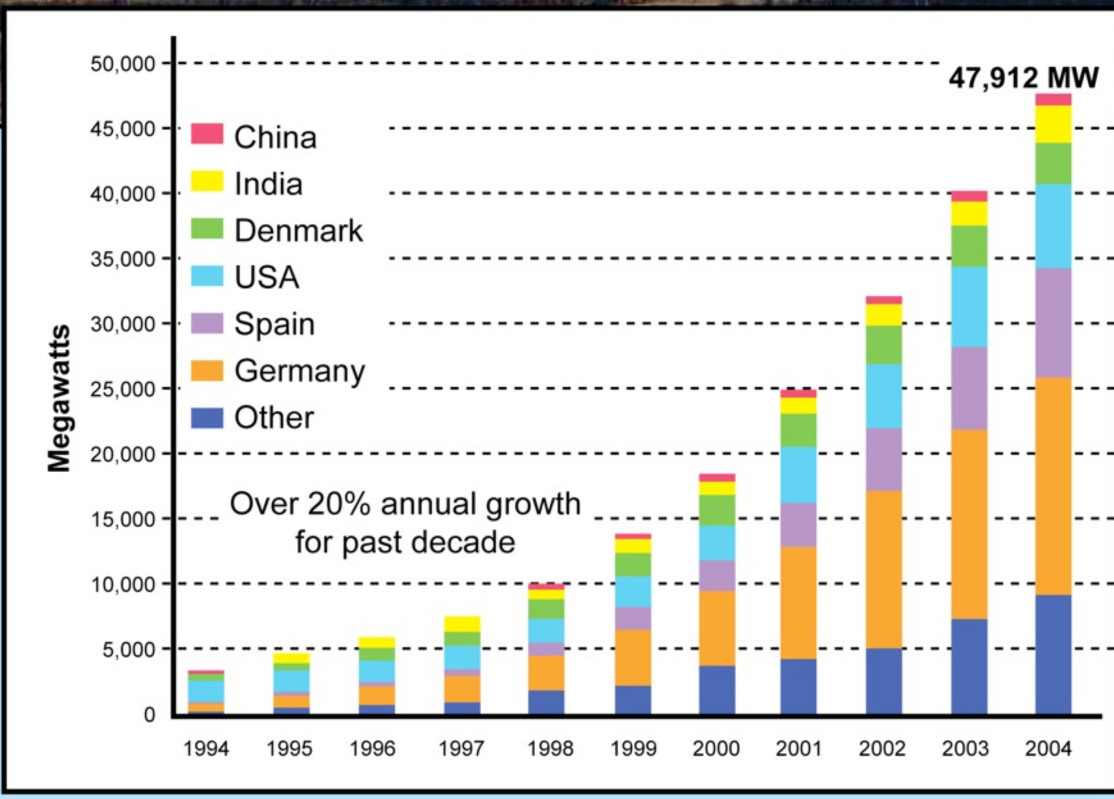
CHOBUGROUP

BUILDING SCIENCE (BSC)

# Renewable Energy Sources

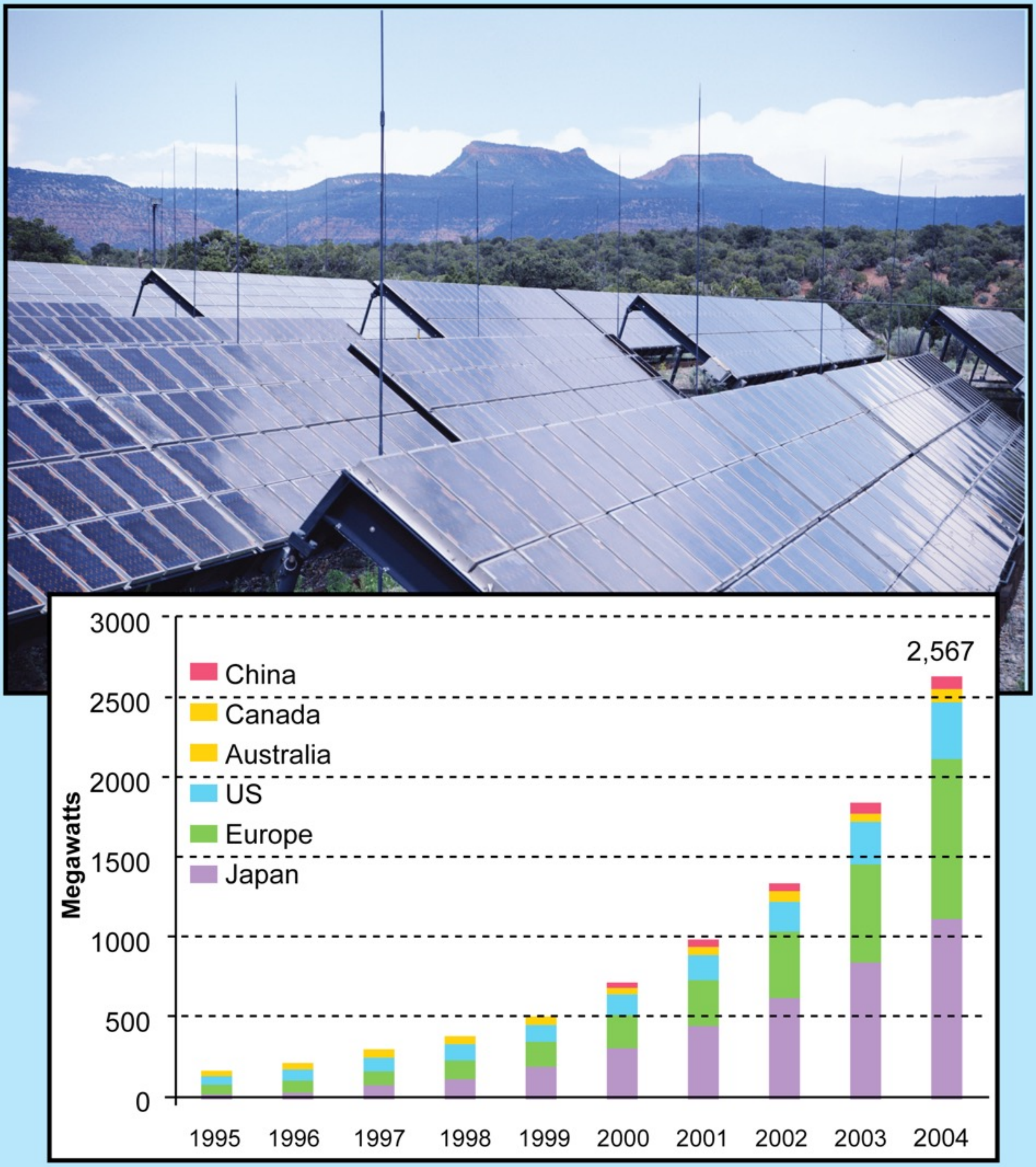
## *World Wind Energy Capacity*




**Source: Center for Resource Solutions, San Francisco, California**

# Renewable Energy Sources

## *World Solar PV Capacity*




**Source: Center for Resource Solutions, San Francisco, California**

# Renewable Energy Sources

## Contributions to Electricity Generation

| | 2003 | 2010 | 2020 |
|---|---|---|---|
| Small Hydro | 8% | 8.6% | 7.5% |
| Biomass | 0.5% | 0.9% | 2% |
| Wind | 0.2% | 0.7% | 2-3% |
| Solar PV | 0.01% | 0.09% | 0.1% |
| All Renewables | 9% | 10% | 12% |

