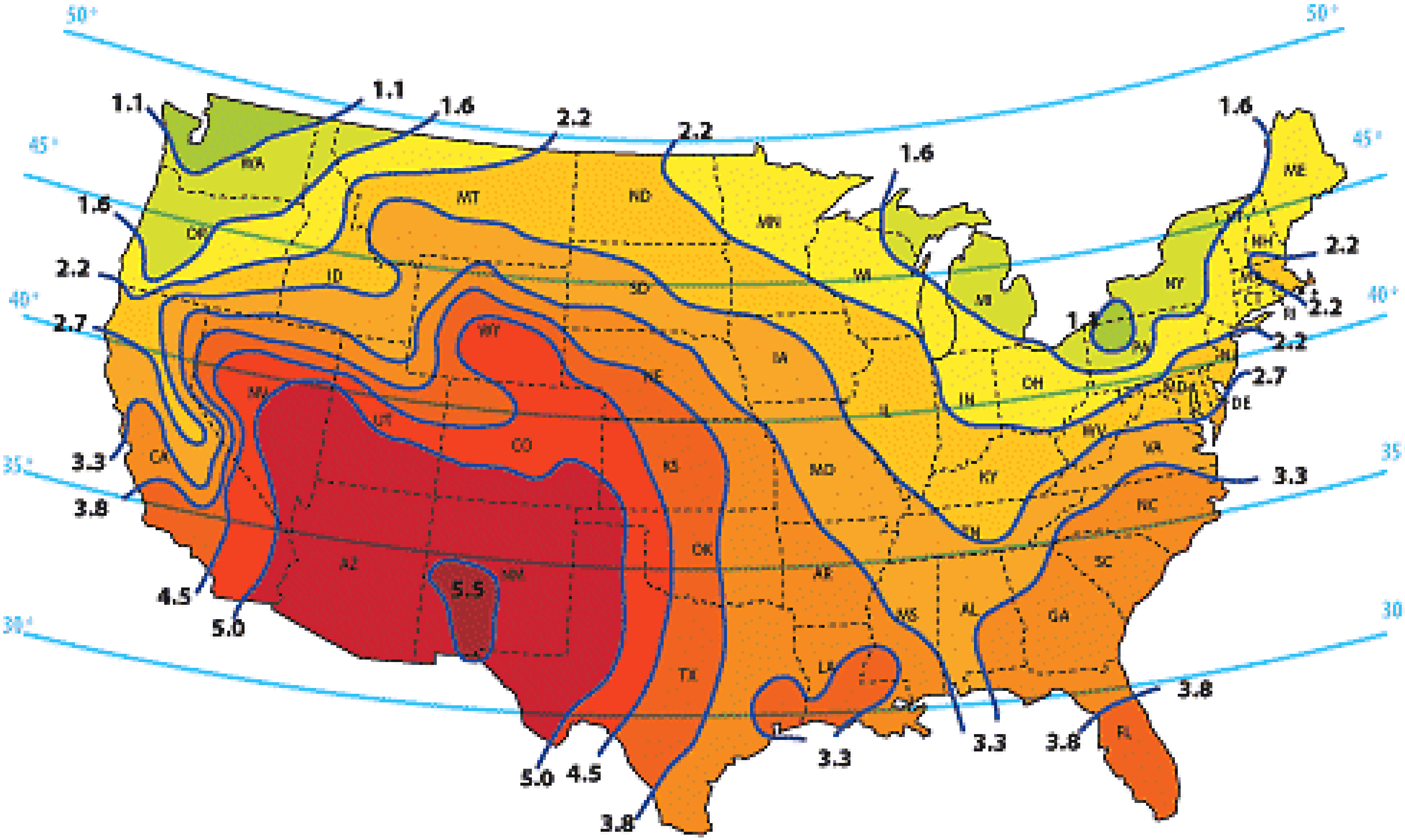
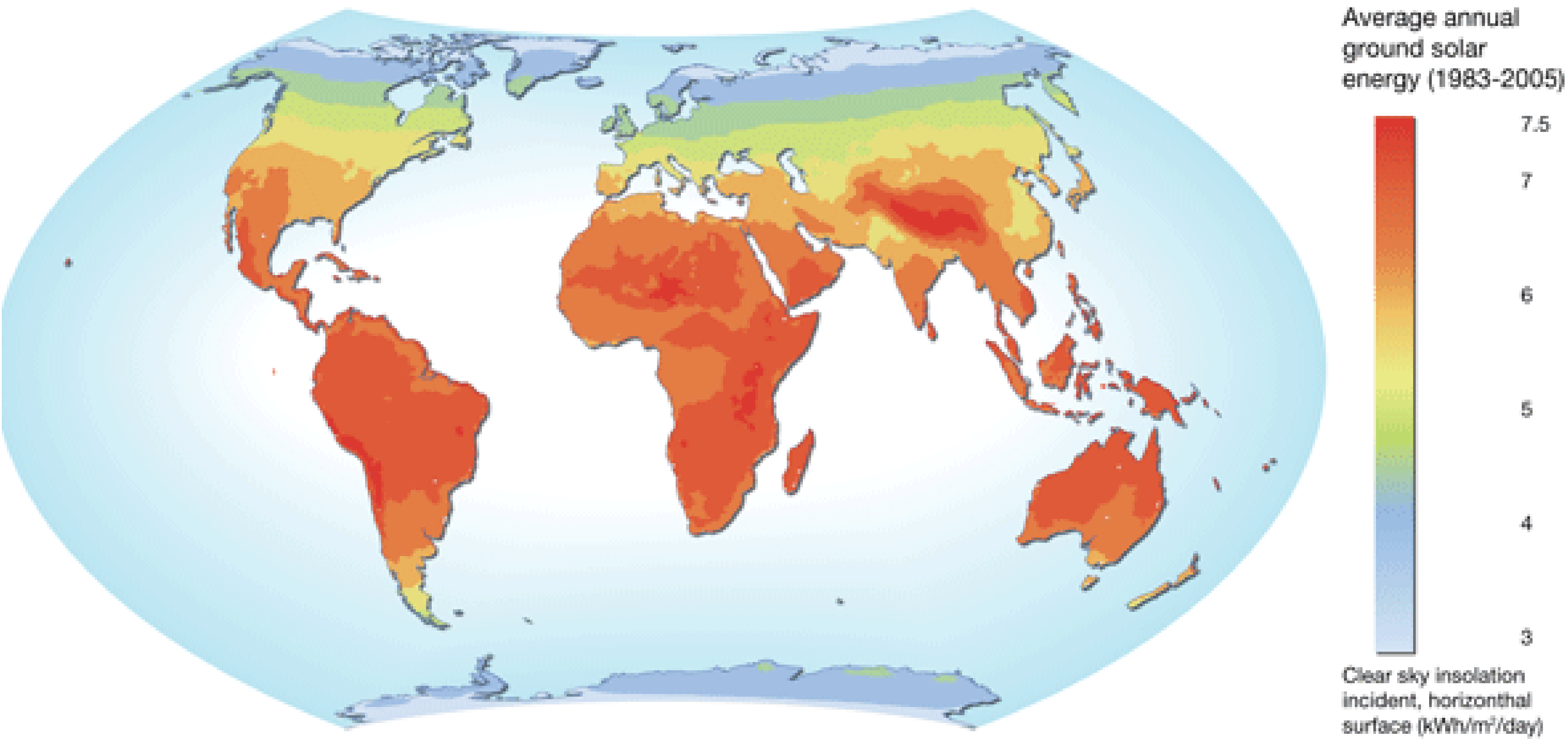
Renewable Energy Technologies: SOLAR

Dr. Masi

Average U.S. Insolation (hours of sun) worst month (Jan.)





Source: NASA 2008

I. Converting Solar Resources

Solar energy resources can be used for:

Light skylight, windows, etc.)

Heat (space heating, water heating, etc.

