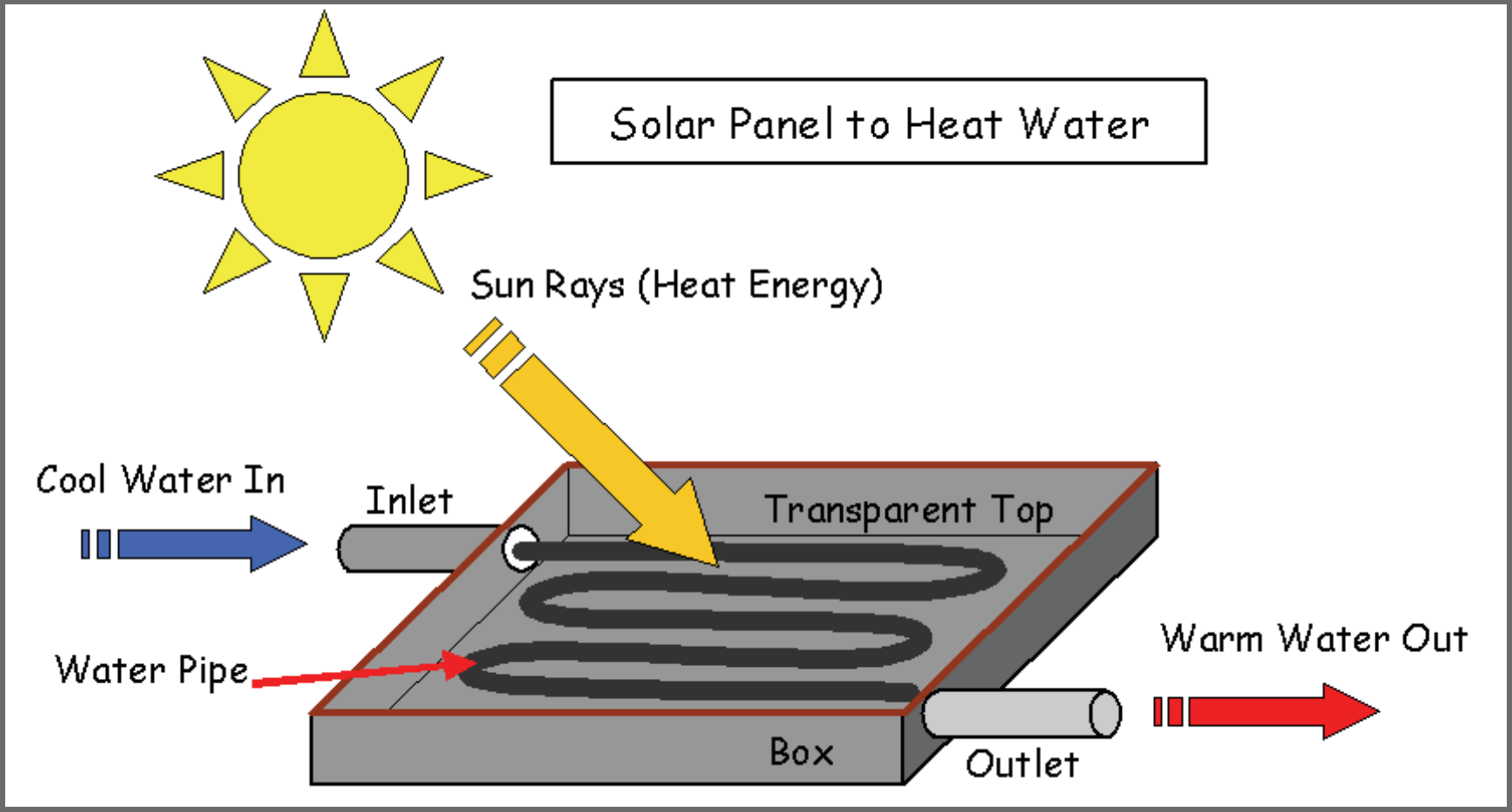
N

Active Solar Design

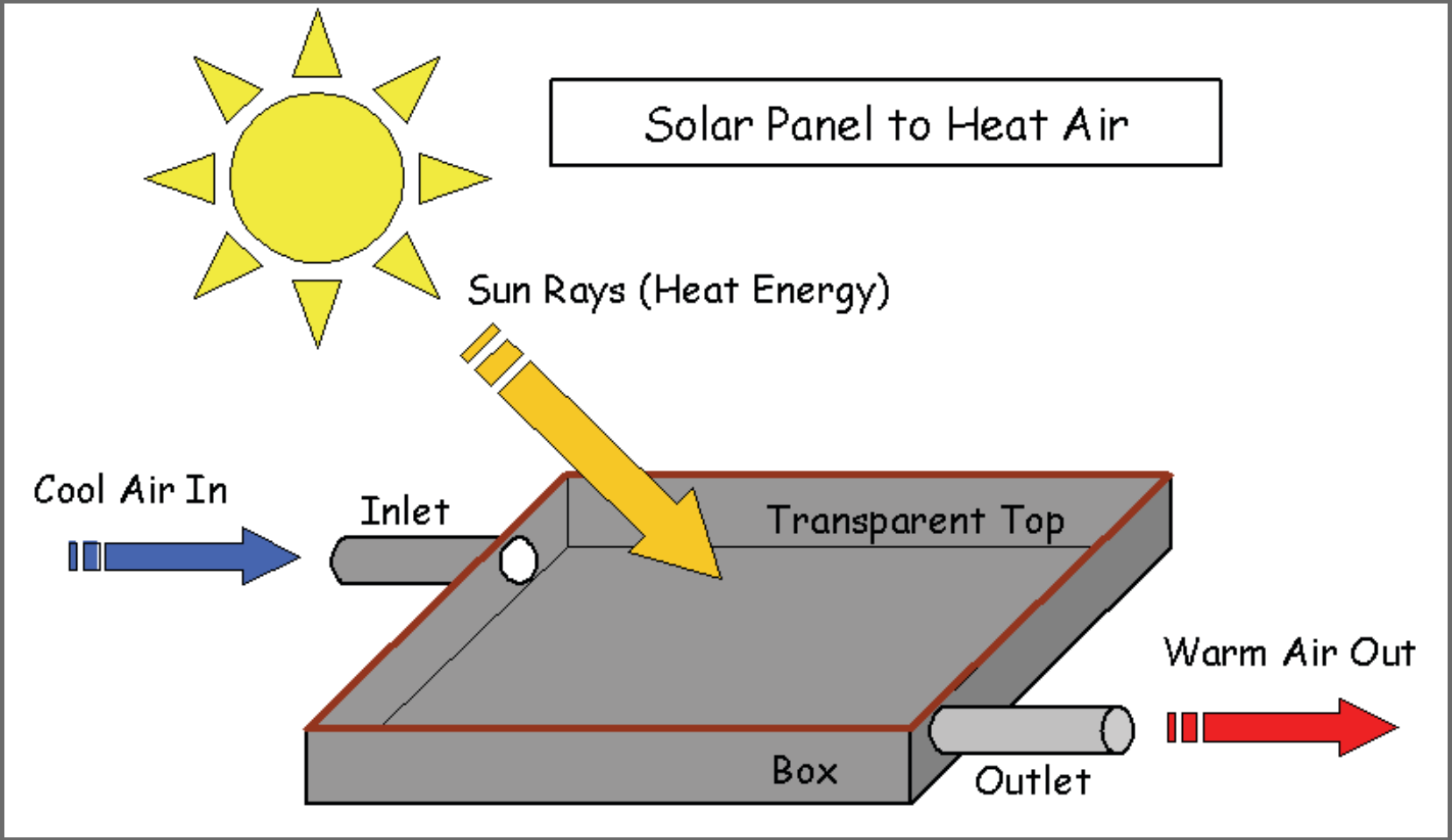
this shows a solar water heating panel

Active Solar mechanisms

- **Active systems: collector panels that heat water, or air, or create electricity through photo voltaic cells.**
- A flat plate collector is essentially an insulated box that allows sunlight in on one side through a glass covered window and absorb it with dark colored metallic surfaces.
- Flat collectors typically heat water or air that runs through the collector is tubes.


Solar Panel to Heat Water
Sun Rays (Heat Energy)
Cool Water In
Inlet
Transparent Top
Water Pipe
Warm Water Out
Box
Outlet

The water heating panel is connected to the building's plumbing system


Solar Panel to Heat Air
Sun Rays (Heat Energy)
Cool Air In
Inlet
Transparent Top
Warm Air Out
Box
Outlet

- The collected (and trapped) heat is then transferred by conduction into a **working fluid** (typically water with or without antifreeze, or air), which is continuously pumped through pipes in contact with the collecting surfaces.

- The working fluid is then routed either to a storage medium, such as a hot water tank, rock bed, or radiant floor, or transferred directly into the air.