# SOLAR ENERGY
## *The Beckoning Opportunity*

**The effective utilization of solar energy, can make at least the 'sunshine states' of the USA virtually independent of fossil fuel for homes.**

**Solar energy is ...**

- Abundantly available in most regions of the world.
- A natural source of energy that is available most of the time.
- A direct source of heat that can be readily captured through absorption.
- A free and completely unpolluted source of heat.
- Controllable through shading devices and/or reflection (i.e., special glass).
- Not impacted by air movement since it is transmitted by radiation.

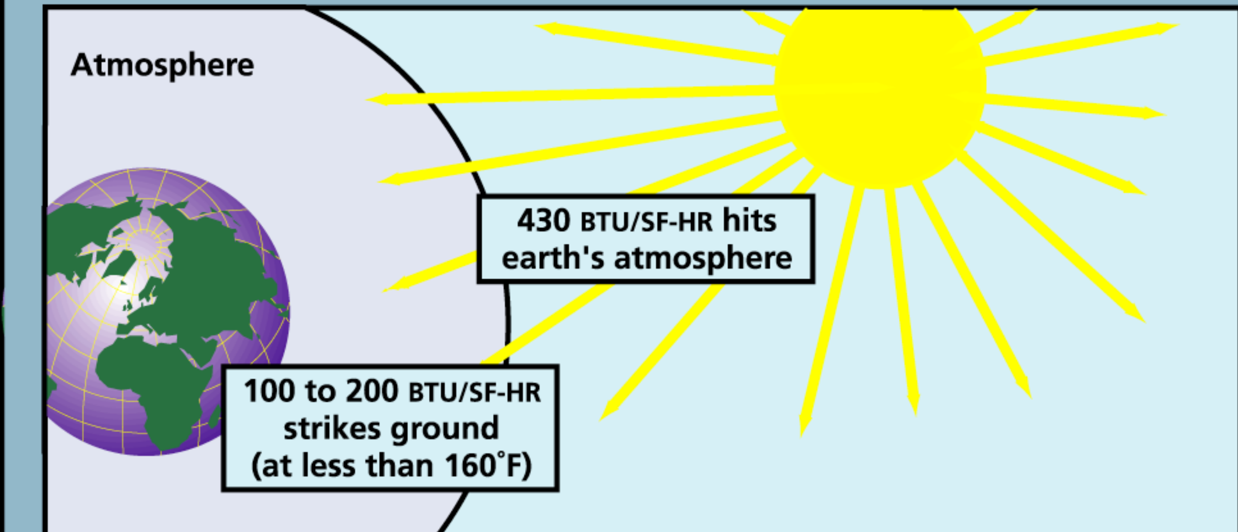
# SOLAR ENERGY
## *Reality*

**Solar energy is unlikely to provide more than 20% of the entire US energy consumption by 2020.**

**Solar energy is ...**

- A low intensity (i.e., low temperature) heat source that is not adequate for most industrial heat requirements.
- Available for only a portion of the 24-hour day (i.e., 8 to 12 hours/day).
- Relatively expensive to collect, control and store.
- Sometimes not available for days due to inclement weather.
- Often (mostly) not an acceptable solution without a back-up system.

# SOLAR ENERGY
## *Availability*




| Location | | JAN | MAR | MAY | JUL | SEP | NOV |
|---|---|---|---|---|---|---|---|
| Santa Maria | CA | 970 | 1779 | 2343 | 2509 | 1934 | 1155 |
| Los Angeles | CA | 897 | 1609 | 2048 | 2402 | 1845 | 1037 |
| Fresno | CA | 679 | 1576 | 2387 | 2517 | 1882 | 923 |
| Davis | CA | 642 | 1439 | 2306 | 2517 | 1819 | 819 |
| Las Vegas | NV | 1022 | 1915 | 2590 | 2491 | 2033 | 1173 |
| Boston | MA | 476 | 1070 | 1642 | 1793 | 1232 | 502 |
| Cleveland | OH | 461 | 1118 | 1852 | 2074 | 1026 | 520 |
| Pittsburgh | PA | 347 | 797 | 1583 | 1834 | 1251 | 435 |
| Seattle | WA | 277 | 978 | 1856 | 2089 | 1196 | 384 |

# SOLAR ENERGY

## *Not Just a Matter of Economics*

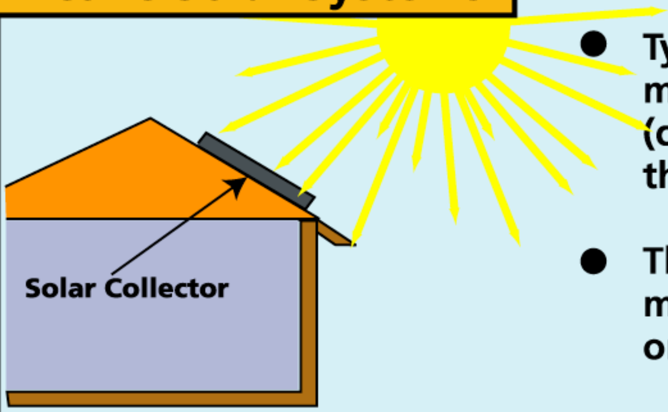
**The arguments for and against solar energy cannot be based purely on economic criteria.**

- Fossil fuel sources are being rapidly depleted (e.g., oil and natural gas).
- Even renewable fossil fuel sources may take years to regenerate (e.g., lumber).
- The production of usable energy from fossil fuel is often accompanied by pollution (e.g., coal).
- Low intensity solar energy is entirely adequate for residential hot water and space heating, but not at all adequate for most industrial heat requirements.