Electricity (local, grid, microgrid)

I. Converting Solar Resources

When converting solar radiation to thermal energy, solar resources can be used to:

Heat Water

In homes, buildings, and **swimming pools**

Heat Spaces

Inside homes, greenhouses, and other buildings

I. Converting Solar Resources

Solar energy resources can also be converted to electricity in 2 ways:

1. Photovoltaics (PV) (local, grid, microgrid)

2. Concentrating Solar Power Plants (e.g. Arizona)
   not a choice for Cape Elizabeth

II. Limitations and Benefits

Limitations

1. The amount of sunlight that arrives at Earth's surface is not constant

Depends on season, weather, location, time of day

2. The sun does not deliver that much energy to any one place at any one time

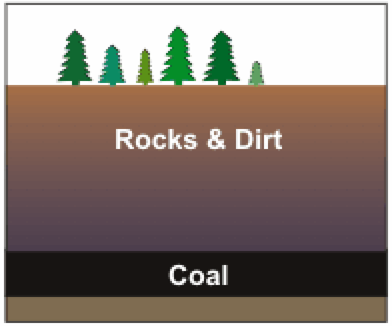
A large surface area is required to collect energy at a useful rate

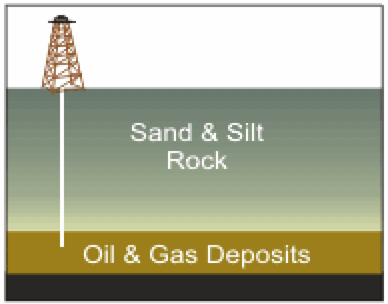
A. A comment on Power Density

A. Power Density

(rate of energy production per unit of earth area)

- Because of the geological timescale, fossil fuel deposits are vast, highly concentrated, and high quality
  - Small areas supply massive energy flows





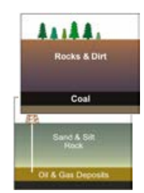
Coal field – 100 W/m^2
Oil field – 1000 W/m^2
<u>….and a carbon footprint</u>

A. The Realities of Power Density

(rate of energy production per unit of earth area)

- Because of the geological timescale, fossil fuel deposits are vast, highly concentrated, and high quality
  - Small areas supply massive energy flows
- No future source from non-fossil sources will be able to match this

- Forest harvested wood – 0.2 W/m^2
- Charcoal – 0.04W/m^2
- Hydro – below 10W/m^2
- Wind – below 10W/m^2
- Solar – 20W/m^2 but not on large scale
- Biofuels – 1.6W/m^2



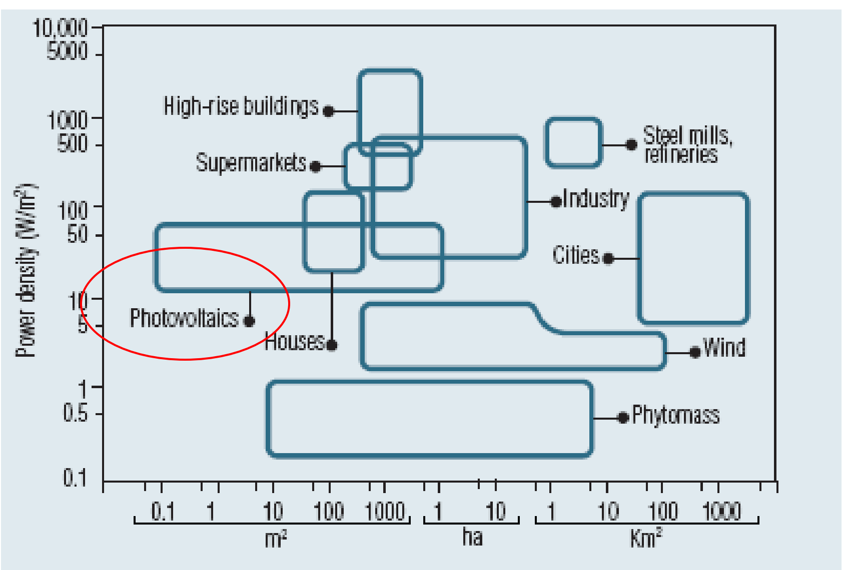
Coal field – 100 W/m^2
Oil field – 1000 W/m^2

How does this compare to power densities of energy consumption?

A. Power Density

(rate of energy consumption per unit of earth area)

- If we just used solar panels to power all of our structures, we would need…



Source: V. Smil

- House – entire roof mounted with PV (good bye trees)
- Supermarket – a field 10x larger than it's roof
- High Rise – a field 1000x larger than it's roof

Our relationship with land use would change dramatically

II. Limitations and Benefits

Benefits

1. Conversion to heat and electricity is direct

    Bulky mechanical generators become unnecessary

2. Arrays can be installed quickly and in any size
3. The local environmental impact is minimal

LOW CARBON FOOTPRINT

NO FUEL DEPENDENCE

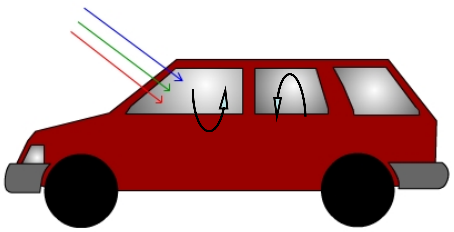
The "fuel" is not on-site

III. Design Types

There are 2 types of solar designs

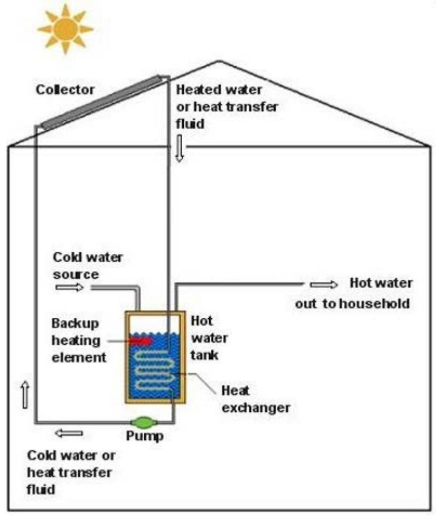
1. **Passive**

   Does not use mechanical and electrical controls to move collected heat



2. **Active**

   Uses a collector and mechanical and electrical controls to move collected heat and/or electrical power.



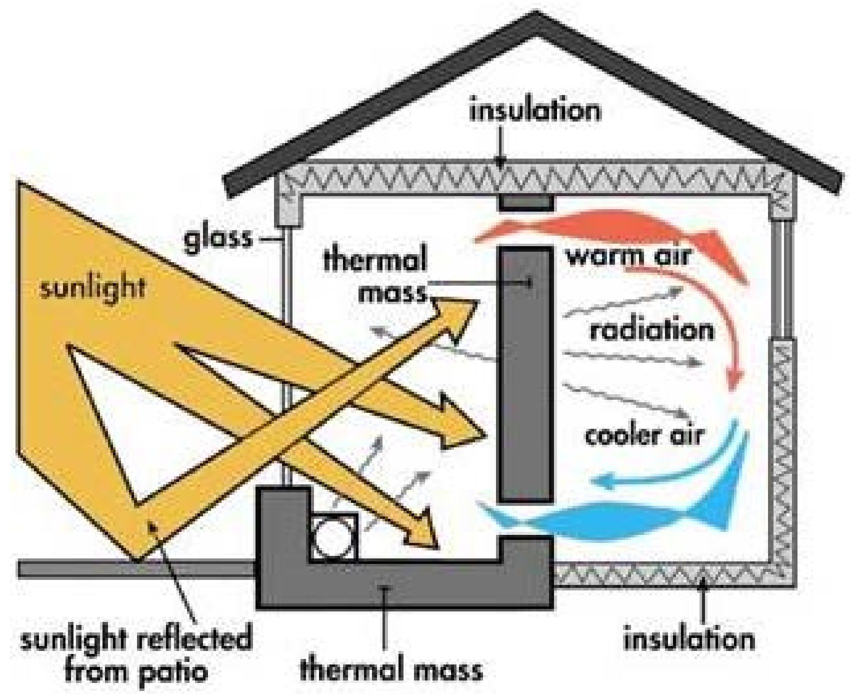
A. Passive Solar Design

A. Passive Solar Design

Windows, walls, and floors can be designed to:

Collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer.