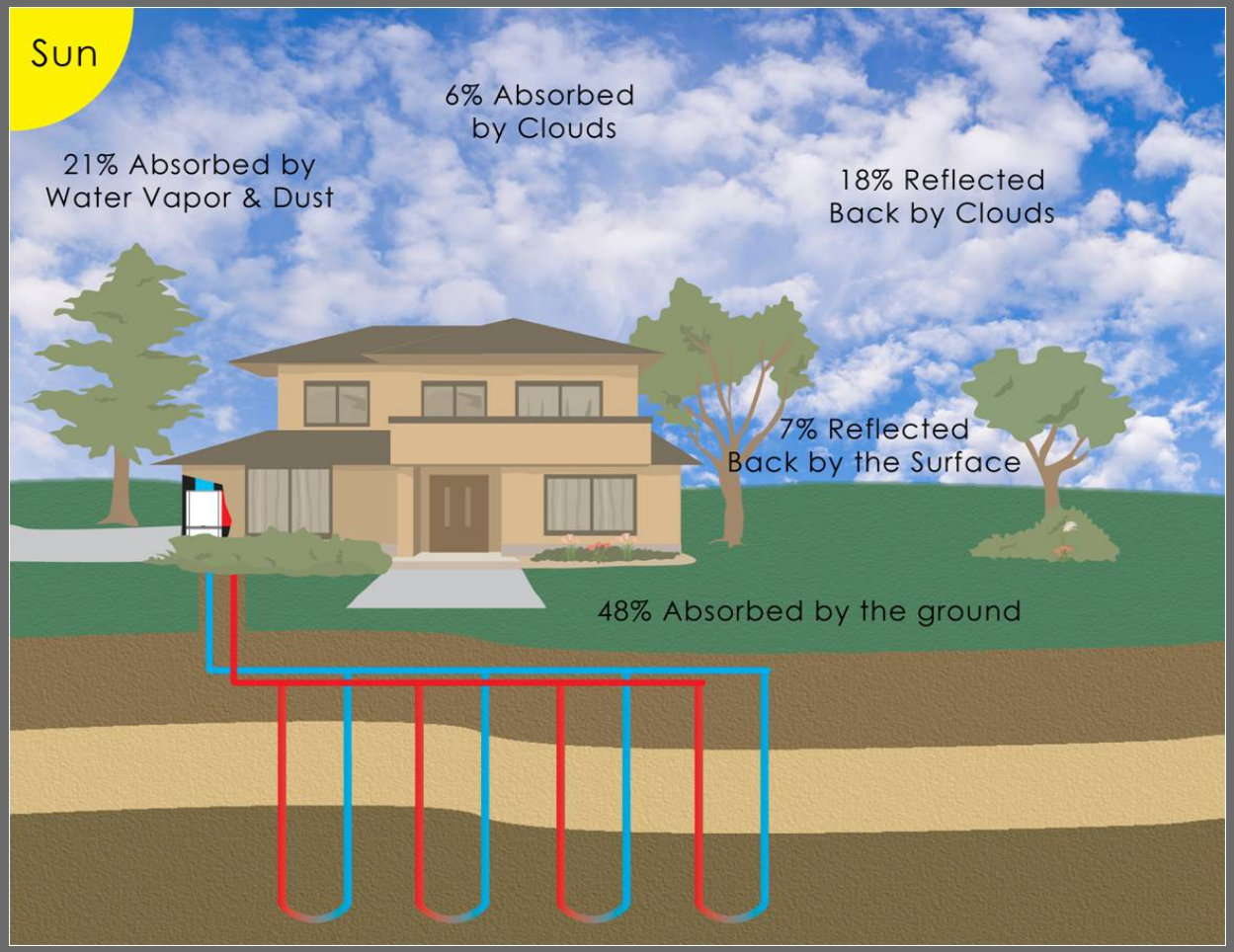
Essential Information in Solar Design

- The sun's light is an energy source.
- The sun's light that strikes the earth varies across the surface of the earth.
- The 'seasons' are a natural response to the varying intensity of sunlight striking the earth's surface due to the tilting of the earth and the thickness of the earth's atmosphere.

- The sun's light that strikes a building varies during the year, and during a day, due to the 'movement' of the sun from east to west.