# SOLAR ENERGY
## *Active or Passive*

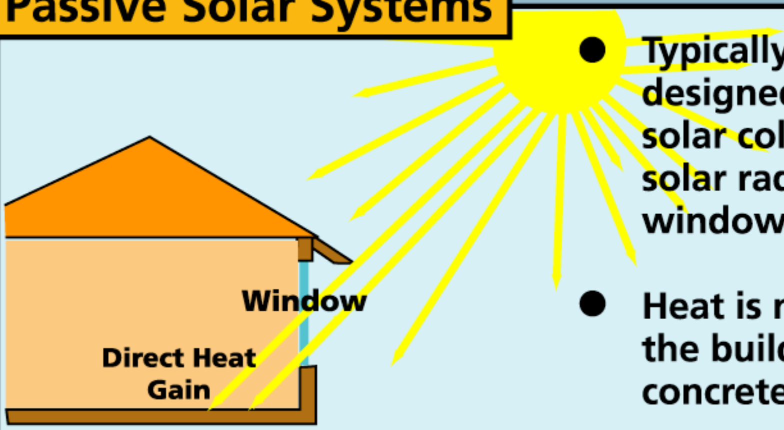
**The difference between active and passive solar systems is not that active systems have mechanical components and passive systems do not. Some passive solar systems are highly mechanical in nature.**

## Active Solar Systems




- Typically consist of manufactured units (collectors) mounted on the roofs of buildings.
- The heat transmission medium is normally water or air.

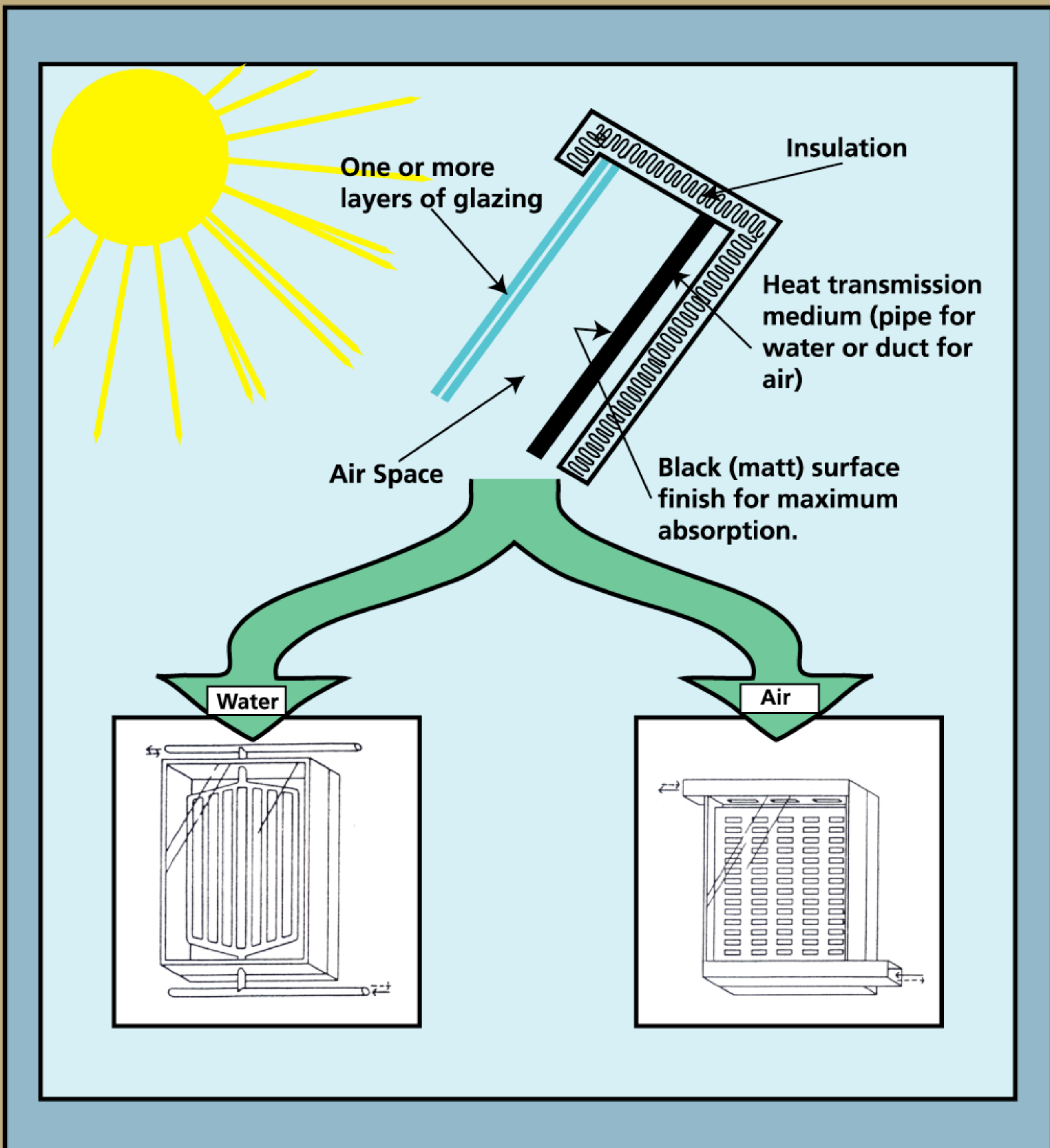
## Passive Solar Systems




- Typically the building is designed to function as a solar collector by capturing solar radiation through windows.
- Heat is normally stored in the building envelope (e.g., concrete floor).

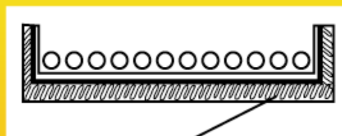
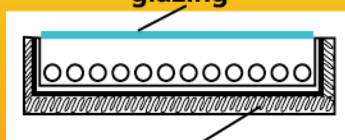
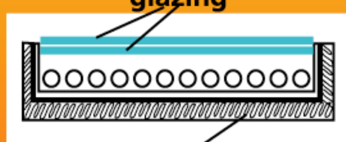
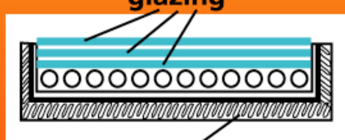
# SOLAR ENERGY

## *Active: Flat Plate Collector Components*



# SOLAR ENERGY

## *Active: Collector Efficiency*

| Collector Type (based on construction) | Typical Temp. (˚F) | Efficiency (%) |
|---|---|---|
| No insulation and no glazing  black garden hose | 90˚F | 20% |
| No glazing (but insulated)  insulation | 130˚F | 30% |
| Single glazing (and insulated) glazing  insulation | 160˚F | 50% |
| Double glazing (and insulated) glazing  insulation | 180˚F | 60% |
| Triple glazing (and insulated) glazing  insulation | 212˚F (boiling) | 70% |

# SOLAR ENERGY

## *Active: Water vs. Air Collectors*

### Water

- Direct heat for hot water service.
- Indirect or direct for space heating.
- Water storage.
- Small pipes.
- Antifreeze or drainage may be required in winter.
- Leakage potential.