You can apply passive solar design techniques most easily when designing a new home/BUILDING



1. How a Passive Solar Design Works

It's all about heat flow

To distribute solar heat through a living space, passive design makes use of this law through the following mechanisms:

Conduction

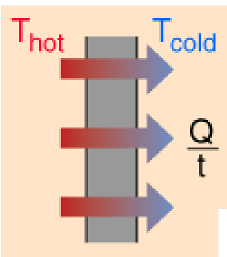
Convection

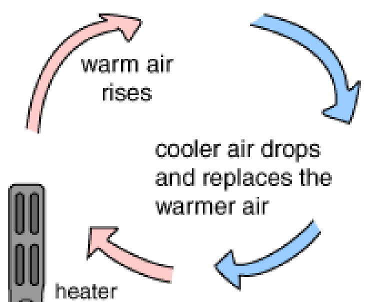
Radiation

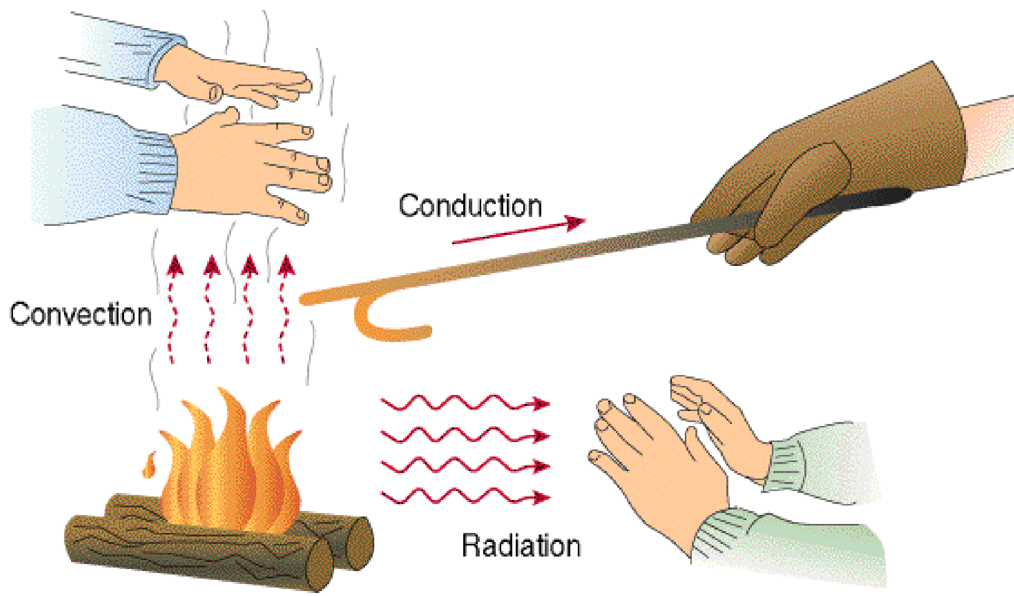
Thermal Capacitance

a. Conduction, Convection, Radiation

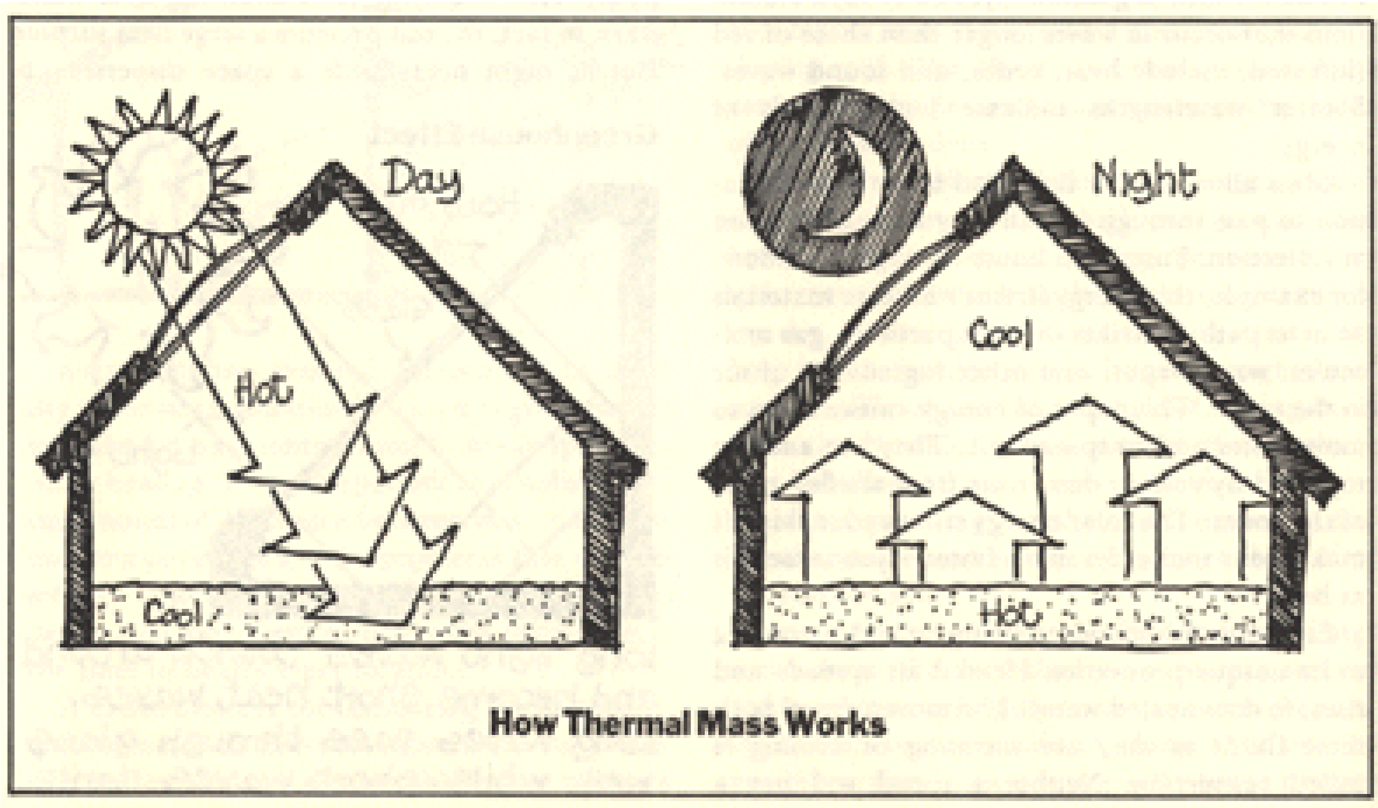
3 ways heat gets transferred





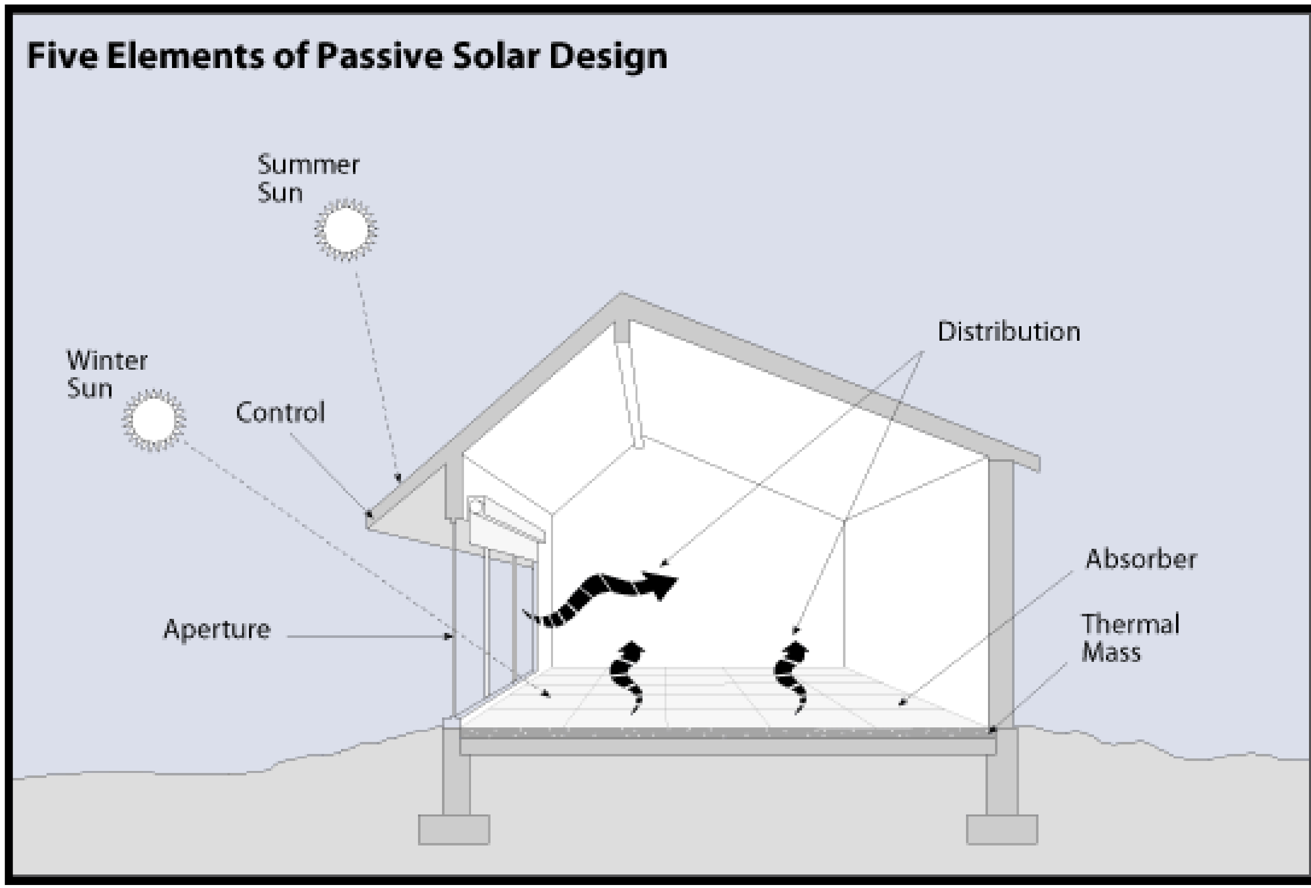


b. Thermal Capacitance



2. Designing a Completely Passive Solar Design

1. **Aperture**
2. **Absorber**
3. **Thermal Mass**
4. **Distribution**
5. **Control**
6. **Window Location**
7. **Window glazing type**
8. **Auxiliary Systems**

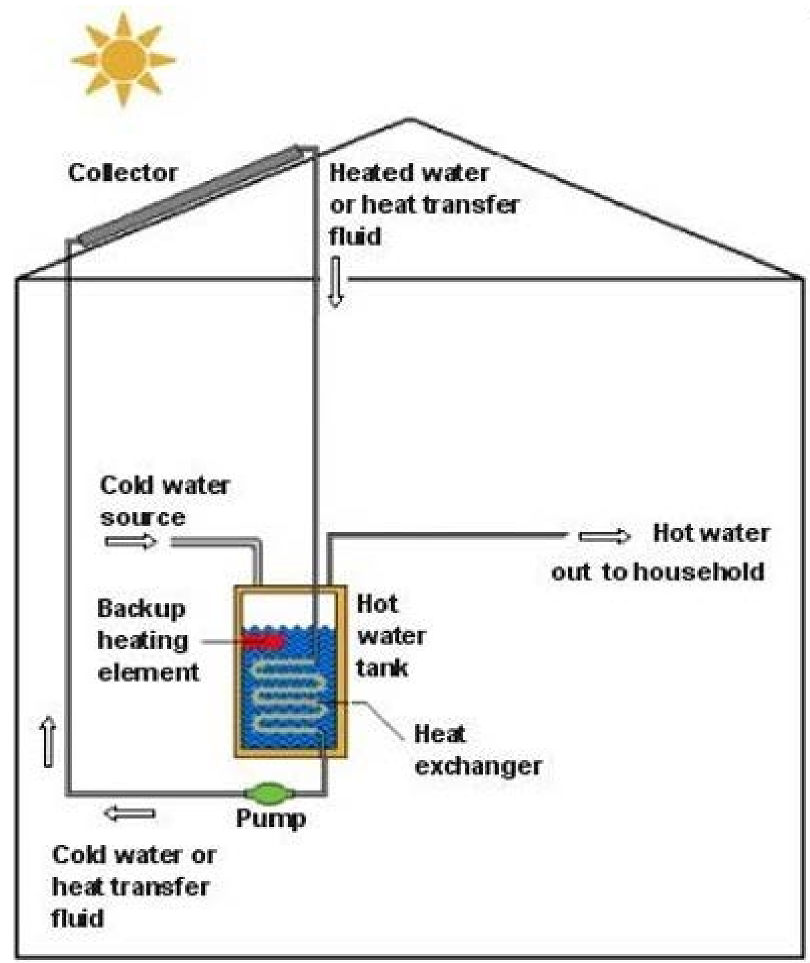


B. Active Solar Design

Active heating systems require a collector to absorb and collect solar radiation.

Fans or pumps are used to circulate the heated air or heat absorbing fluid.

Active systems often include some type of energy storage system.



1. Active Solar Heating

There are 2 types of active solar heating based on the type of fluid that is heated in the solar energy collectors

