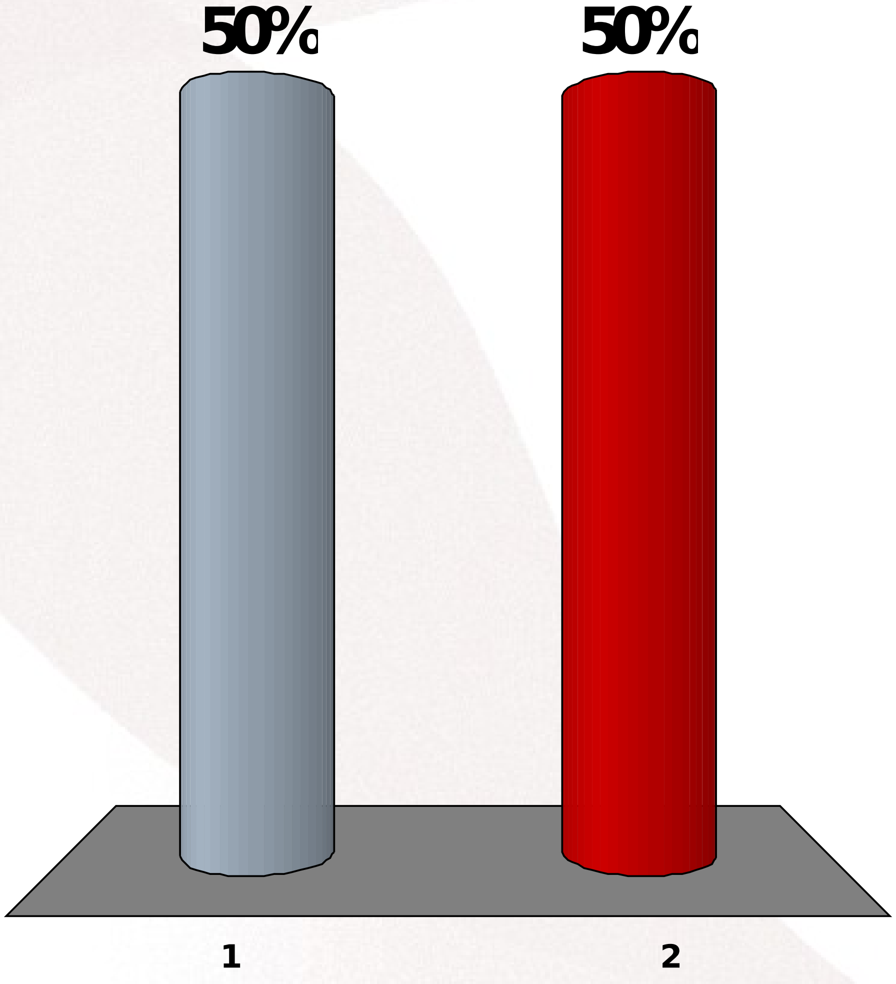
SOLAR ENERGY I

Original slides provided by Dr. Daniel Holland

Do you believe that solar energy can be used to completely replace fossil fuels?