### Air

- Direct heat for space heating.
- Indirect heat for hot water service.
- Rock storage.
- Large ducts.
- No freezing problems in winter.
- Fewer leakage problems.

### Collector Efficiency Factors

1. Operating temperature (difference between $T_{Entry}$ and $T_{Collector}$ is very significant).
2. Degree of thermal insulation.
3. Number of glazing layers.
4. Selective surface finish of collector plate (emissivity of heat absorbing surface).

# SOLAR ENERGY

## *Active: Heat Storage*

**The ability of a material to store heat is a function of its heat capacity, which is a product of the specific heat and the density.**

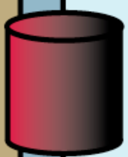
| Storage Material | Specific Heat (BTU/LB-°F) | Density in Container (LB/CF) | Heat Capacity (BTU/CF-°F) |
|---|---|---|---|
| Water | 1.00 | 62 | 62 (0% void) |
| Air | 0.24 | 0.075 | 0.018 |
| Rock* | 0.21 | 130 | 27 (25% void) |
| Concrete | 0.23 | 140 | 32 (0% void) |
| Brick | 0.20 | 140 | 27 (5% void) |
| Scrap Iron | 0.12 | 490 | 41 (30% void) |
| Sand | 0.19 | 120 | 16 (30% void) |

* Rock is really gravel (i.e., pebbles).

# SOLAR ENERGY

## *Active: Water vs. Rock Storage*

### Water Storage



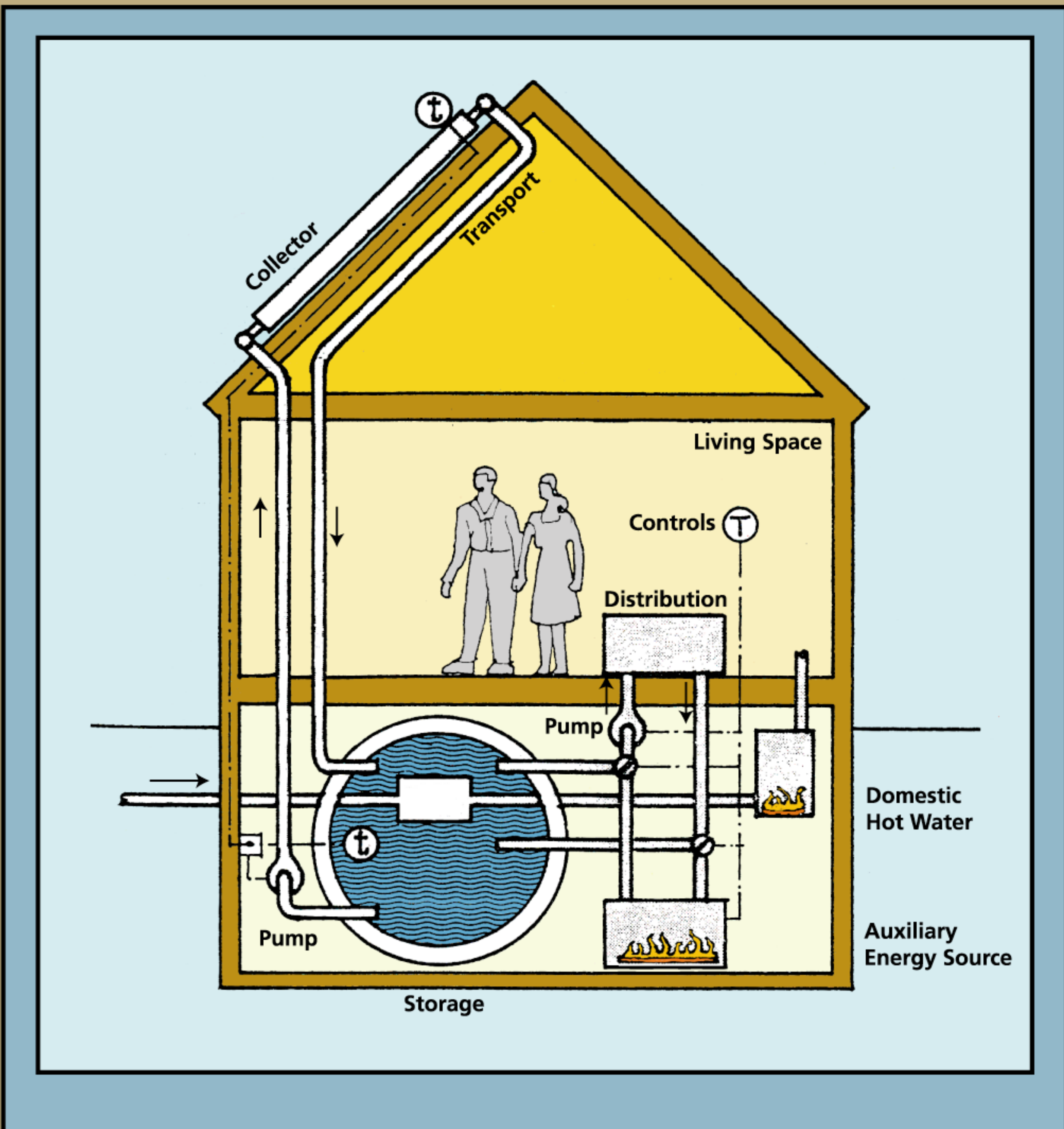
- Water is readily available at virtually no cost and has a high heat capacity (62 BTU/CF-°F).
- Heat does not stratify well in water (additional small tank may be required).
- Pipes are small, contain sharp bends, and are easily accommodated in walls, floors and ceilings.
- Tanks are subject to leakage, freezing and corrosion.

### Rock Storage

- Requires 2.5 times the volume of water and has to be purchased (pebbles are usually 0.75 to 3 inches in diameter).
- The smaller the pebble size the greater the resistance to air flow, the larger the fan and the more electricity consumed.
- High degree of heat stratification allows reverse air flow for withdrawing heat.