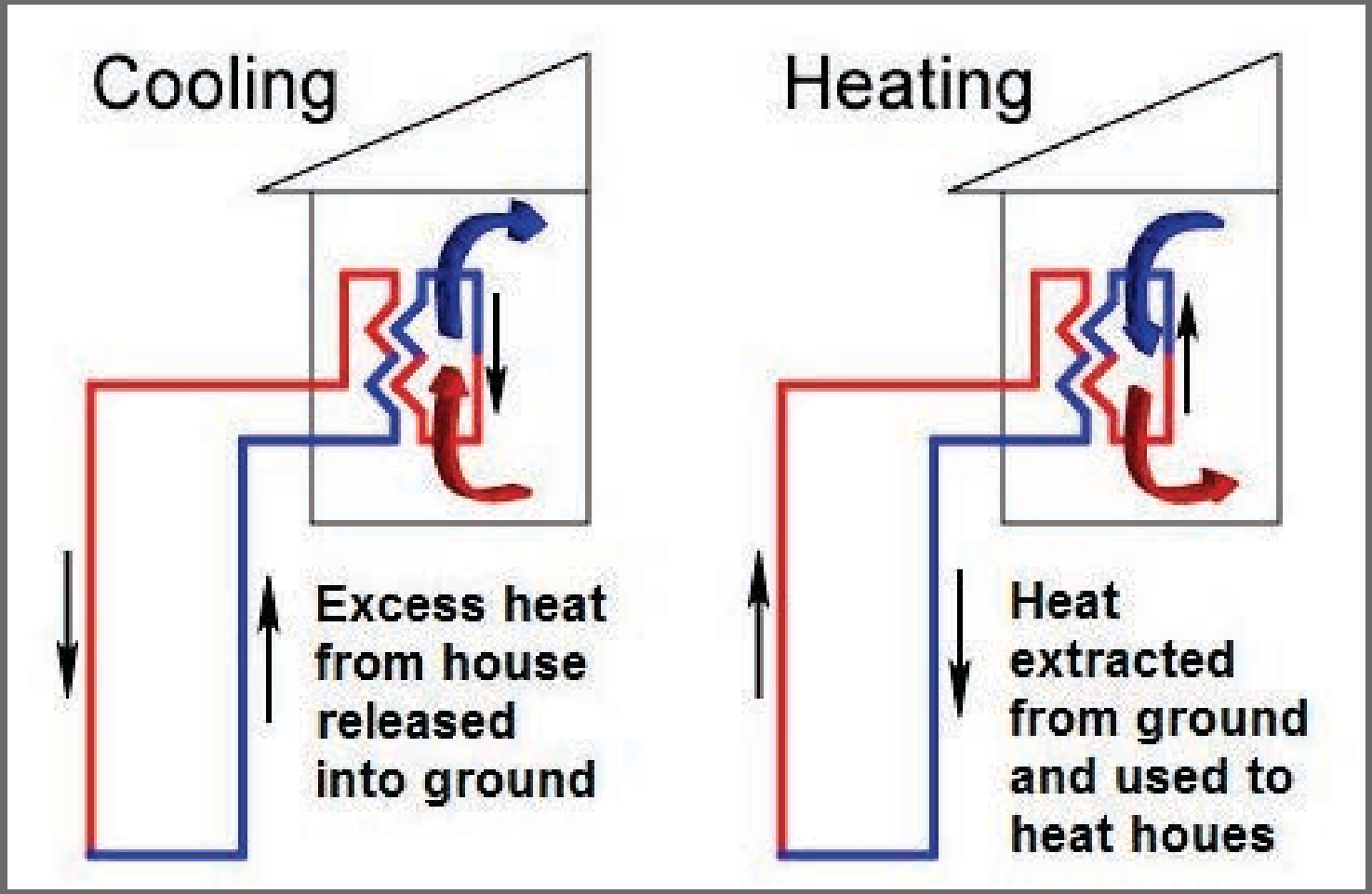
- The sun's light that strikes a building can be controlled by the placement (orientation) of the building on its site, and by the design of the building's overall shape, and the placement of openings.