1. Yes
2. No

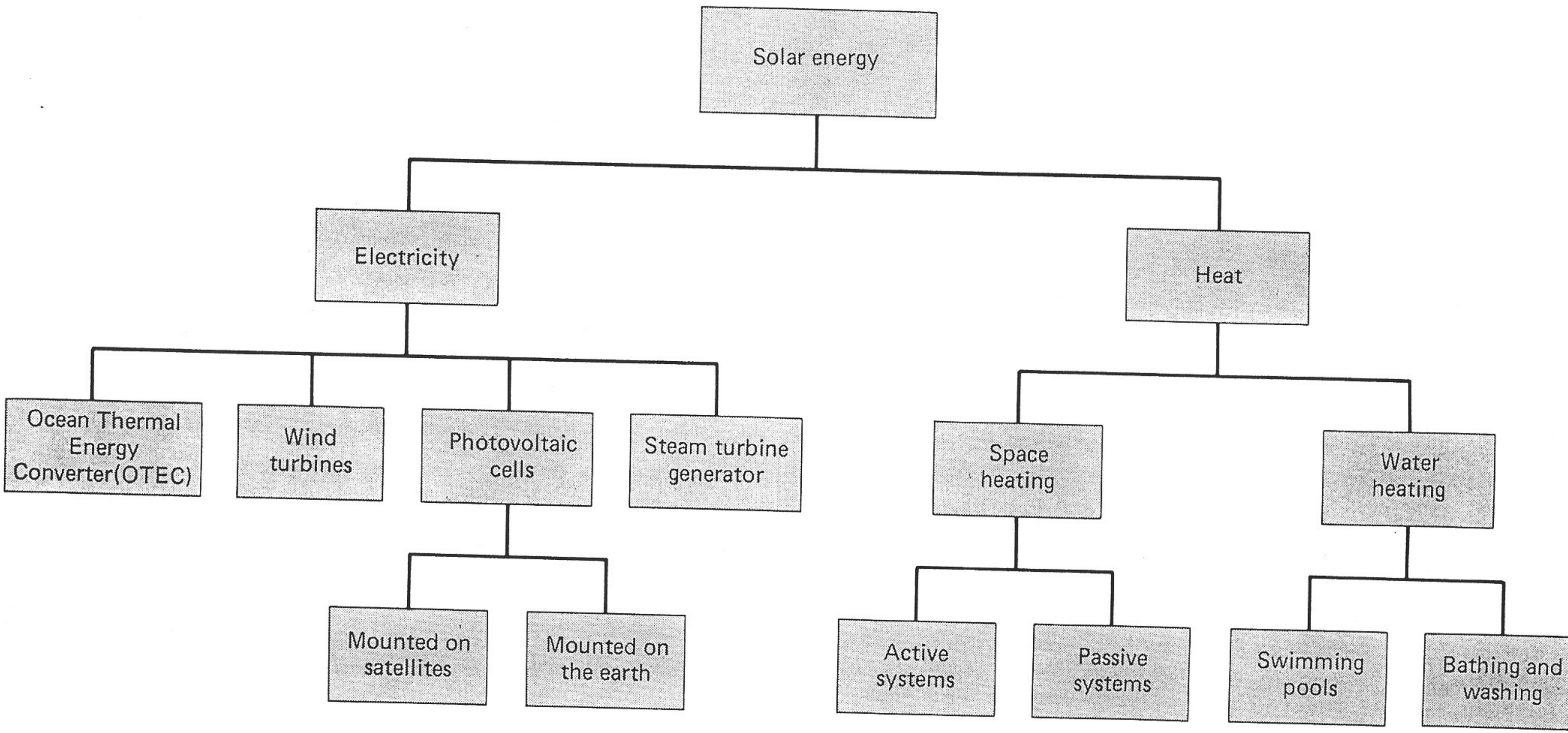


Audio Link

Solar Energy is an energy flow

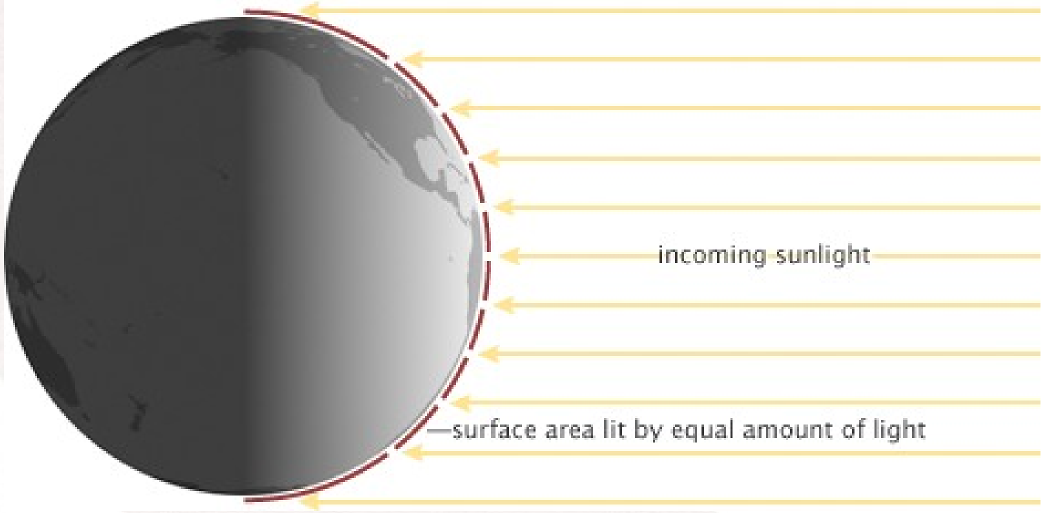
- Many different forms of energy ultimately come from solar
  - Solar heating
  - Photovoltaic
  - Wind
  - Hydroelectric
  - Biomass
  - OTEC
  - Other?

There are many uses of solar energy. This chart delineates most of the uses and charts our study strategy.