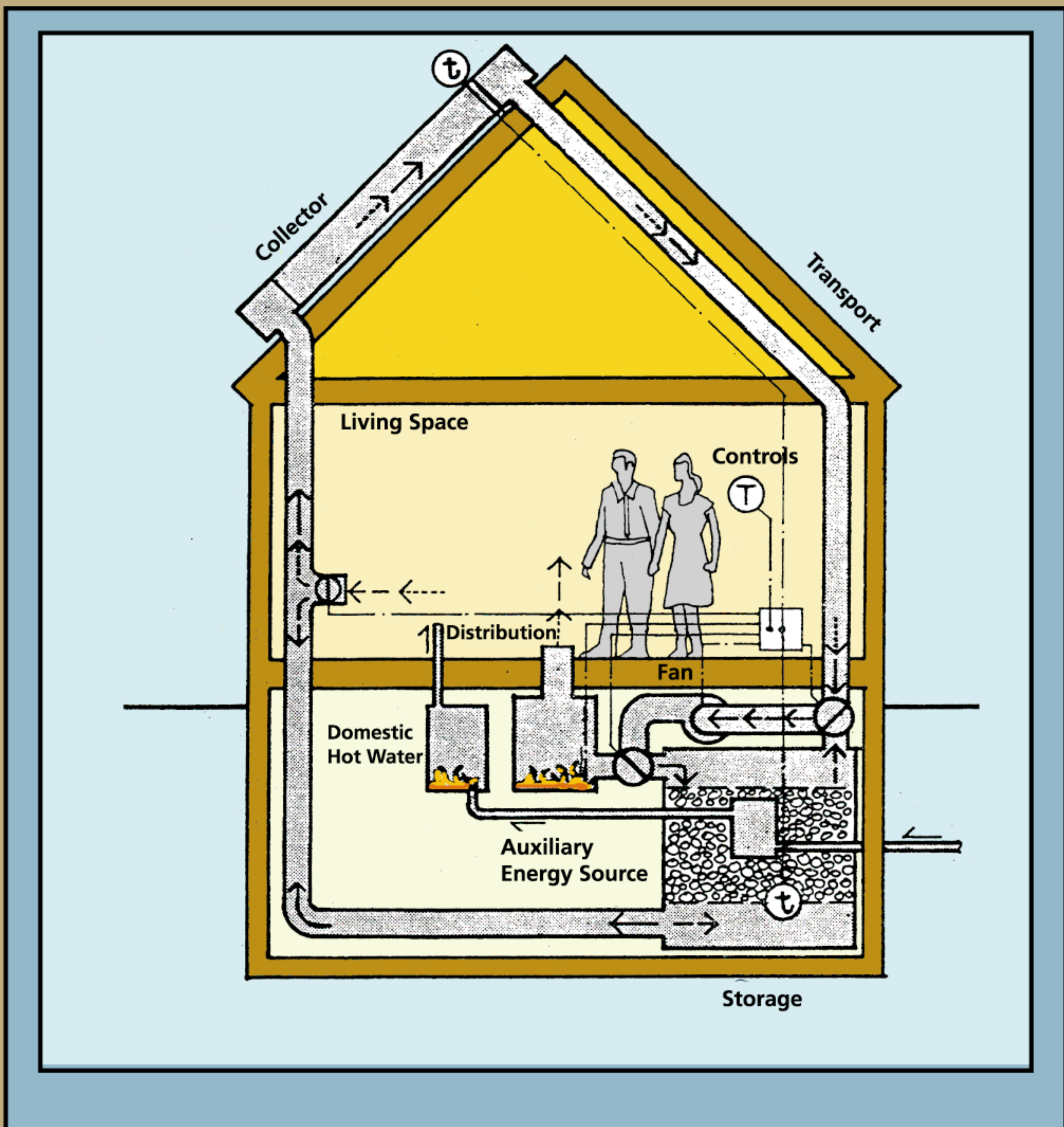
# SOLAR ENERGY

## *Active: Typical Water System*



# SOLAR ENERGY

## *Active: Typical Air System*



# SOLAR ENERGY

## *Sizing a Hot Water Service*

$$\text{Collector Area (SF)} = 834 \frac{\left[\text{Gallons of hot water required per day}\right] \times \left[\text{Temperature of hot water} - \text{Temperature of cold water}\right]}{\left[\text{Daily solar radiation (BTU/SF)}\right] \times \left[\text{Collector efficiency (\%)}\right] \times \left[\frac{\text{\% Sunshine}}{100}\right]}$$

### Typical Example

Total hot water required = 72 gal/day*
Temperature of hot water = 120 ˚F
Temperature of cold water = 60 ˚F
Daily solar insolation = 2,200 BTU/SF/day
% Sunshine = 70%
Collector efficiency = 50%

$$\text{Required Collector Area (SF)} = \frac{834 \times 72 \times [120 - 60]}{2{,}200 \times 50 \times 0.70} = 47\ \text{SF}$$

*(Average daily consumption of hot water is about 12 gal./person.)

# SOLAR ENERGY

## *The 'Degree-Day' Concept*

**The Degree-Day (DD) concept provides a simplified procedure for calculating the size of a solar collector system. It assumes that there is no heating requirement if the external temperature is higher than a certain temperature (e.g., 65˚F).**

- **Each degree below the 'DD base temperature' (e.g., 65˚F) is considered to be one DD.**
- **If the mean monthly temperature for May in a particular locality is 60˚F, then each day of May has 5 DD (i.e., 5 DD/day or 155 DD/month).**
- **If the heat loss for a building (in the same locality) is 1,000 BTU/HR/˚F, then:**

$$\text{heat loss} = 24 \times 1{,}000 \times [65 - 60] = 120{,}000 \text{ BTU/DD}$$

$$\text{heat loss} = 120{,}000 \times 155 = 18.6 \times 10^6 \text{ BTU/month}$$

# SOLAR ENERGY

## *Sizing a Space Heating System*

$$\text{Collector Area (SF)} = 100\,\frac{\left[\text{Heat required (BTU/month)}\right] \times \left[\text{Heat from sun (\%)}\right]}{\left[\text{Monthly solar insolation at collector tilt (BTU/SF)}\right] \times \left[\text{Collector efficiency (\%)}\right] \times \left[\text{Monthly sunshine (\%)}\right]}$$

**Typical Example**

| | | |
|---|---|---|
| Location and latitude | = | Santa Maria (35°N) |
| Total heating load | = | 30,000 BTU/DD |
| Degree Days in January | = | 459 DD |
| Collector efficiency | = | 38% |
| Percentage of sunshine in January | = | 60% |
| Heat from sun | = | 80% |

$$\text{Required Collector Area (SF)} = \frac{100 \times [30{,}000 \times 459] \times 80}{100{,}000 \times 38 \times 60} = 484\ \text{SF}$$

# SOLAR ENERGY

## *Sizing a Heat Storage Facility*

$$\text{Storage Volume (CF)} = \frac{\left[\text{Heat required (BTU/day)}\right] \times \left[\text{Storage period (days)}\right]}{\left[\text{Storage material heat capacity (BTU/CF-°F)}\right] \times \left[\text{Max. temp. of storage material} - \text{Min. temp. of usable heat}\right]}$$

### Typical Example

Heat capacity of water = 62 BTU/CF-˚F
Max. temp. of storage material = 150˚F
Min. temp. of usable heat = 90˚F
Storage period = 2 days

$$\text{Storage Volume (CF)} = \frac{[30{,}000 \times 459/31] \times 2}{62 \times [150 - 90]} = 239 \text{ CF}$$

(i.e., approx. 2,000 gal.)