1. Liquid Systems

   Heat water or antifreeze in a hydronic collector

2. Air Systems

   Heat air in an air collector

2. The Solar Collector

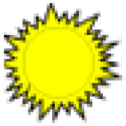
Types of solar thermal collectors

- **Flat-plate and evacuated-tube solar collectors are used to collect heat for space heating, domestic hot water or cooling with an absorption chiller.**
  – Flat plate collectors.
  – Evacuated tube collectors.
  – Comparisons of flat plate and evacuated tube collectors.
  – Bowl.
  – Through-pass air collector.
  – Unglazed transpired solar collectors

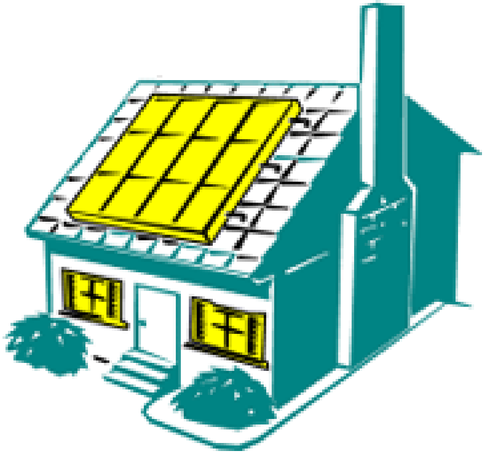
2. The Solar Collector

Flat-plate collectors are the most common type use when temperatures below 200^{o}F are sufficient

A flat-plate absorber that intercepts and absorbs the solar energy



A transparent cover that allows solar energy to pass through but reduces heat loss from the absorber



A heat-transport fluid flowing through tubes to remove heat from the absorber and a heat insulating backing

Flat Plate Collectors

These collectors consist of airtight boxes with a glass, or other transparent material cover. There are several designs on the arrangement of the internal tubing of flat plate collectors as shown.