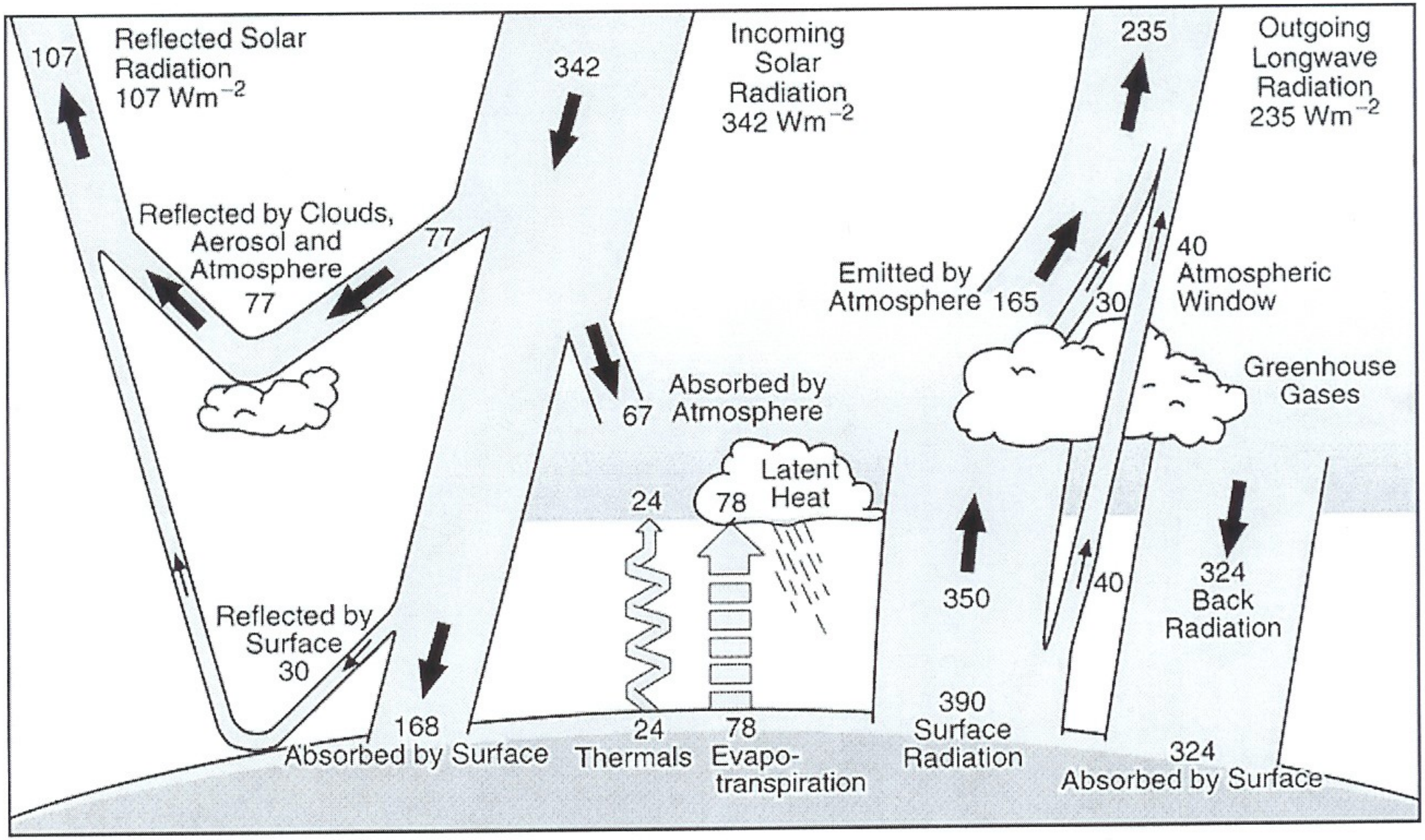


How Much Energy is Available?

- Solar constant id 1367 W/m^2 or 2(cal/min)/cm^2.
- When averaging over the whole planet, reduce by ½ because ½ of earth is night, reduce by another ½ because earth is curved. (This is still at top of atmosphere.)



Only approximately 49% of the sunlight at the top of the atmosphere actually reaches the surfaces. (We'll usually assume 50%)