# SOLAR ENERGY

## *Solar System Design Steps*

1. Determine the heat loss experienced by the building each month (i.e., BTU/DD x DD/month).

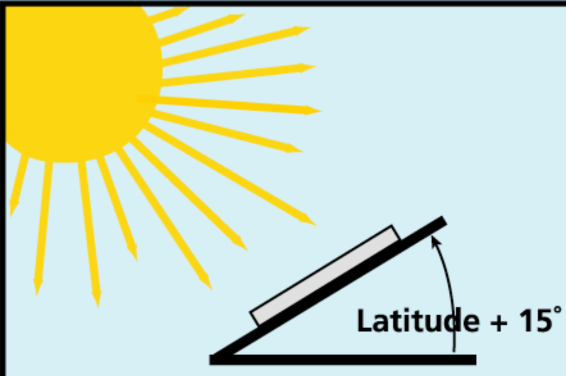
2. Establish the amount of solar insolation per month (i.e., depends on latitude, tilt and efficiency of collector, and % of sunshine).

3. Assume the percentage of the total heating requirements to be provided by solar energy.

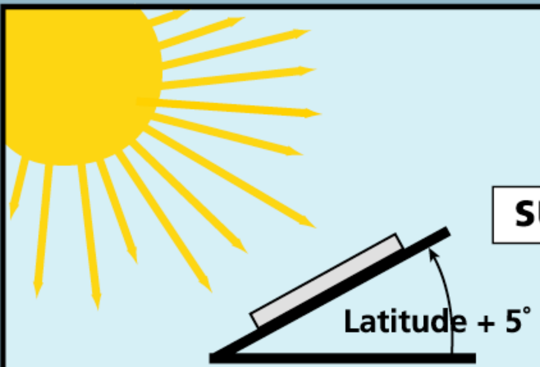
4. Select the heat storage material and decide on the storage period.

# SOLAR ENERGY

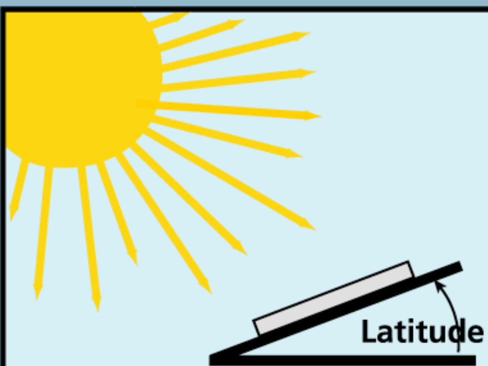
## *Active: Optimum Collector Tilts*




For **winter heating** optimum collector tilt is approx. **latitude + 15°**.




For combined **winter heating** and **summer cooling** optimum collector tilt is approx. **latitude + 5°**.




For year round **hot water** heating, optimum collector tilt is approx. equal to the **latitude**.