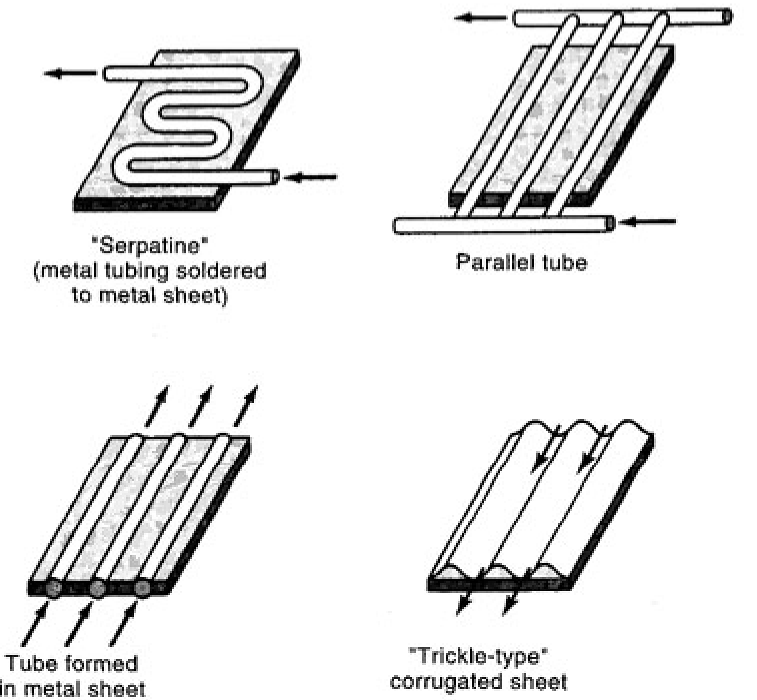


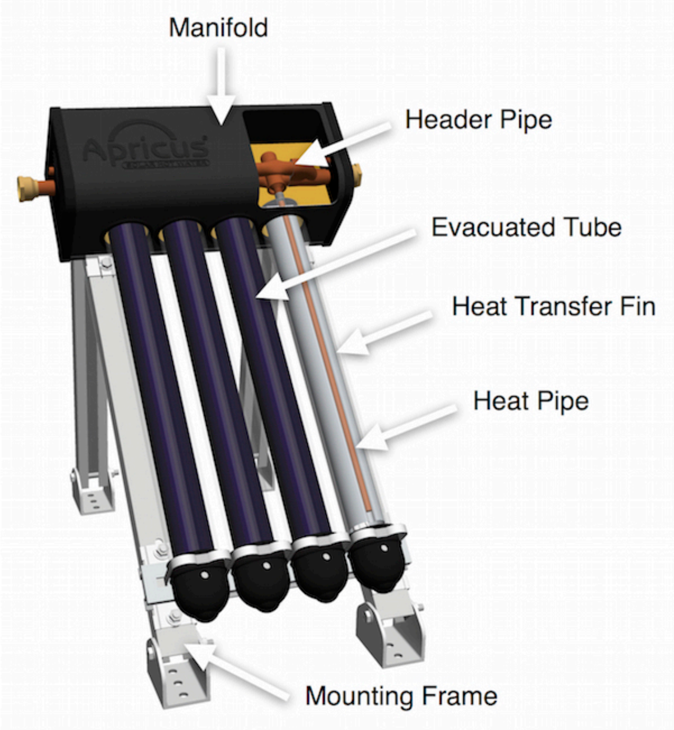
Figure 1 Internal tubing arrangement in flat plate collectors (copyright Saunders College Publishing)

This is a common type of solar collector which has been in use since the 1950s. The main components of a flat plate panel are a dark colored flat plate absorber with an insulated cover, a heat transferring liquid containing antifreeze to transfer heat from the absorber to the water tank, and an insulated backing. The flat plate feature of the solar panel increases the surface area for heat absorption.

Evacuated tube solar thermal systems

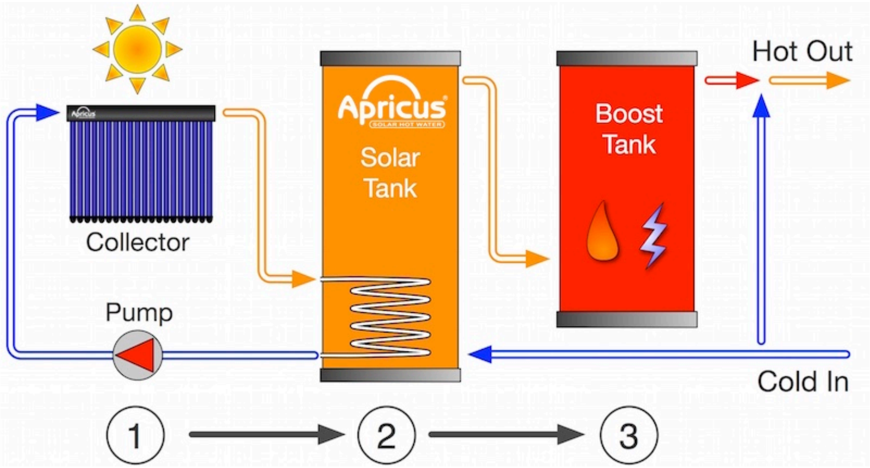
The **evacuated tube solar thermal system** is one of the most popular solar thermal systems in operation. An evacuated solar system is the **most efficient** and a common means of solar thermal energy generation with a rate of efficiency of 70 per cent. As an example, if the collector generates 3000 kilowatt hours of energy in a year then 2100 kilowatt hours would be utilized in the system for heating water. The rate of efficiency is achieved because of the way in which the evacuated tube systems are constructed, meaning they have excellent insulation and are virtually unaffected by air temperatures. The collector itself is made up of rows of insulated glass tubes that contain copper pipes at their core. Water is heated in the collector and is then sent through the pipes to the water tank. This type of collector is the most efficient, but also the most expensive

Evacuated Tube (ET)
Absorbs solar energy and converts it to usable heat. A vacuum between the two glass layers insulates against heat loss.
The Heat Transfer Fin helps to transfer heat to the Heat Pipe.
Heat Pipe (HP)
Copper vacuum pipe that transfers the heat from within the ET up to the manifold.
Manifold
Insulated box containing the copper header pipe. The header is a pair of contoured copper pipes with dry connect sockets that the heat pipes plug into.
Mounting Frame
Strong and easy to install with a range of attachment options.