Geo thermal heating & cooling

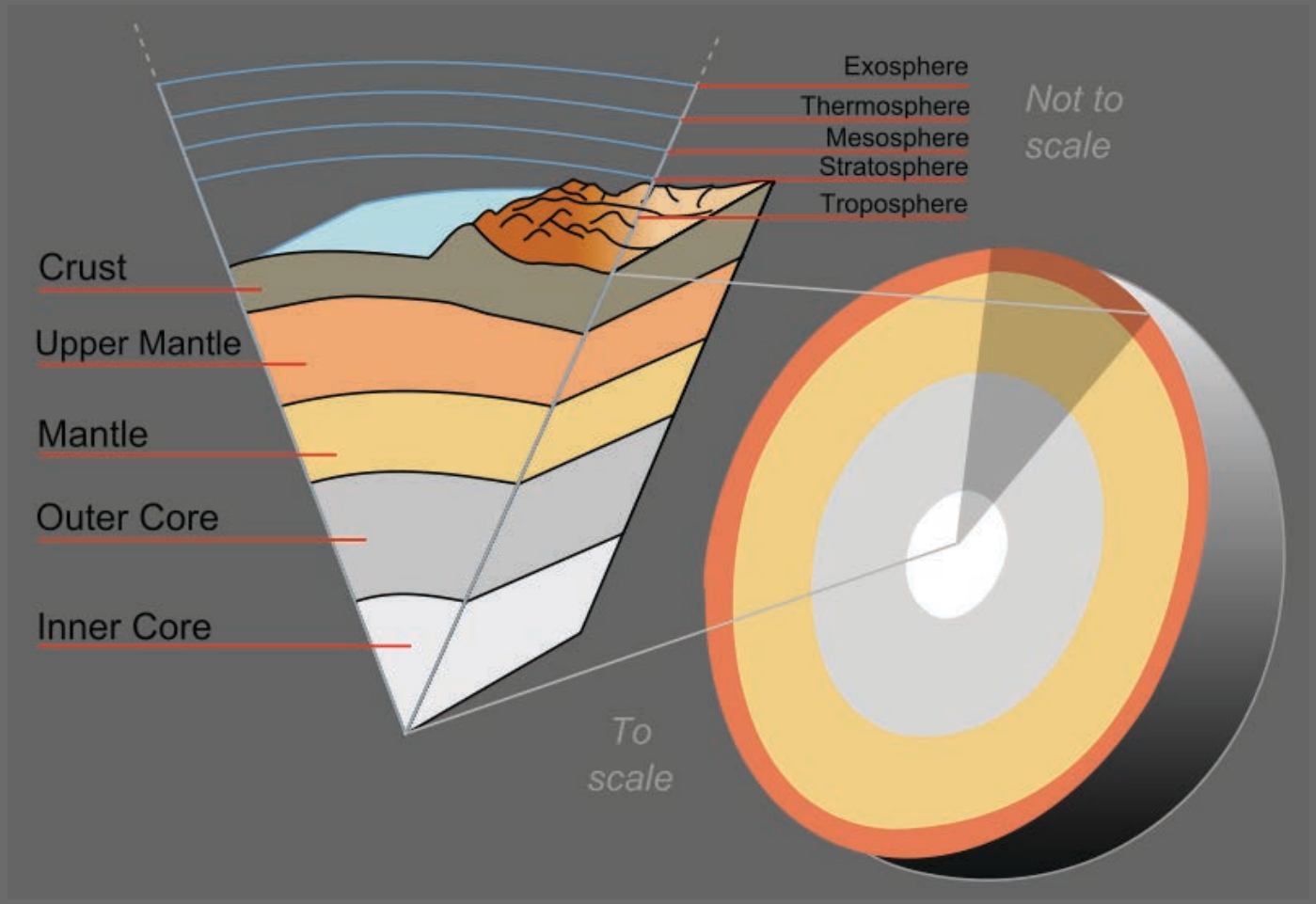


Geo thermal heating & cooling

[How Geo Thermal Heating and Cooling Work]



Temperature of the earth underground



Geothermal gradient

- Temperature within the Earth increases with depth.
- Highly viscous or partially molten rock at temperatures between 650 to 1,200 °C (1,200 to 2,200 °F) is postulated to exist everywhere beneath the Earth's surface at depths of 80 to 100 kilometers (50 to 60 mi)
- The Earth's crust effectively acts as a thick insulating blanket which must be pierced by fluid conduits (of magma, water or other) in order to release the heat underneath.

Geothermal gradient

- **Geothermal gradient** is the rate of increasing temperature with respect to increasing depth in the Earth's interior.

- Away from tectonic plate boundaries, it is about **25°C per km of depth** (1°F per 70 feet of depth) in most of the world.

- The Earth's internal heat comes from a combination of residual heat from:

- planetary accretion (about 20%)
- heat produced through radioactive decay (80%)

- At the center of the planet, the temperature may be up to 7,000 K and the pressure could reach 360 GPa

Geo Thermal Heating in Iceland

- For centuries, the people of Iceland have been using hot springs for washing and cleaning, however it was not until 1907, when a farmer from the West of Iceland used a concrete pipe to direct steam from a hot spring into his house, taking advantage of this naturally occurring product for heating.
- Since then, Iceland has been taking ever increasing advantage of it's unique geology.
- It has even got to the point where in the capital Reykjavik, the pavements are heated.

The ‘Blue Lagoon’, Iceland
a natural hot spring