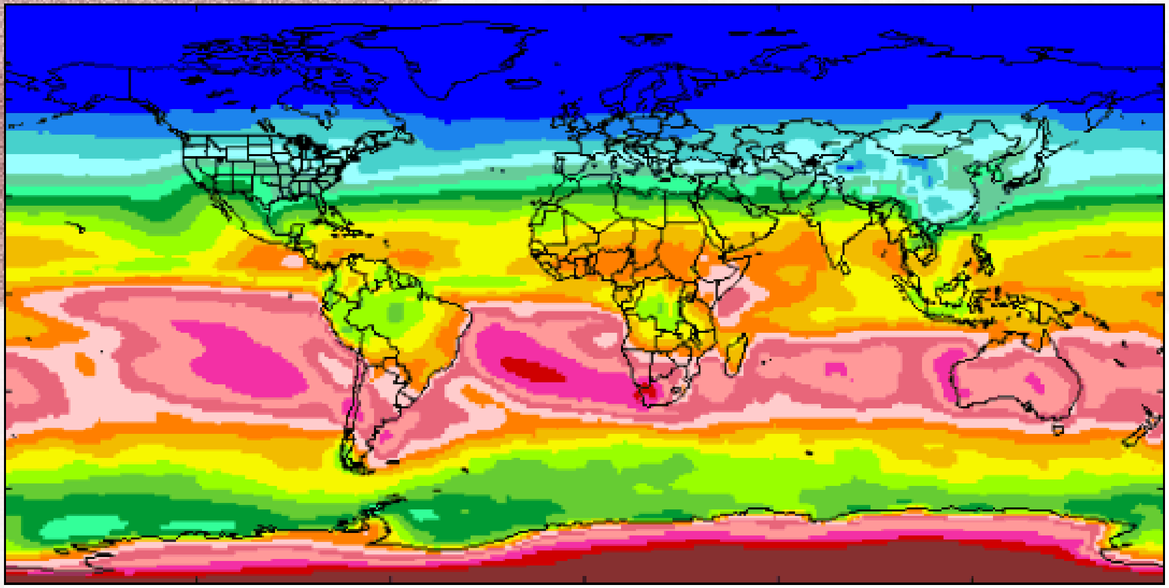


Power Density at the Surface

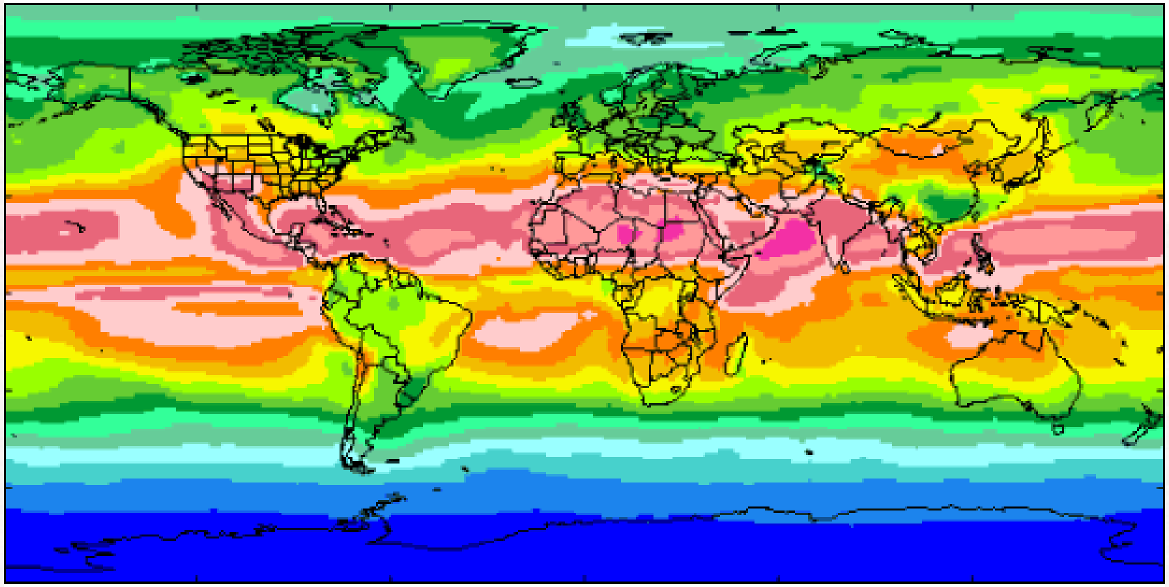
- Average energy at the surface has been reduced by a factor of 8.
- Average power over the entire planet is approximately 170 W/m^2 or 0.25(cal/min)/cm^2
- Obviously the power density depends on where you are, but this is a global average.

Average Energy Density for a Full Day

- $170 W/m^2 (24 \text{ hrs}) = 4.08 \text{ kW} \cdot \text{hr}/m^2$.
- ***Solar Insolation***: Amount of solar radiation reaching the earth's surface.
- Solar insolation varies with time of day, time of year, location on earth, weather.