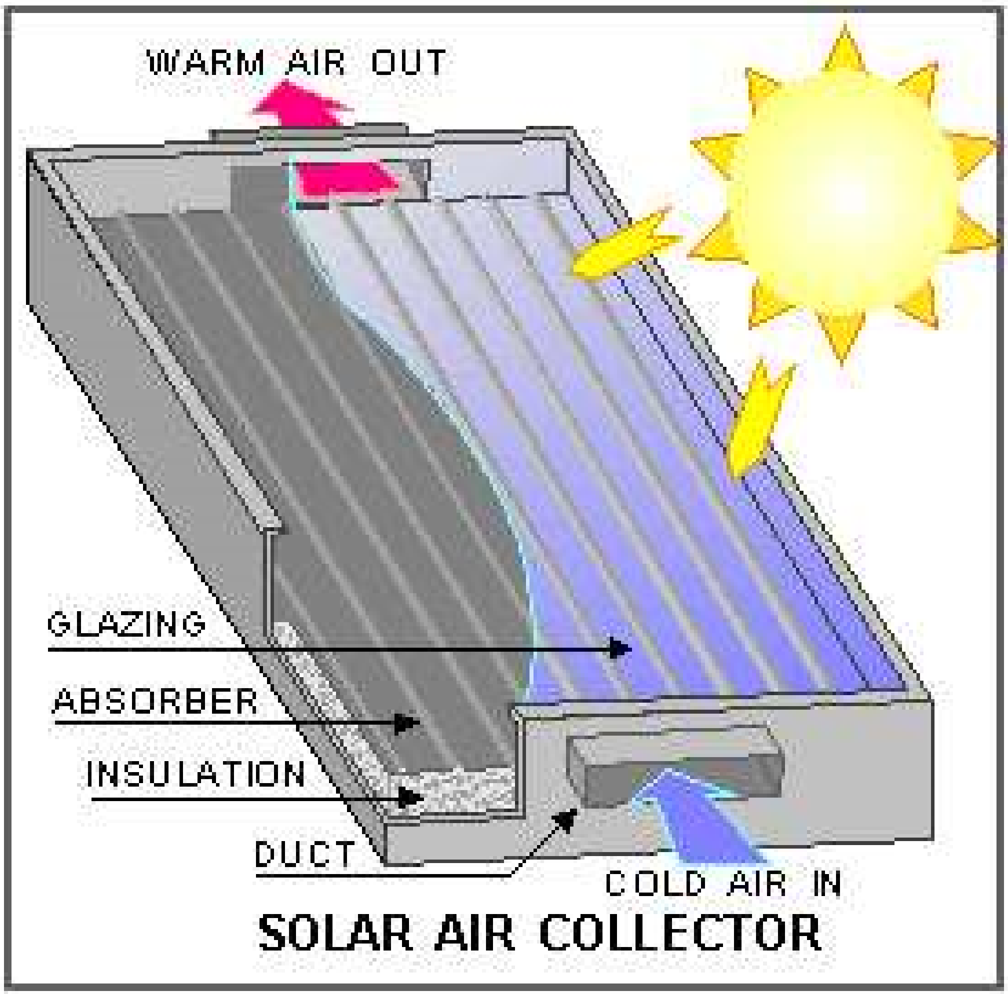


Collector Operation

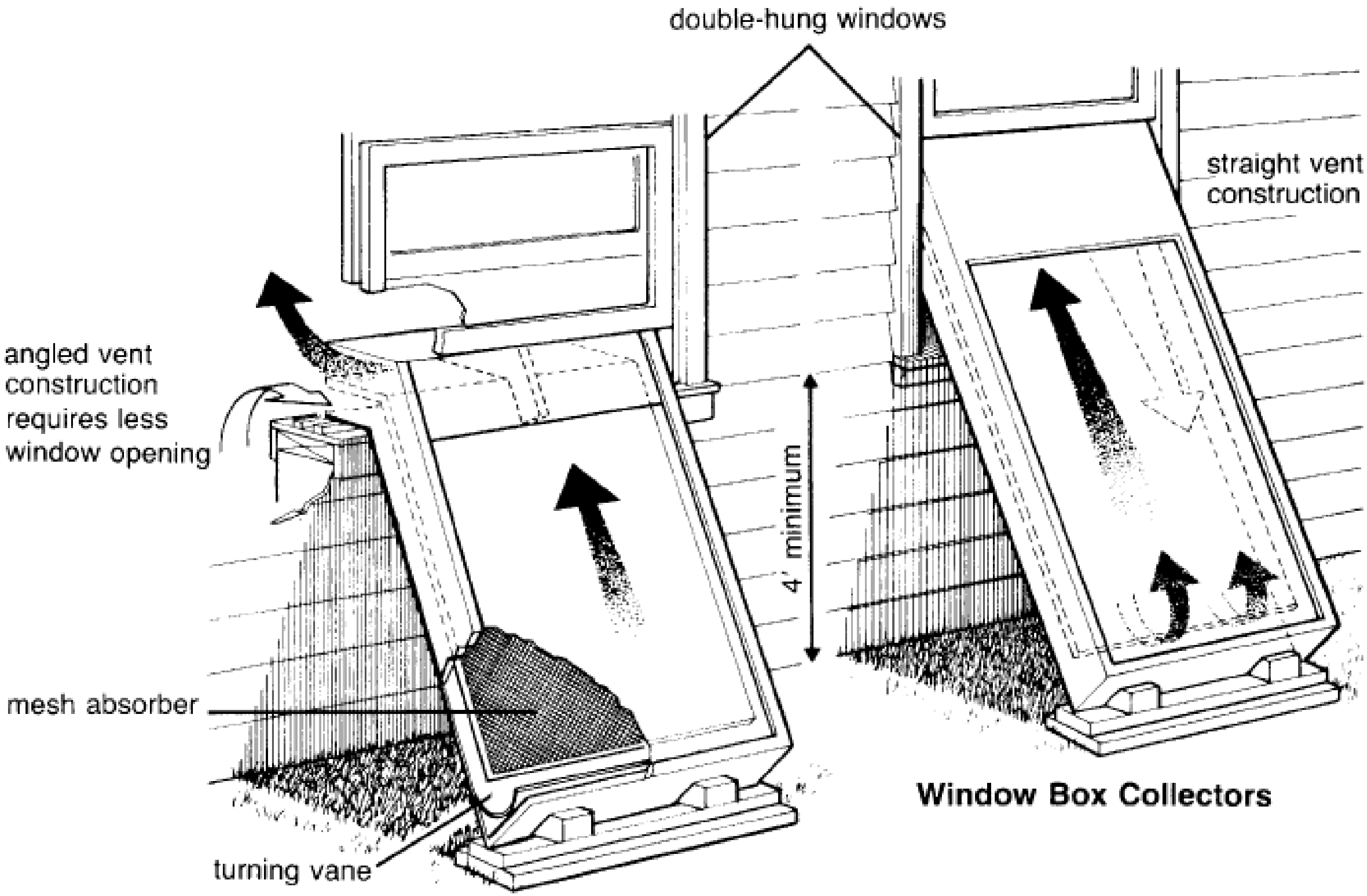
Step 1: The Apricus evacuated tube solar collector converts sunlight into heat. A circulation pump moves liquid through the collector, carrying heat back to the solar storage tank.
Step 2: Gradually throughout the day the water in the solar storage tank is heated up, either directly or via a heat exchanger (as shown).
Step 3: When hot water is used, solar pre-heated water is fed into a traditional water heater which boosts the temperature if not already hot enough.



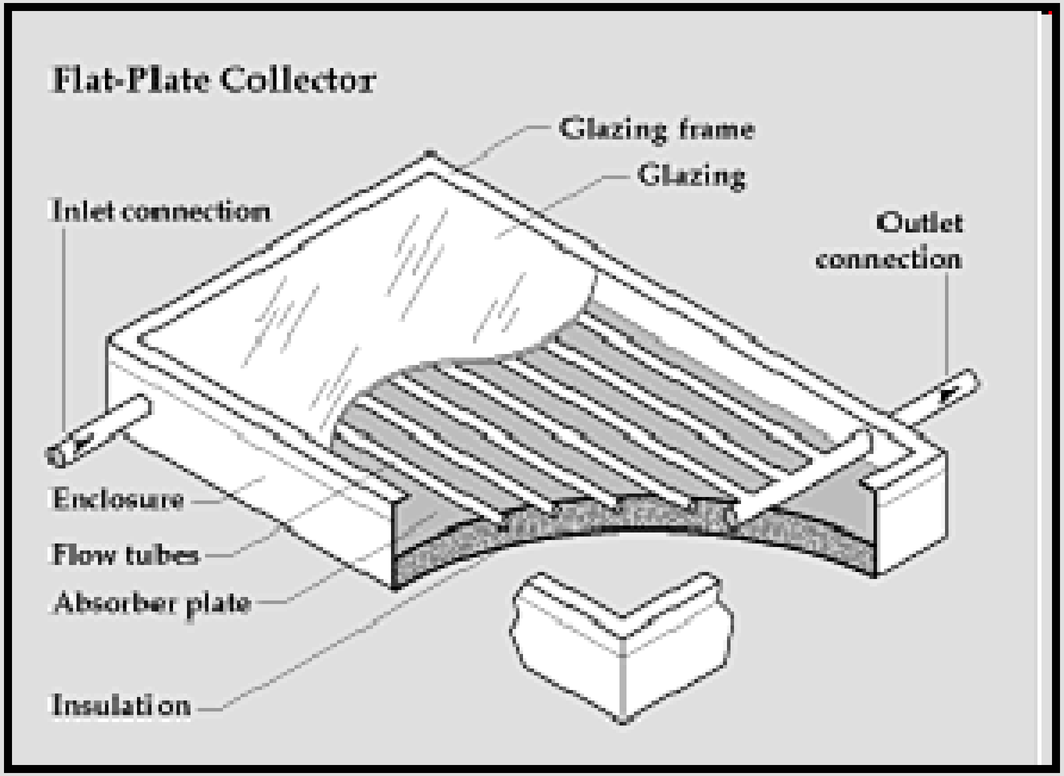
a. Solar Air Collector



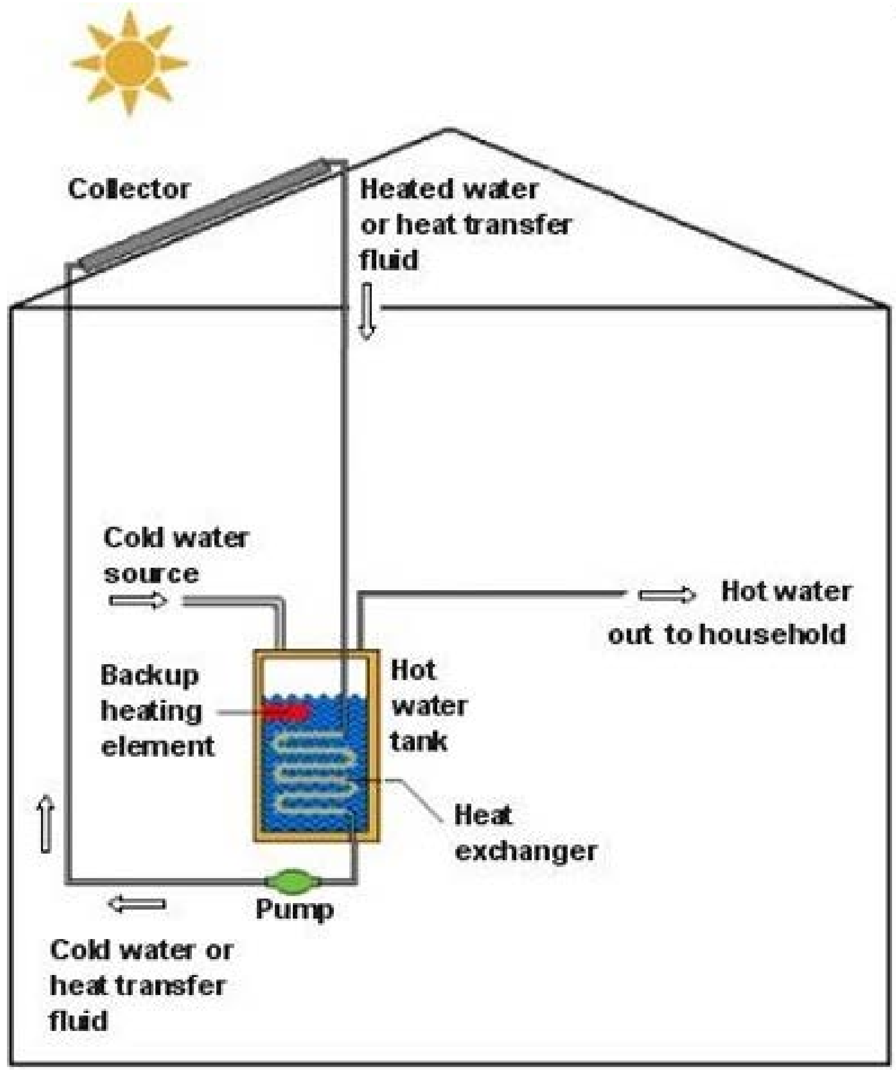
a. Solar Air Collector



b. Solar Liquid Collector



b. Solar Liquid Collector



2. Distributing Solar Heat

Air Systems

- Immediate use in nearby rooms

Liquid Systems

- Domestic hot water
- Radiant floor
- Hot water baseboards
- **Pool, Spa, etc.**