# SOLAR ENERGY

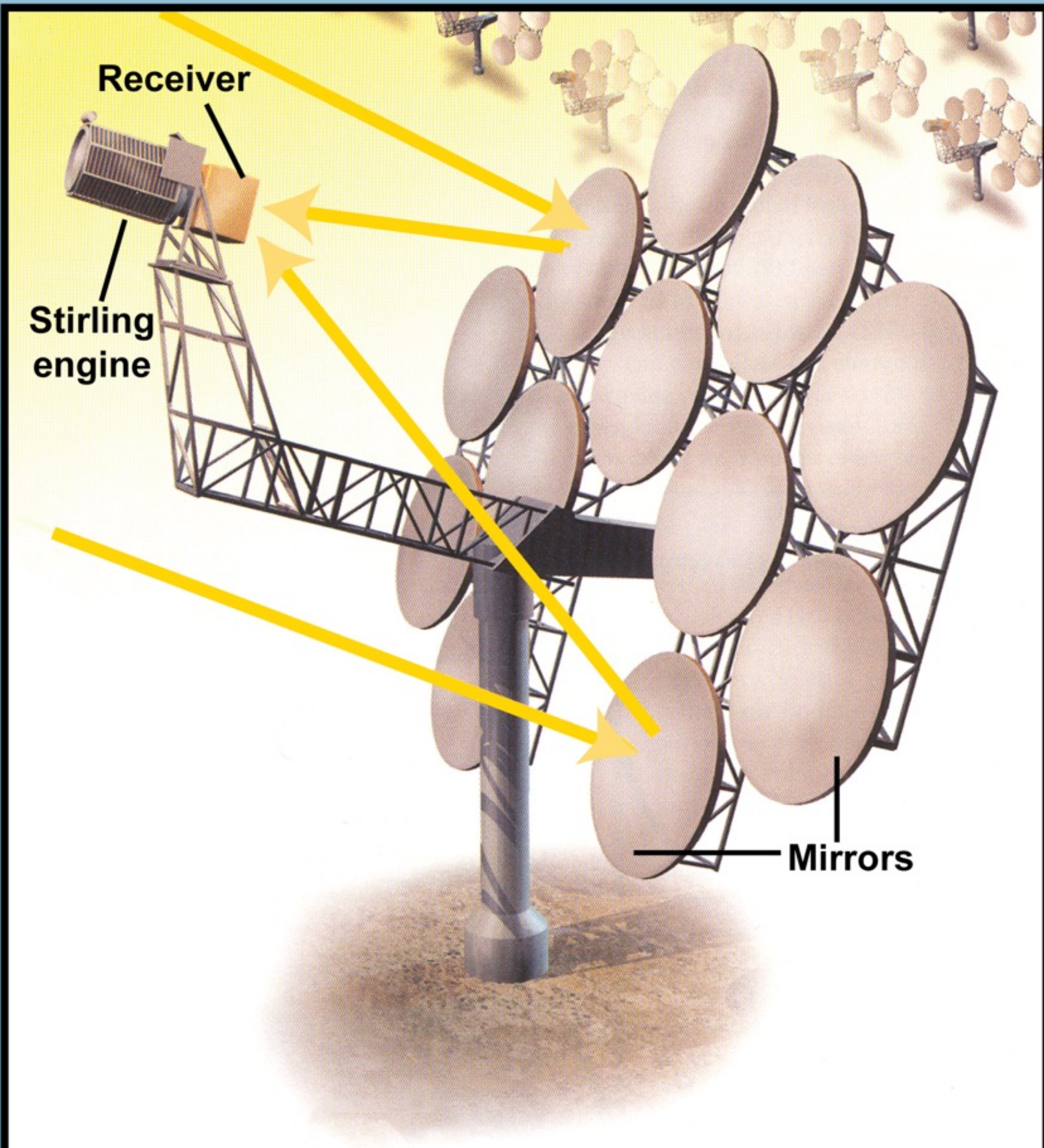
## *Active: Rules of Thumb*

- √ Approximately 1 to 10 gallons of water are normally required per SF of collector area for heat storage.
- √ Rock heat storage is approximately 2.5 times larger in volume than water storage.
- √ Pebble sizes in rock storage normally range between 0.75 to 3 inches.
- √ Heat storage facilities require substantial thermal insulation (R20 to R30, i.e., 3 to 5 inches of polyurethane foam).
- √ Under good weather conditions 1 SF of single-glazed solar collector should be able to heat 1 gallon of water from 60° to 120°F.

# SOLAR ENERGY

## *Solar Concentrators*

**A solar-thermal array consists of hundreds of dish-shaped solar concentrators focused on an electricity generating engine capable of converting heat to electricity.**

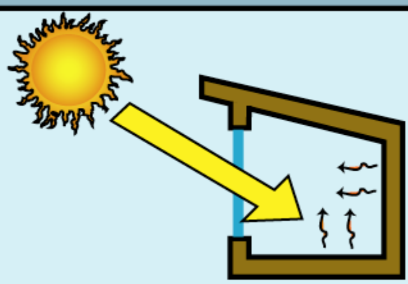



Source: Kammen, Daniel M., "The Rise of Renewable Energy", Scientific American, September 2006, pg. 88

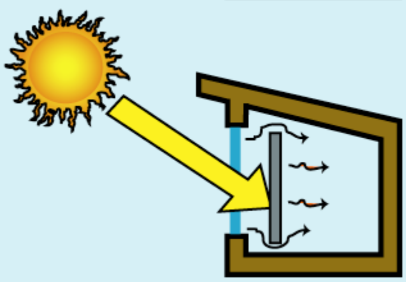
# SOLAR ENERGY

## *Passive Solar System Types*

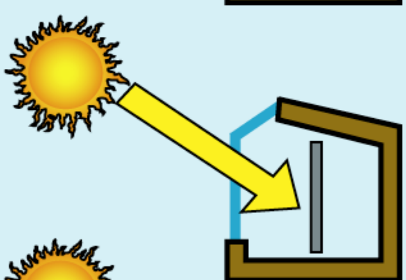
**In passive solar systems the building itself is designed to be a solar collector.**



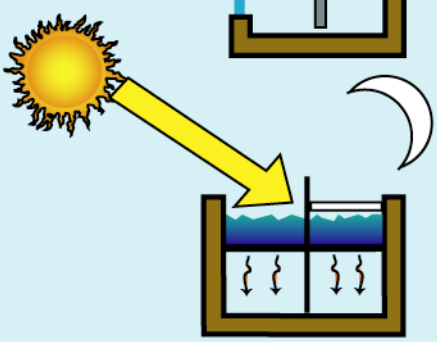
**Direct Gain** Sun penetrates directly through south facing windows or skylights into building space and is absorbed by internal surfaces, which serve as heat stores.



**Trombe Wall** Sun penetrates through south facing windows or skylights, but is blocked by a heat storage wall (Trombe Wall). Heat storage and utilization can be controlled by sliding insulation panels on the internal and external sides of the Trombe Wall.



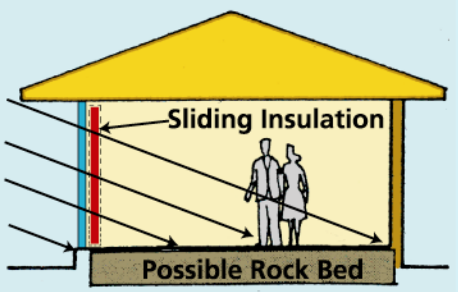
**Sunspace** Similar to Trombe Wall with Sunspace in front of wall (often serving as a planted (greenhouse) area). Sunspace can be insulated from adjoining interior building space.



**Roof Pond** Water pool on roof is exposed to sun during day and covered with insulation panels at night during Winter. Strategy is reversed for Summer cooling.

# SOLAR ENERGY

## *Direct Gain Systems*




### Orientation and Planning

- Large windows must face south (or skylights in roof).
- Open plan would allow sun and stored heat to serve entire building floor.
- Darker colored internal surfaces will aid heat absorption.

**Heating**

- Warms up quickly in the morning.
- Tends to overheat at midday.
- Much radiant loss through windows at night.
- Insulation panels or triple glazing recommended.

**Cooling**

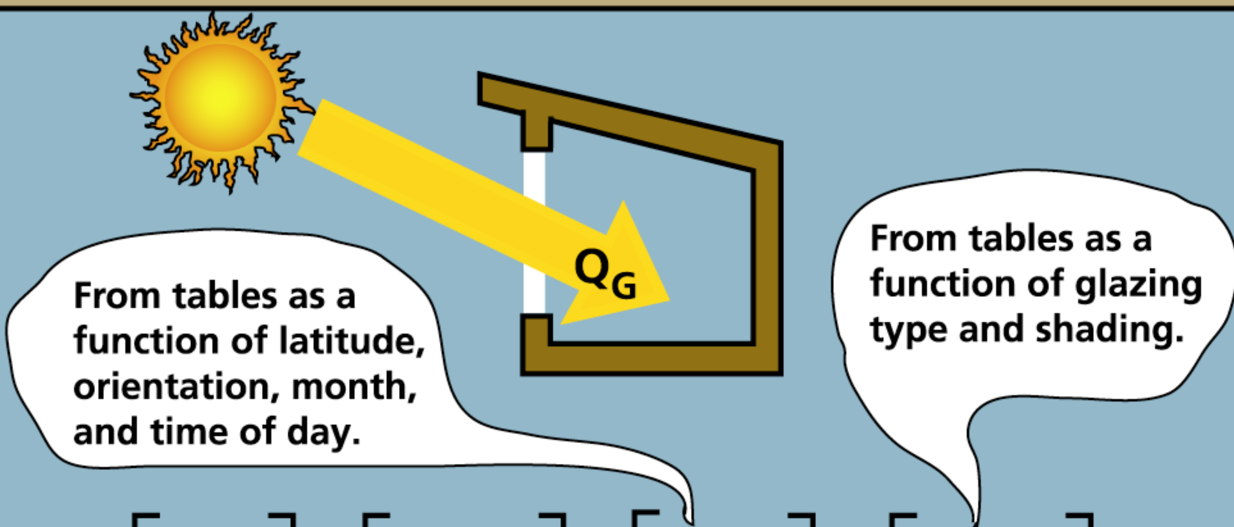
- Difficult to adapt to Summer cooling.
- Cross ventilation and shading will be necessary.