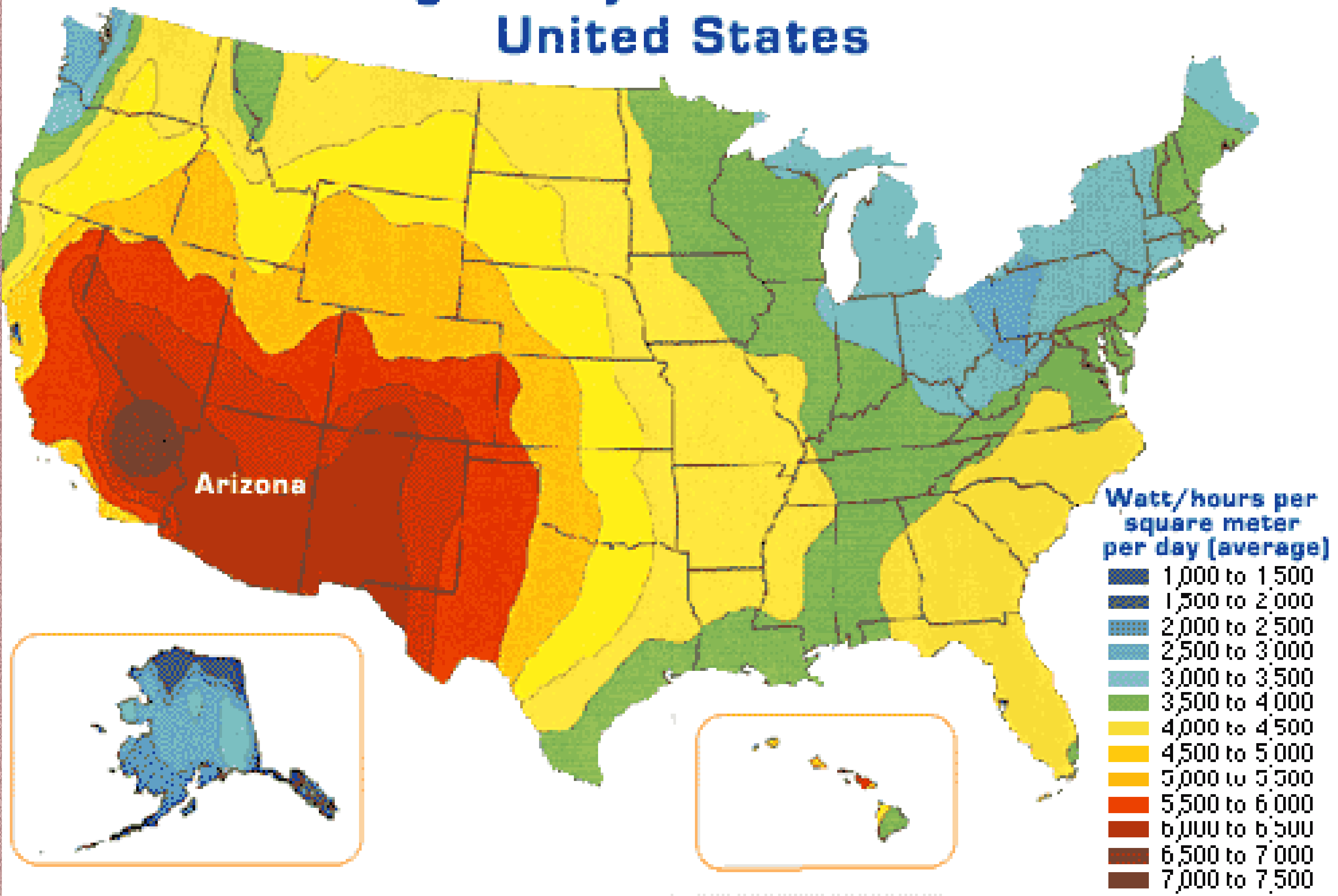


January 1984–1993

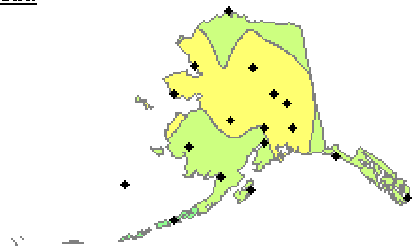


April 1984–1993

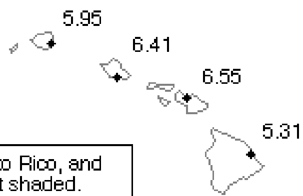
Average Daily Solar Insolation: United States



Alaska

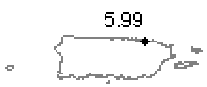


Hawaii



Hawaii, Puerto Rico, and Guam are not shaded.

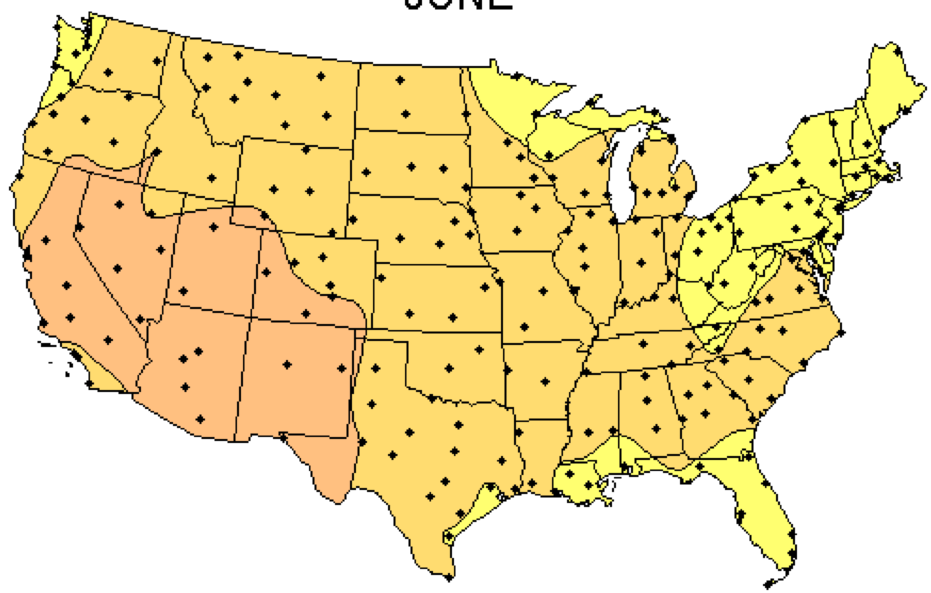
San Juan, PR



Guam, PI

Average Daily Solar Radiation Per Month

JUNE



Flat Plate Tilted South at Latitude - 15 Degrees

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site minus 15 degrees: To optimize performance in the summer, this tilt angle is recommended.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

NREL

National Renewable Energy Laboratory
Resource Assessment Program

$kWh/m^2/day$

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

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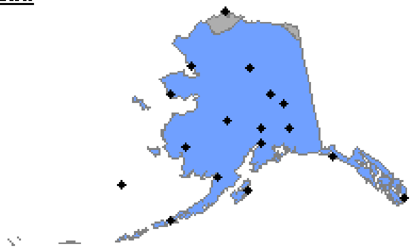
Average Daily Solar Radiation Per Month