IV. Electricity

Solar energy can be converted to electricity in 2 ways:

1. Photovoltaic Cells

2. Concentrating Solar Power Plants

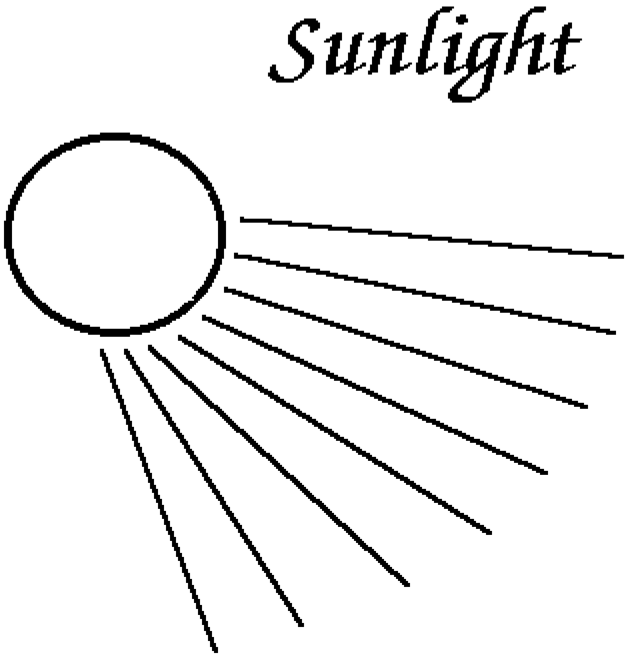
A. Photovoltaics (PV)

Photo **"Light"**

Voltaic **"Electricity"**

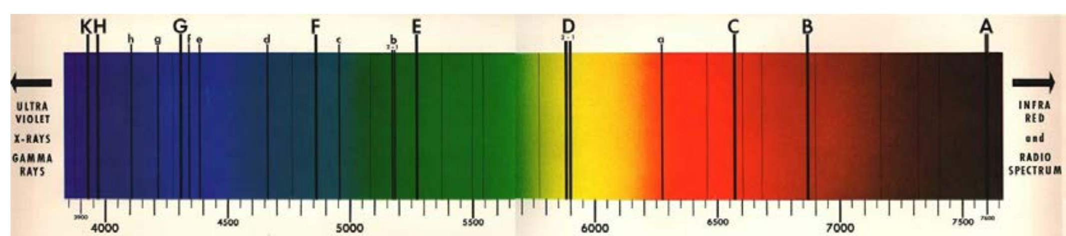
PV converts sunlight directly into electricity

1. PV Basics



Sunlight is comprised of photons, or packets of energy

The packets hold various amounts of energy corresponding to the wavelengths ("colors") of the solar spectrum



1. PV Basics

When photons strike a PV cell, they may be reflected, pass right through, or be absorbed

absorbed photons provide energy to generate electricity

When enough sunlight is absorbed by the semi-conducting material (Silicon, in our case) electrons are dislodged from the material's atoms

(These devices are basically large p-n junctions)

Animations

Photovoltaics

http://www.solar-is-future.com/solar-energy-source/how-photovoltaics-work/animation/index.html

Solar Thermal

http://www.solar-is-future.com/solar-energy-source/how-solar-thermal-energy-works/heat-from-light/index.html

2. Solar Cells/Modules/Arrays

The typical PV cell produces only a small amount of power

To produce more, cells can be interconnected to form panels or modules

2. Solar Cells/Modules/Arrays

The typical PV cell produces only a small amount of power

To produce more, cells can be interconnected to form panels or modules

Several modules can then be installed on a building or at ground level to form an array

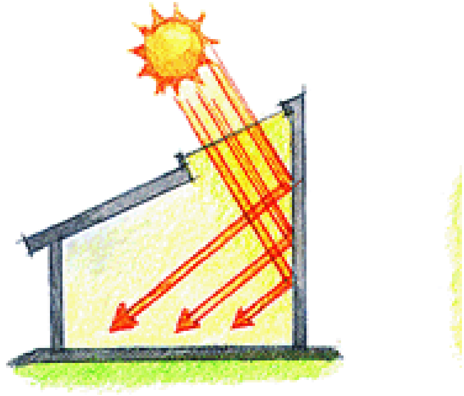
MORE ABOUT DAYLIGHTING

Find other ways to let in light.

Not every room in a house can have generously sized windows that admit natural light. Rooms at the interior core of a house as well as those facing north sometimes get shortchanged.

Open floor plans allow light from skylights and windows to penetrate deep into a house. Skylights over stairways, for example, can bring light into the center of a house.

Skylights are a simple way of introducing light to rooms right below roof level. Both fixed and operable skylights are available. The cost of an efficient skylight usually pays back in less than a year.