**Daylighting**

- Very high Daylight Factor possible.
- Serious glare potential at window.
- Summer shading reduces daylighting potential.

# SOLAR ENERGY

## *Solar Heat Gain Through Glass*



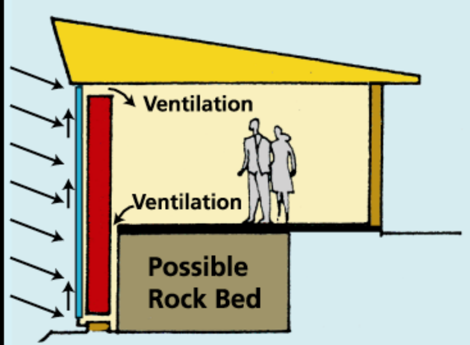

$$Q_G = \left[\begin{matrix}\text{Window}\\ \text{Area}\\ \text{(SF)}\end{matrix}\right] \times \left[\frac{\text{Glass (\%)}}{100}\right] \times \left[\begin{matrix}\text{Solar}\\ \text{Heat Gain}\\ \text{(BTU/HR)}\end{matrix}\right] \times \left[\begin{matrix}\text{Shading}\\ \text{Coefficient}\end{matrix}\right] \text{(BTU/HR)}$$

### Typical Example

| | | |
|---|---|---|
| clear double glazed window | = | 4 FT by 5 FT (20 SF) |
| timber window frame | = | 80% glass area |
| Latitude | = | 32˚ N |
| orientation | = | south |
| date | = | May 21 |
| time | = | 10 a.m. |

$$Q_G = [20] \times [0.8] \times \left[\begin{matrix}54\\ \text{(from}\\ \text{tables)}\end{matrix}\right] \times \left[\begin{matrix}0.84\\ \text{(from}\\ \text{tables)}\end{matrix}\right] = 726 \text{ (BTU/HR)}$$

# SOLAR ENERGY
## *Trombe Wall Systems*




### Orientation and Planning

- Trombe wall can be masonry or water.
- Large windows must face south.
- Outdoor view is blocked.

**Heating**

- Unvented systems are slow to warm by day and slow to cool at night.
- Comfort is best near the Trombe wall surface.

**Cooling**

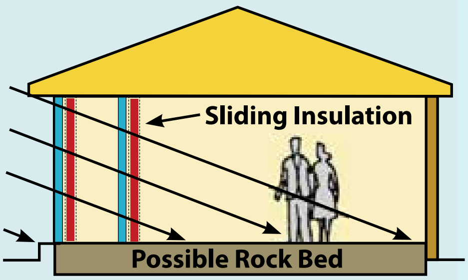
- Cross ventilation is difficult because of wall obstruction.
- High risk of evening overheating.
- Good mass capacity where such is desirable.

**Daylighting**

- Most of the daylight is blocked by wall.
- High glare potential around wall perimeter.
- Diffuse light transmission possible through water wall.

# SOLAR ENERGY

## *Sunspace Systems*




### Orientation and Planning

- Large glass wall must face south.
- Sunspace area is not intended to be a greenhouse.
- Sunspace can be insulated from adjoining spaces.
- Outdoor view blocked from adjoining space(s).

**Heating**

- Sunspace thermal characteristics similar to Direct Gain systems, but more extreme temperature swings.

**Cooling**

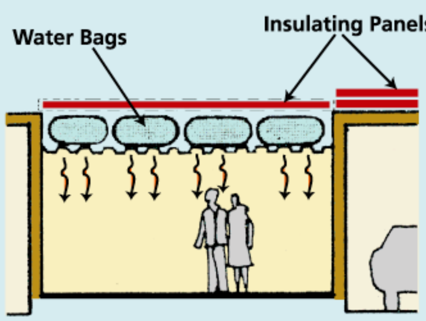
- Accentuated radiant heat loss at night.
- To prevent overheating, sunspace must be vented to outdoors.
- Cross ventilation potential reduced by wall to adjoining space(s).
- Stack ventilation may be effective.

**Daylighting**

- Very high Daylight Factor in sunspace.
- Very low Daylight Factor in adjoining space(s).
- Summer shading reduces daylight potential.

# SOLAR ENERGY

## *Roof Pond Systems*




### Orientation and Planning

- Requires flat or nearly flat roof.
- Completely unrestricted internal plan.
- Unrestricted outside views.
- Requires mechanical movement of insulating panels.

**Heating**

- Low temperature swings throughout year.
- Large solar collection area on roof.

**Cooling**

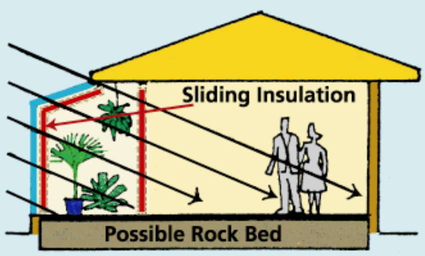
- Excellent cooling potential with nighttime exposure of water to cool sky (radiation).
- Good solar control with automated movement of insulation panels.
- Excellent cross ventilation potential.

**Daylighting**

- No restriction on side lighting.
- Significant restriction on sky lights.
- Light color on ceiling recommended.

# SOLAR ENERGY

## *Greenhouse Systems*




### Orientation and Planning

- Large glass wall must face south.
- Planted greenhouse area adds pleasant character.
- Greenhouse can be insulated from adjoining spaces.
- Outdoor view blocked from adjoining space(s).

**Heating**

- Greenhouse thermal characteristics similar to Sunspace systems, with potentially extreme temperature swings.

**Cooling**

- Accentuated radiant heat loss at night.
- Higher relative humidity due to plants is welcome in hot dry climate.
- Cross ventilation potential reduced by wall to adjoining space(s).
- Stack ventilation may be effective.

**Daylighting**

- Very high Daylight Factor in sunspace.
- Very low Daylight Factor in adjoining space(s).
- Summer shading reduces daylight potential.