DECEMBER

Alaska



Hawaii

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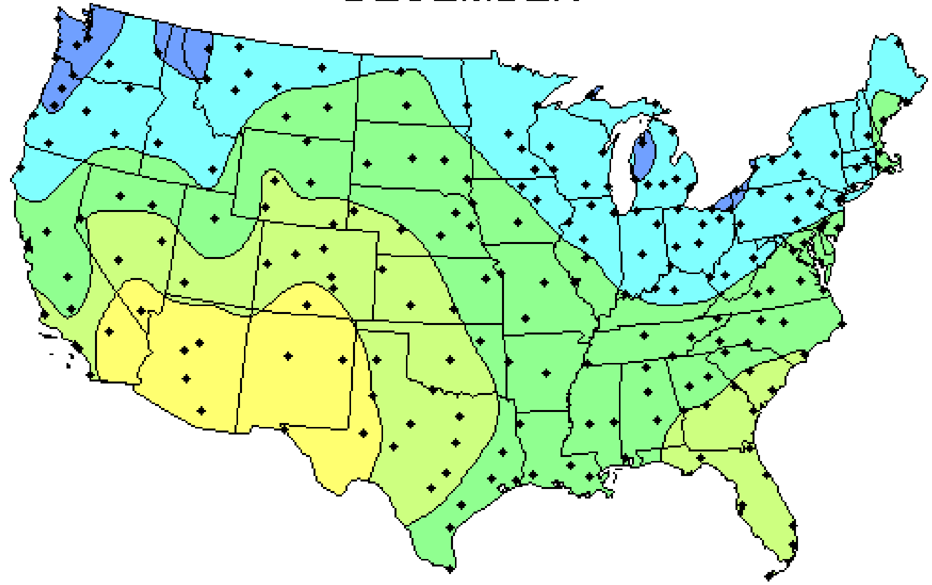
San Juan, PR

Guam, PI



Flat Plate Tilted South at Latitude + 15 Degrees

Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site plus 15 degrees: To optimize performance in the winter, this tilt angle is recommended.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

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- 10 to 14
- 8 to 10
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- none

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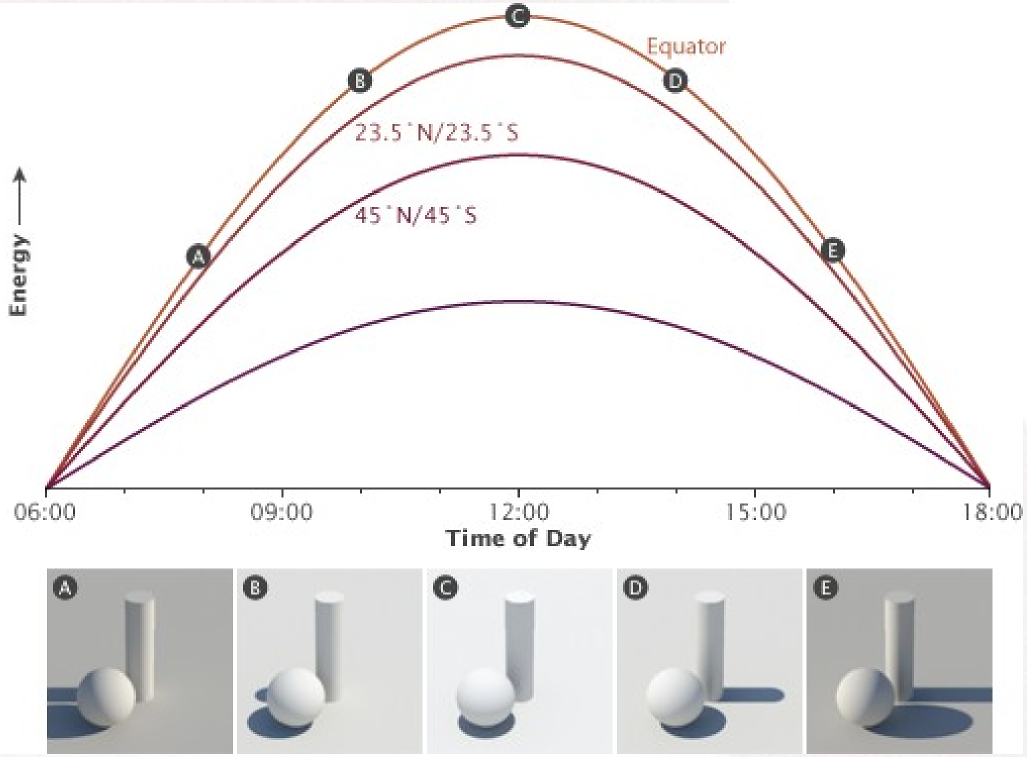
Solar Insolation at 40° N Latitude