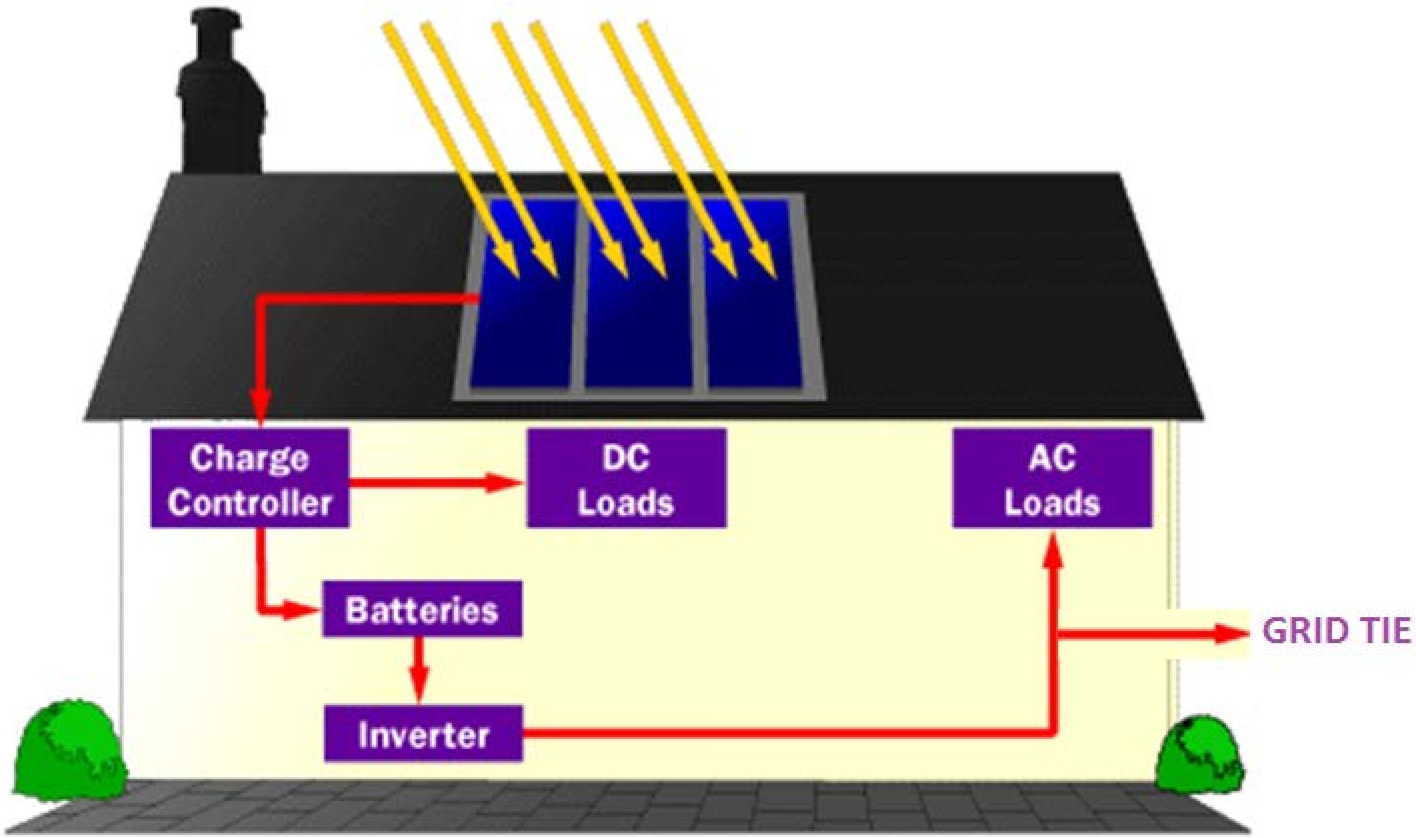


Day lighting Program

http://astro.unl.edu/classaction/animations/coordsmotion/daylighthoursexplorer.html

Don't forget solar daylighting:
Skylights work

4. Converting to AC/GRID



B. Solar Thermal Power Plants

(**These are not Cape Elizabeth Options**)

(added for completeness)

Concentrated the sun's rays to heat a working fluid to very high T

The fluid is then circulated through pipes so it can transfer its heat to water to produce steam

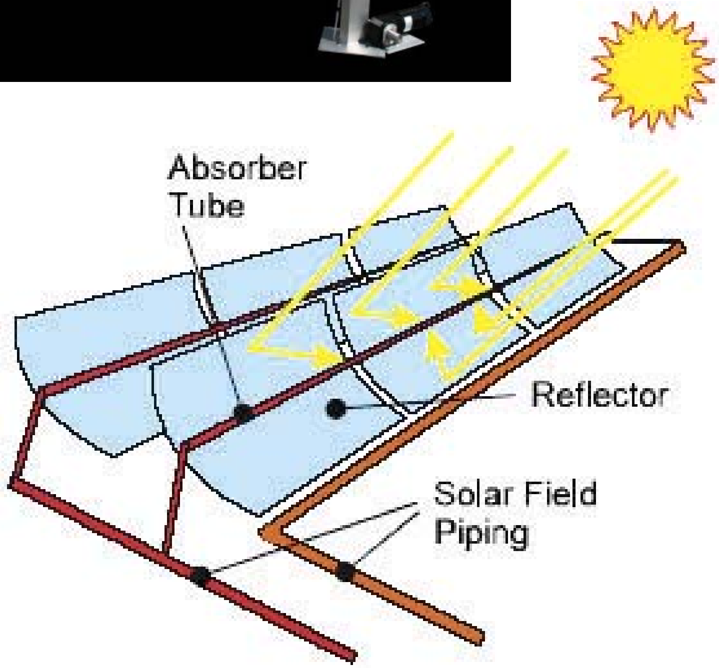
The steam is then converted to mechanical energy in a turbine and into electricity by a conventional turbine/generator coupling

1. 3 Main Types

a. **Parabolic Troughs**
b. **Solar Dish**
c. **Solar Power Tower**

a. Parabolic Troughs

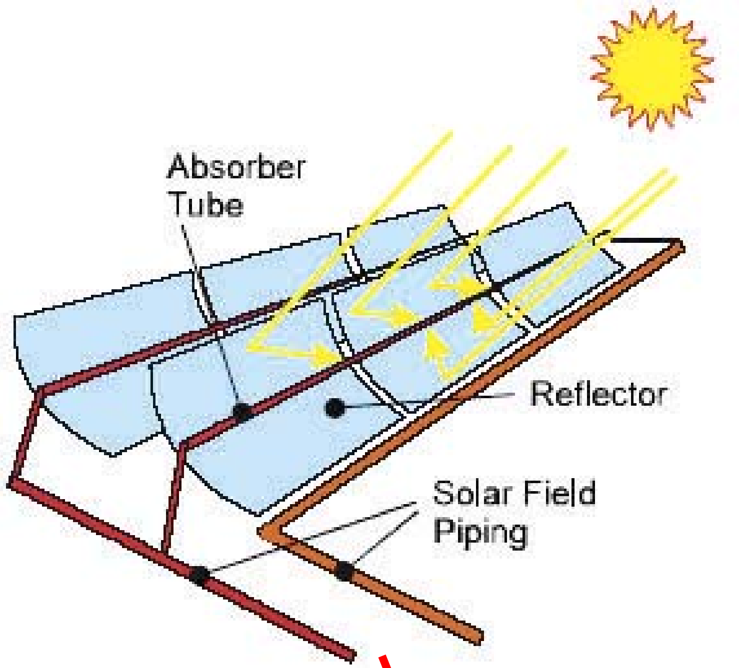
A parabolic trough collector has a long parabolic-shaped reflector that focuses the sun's rays on a receiver pipe located at the focus of the parabola.

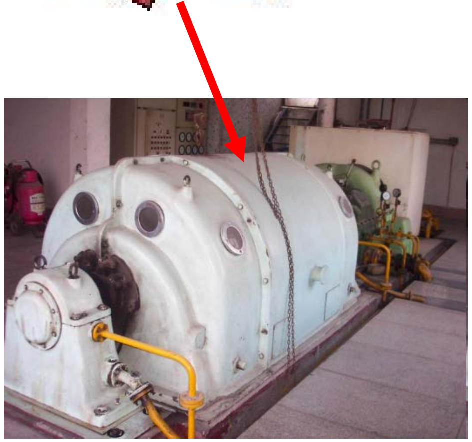


The collector tilts with the sun as the sun moves from east to west during the day to ensure that the sun is continuously focused on the receiver.

Because of its parabolic shape, a trough can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on the receiver pipe located along the focal line of the trough, achieving operating temperatures over 750°F.

a. Parabolic Troughs





A working (heat transfer) fluid is heated as it circulates through the receiver pipes and returns to a series of "heat exchangers" at a central location. Here, the fluid circulates through pipes so it can transfer its heat to water to generate high-pressure, superheated steam.

The steam is then fed to a conventional steam turbine and generator to produce electricity. When the hot fluid passes through the heat exchangers, it cools down, and is then re-circulated through the solar field to heat up again.

b. Solar Dish

b. Solar Dish

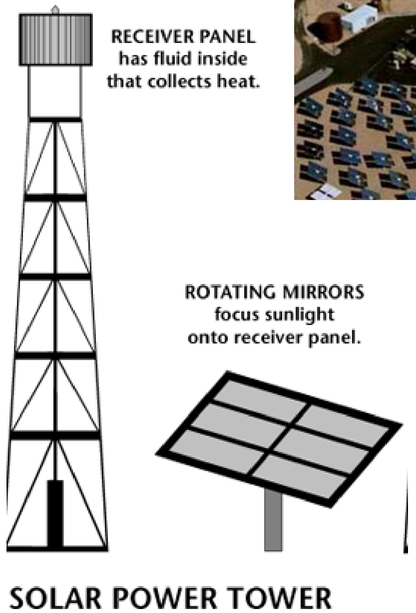
A solar dish/engine system uses concentrating solar collectors that track the sun, so they always point straight at the sun and concentrate the solar energy at the focal point of the dish.

A solar dish's concentration ratio is much higher than a solar trough's, typically over 2,000, with a working fluid temperature over 1380°F.

The power-generating equipment used with a solar dish can be mounted at the focal point of the dish, making it well suited for remote operations or, as with the solar trough, the energy may be collected from a number of installations and converted to electricity at a central point.

c. Solar Power Tower

c. Solar Power Tower



A solar power tower or central receiver generates electricity from sunlight by focusing concentrated solar energy on a tower-mounted heat exchanger (receiver).

This system uses hundreds to thousands of flat sun-tracking mirrors called heliostats to reflect and concentrate the sun's energy onto a central receiver tower.

The energy can be concentrated as much as 1,500 times that of the energy coming in from the sun.