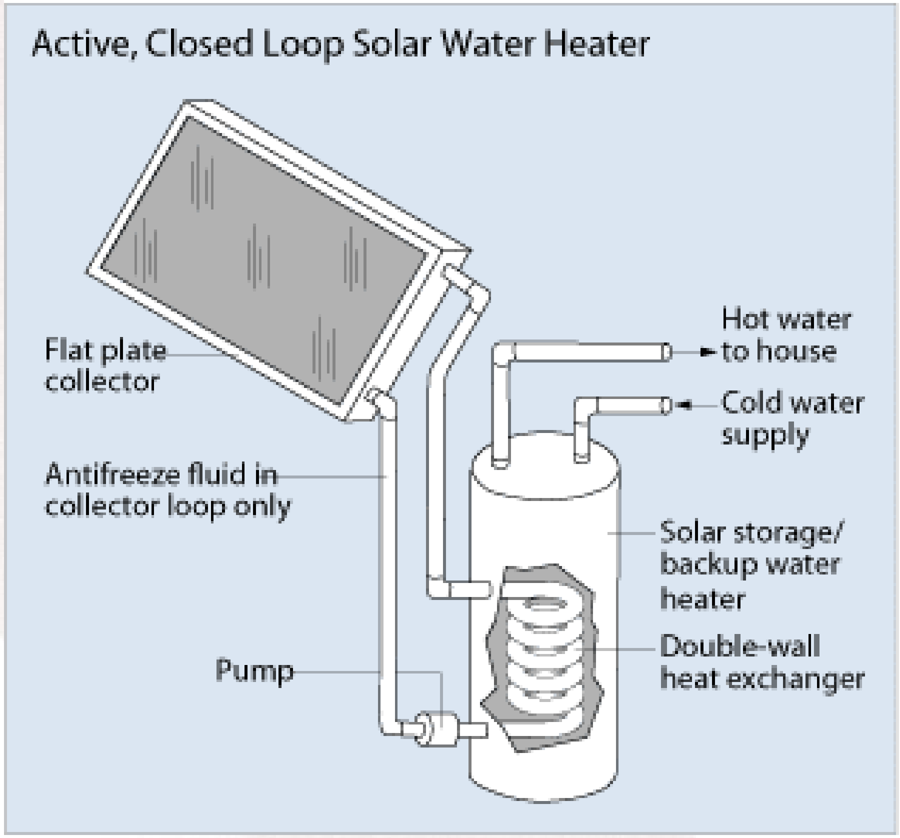


Total Solar Energy in US.

- If we sum the total solar insolation over the entire US we receive approximately 5.6×10^{19} Btu/year.
- We use approximately 94×10^{15} Btu of energy per year.
- Thus , we get around 600 times more energy from the sun than we use every year. If we had 100% efficient solar collectors, we could run the country and still only cover 0.16% with solar collectors!

Solar Heating: Active system

- Fluid is forced through a collector by a pump or blower.



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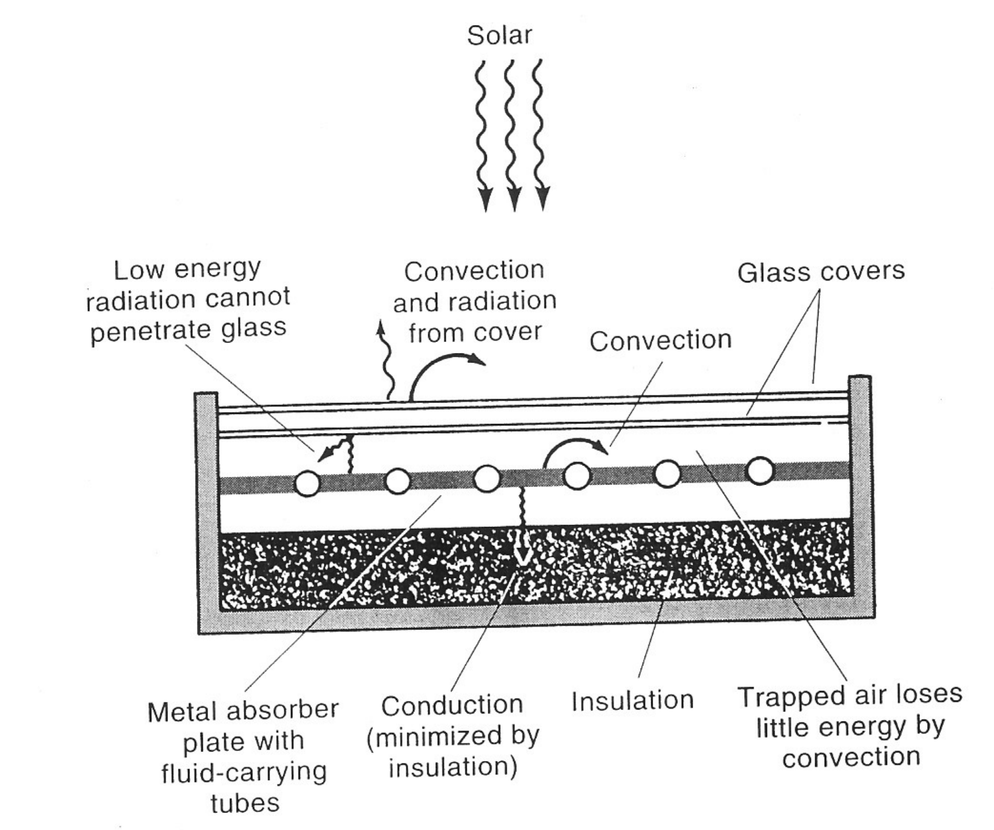
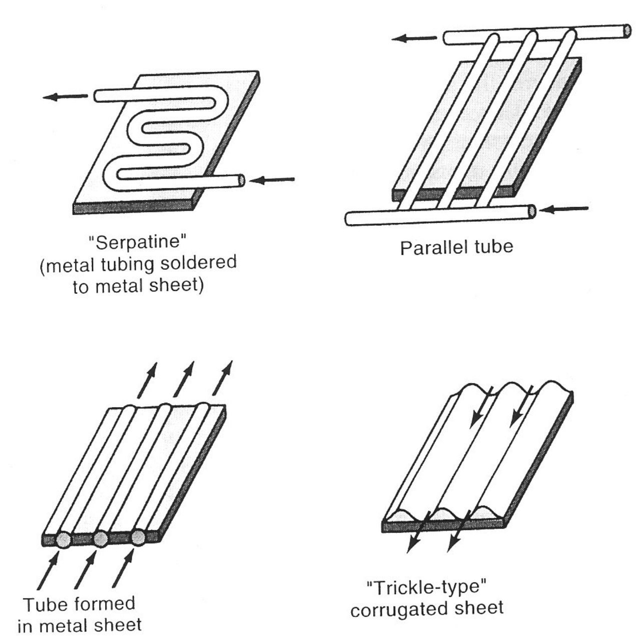


Solar
Low energy radiation cannot penetrate glass
Convection and radiation from cover
Glass covers
Convection
Metal absorber plate with fluid-carrying tubes
Conduction (minimized by insulation)
Insulation
Trapped air loses little energy by convection



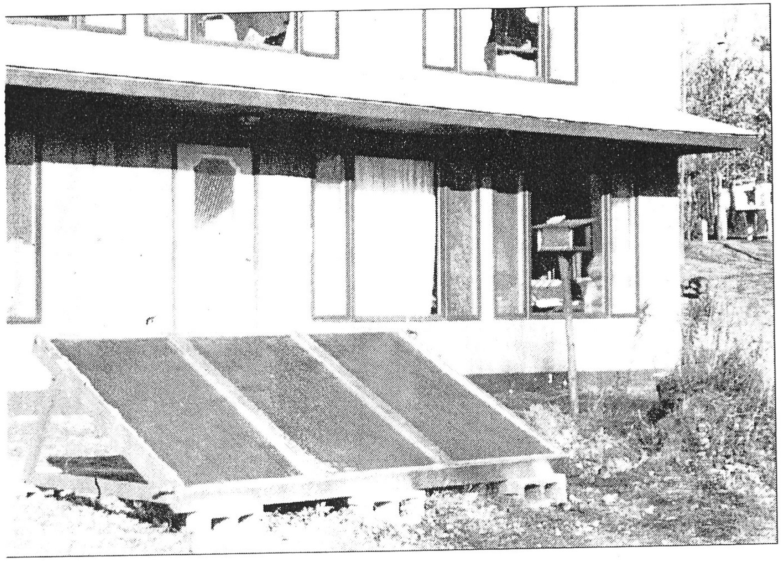
"Serpatine" (metal tubing soldered to metal sheet)
Parallel tube
Tube formed in metal sheet
"Trickle-type" corrugated sheet

Advantages of active systems

- Compact components
- Flexibility of placement/storage units
- Easy to control.

Disadvantage: It takes a least a small amount of power to operate it.

Active Solar Collectors



Selecting the proper angle is important for optimal collection

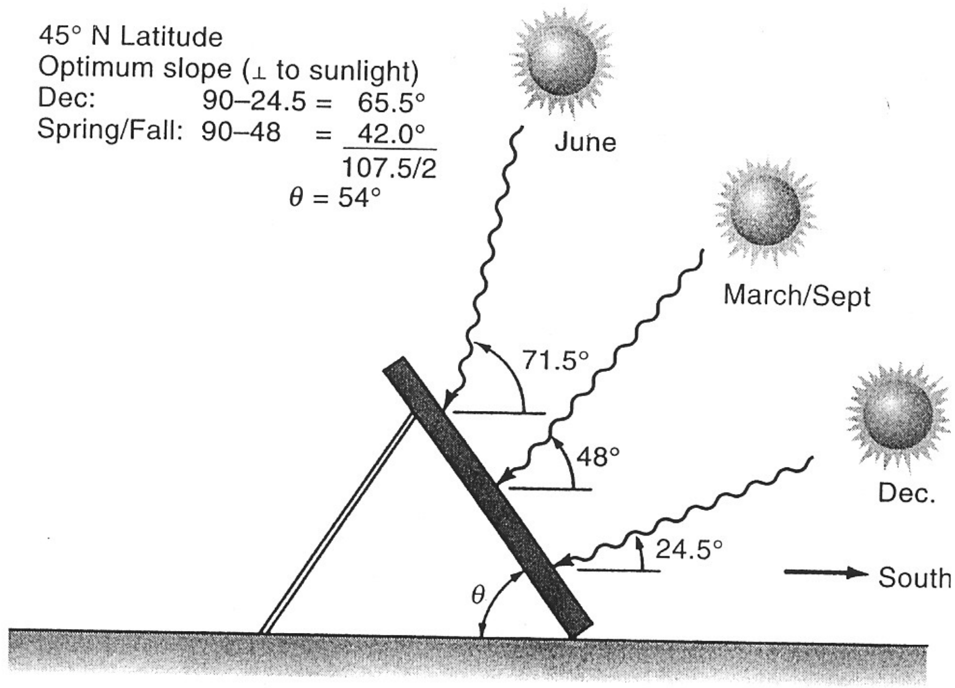
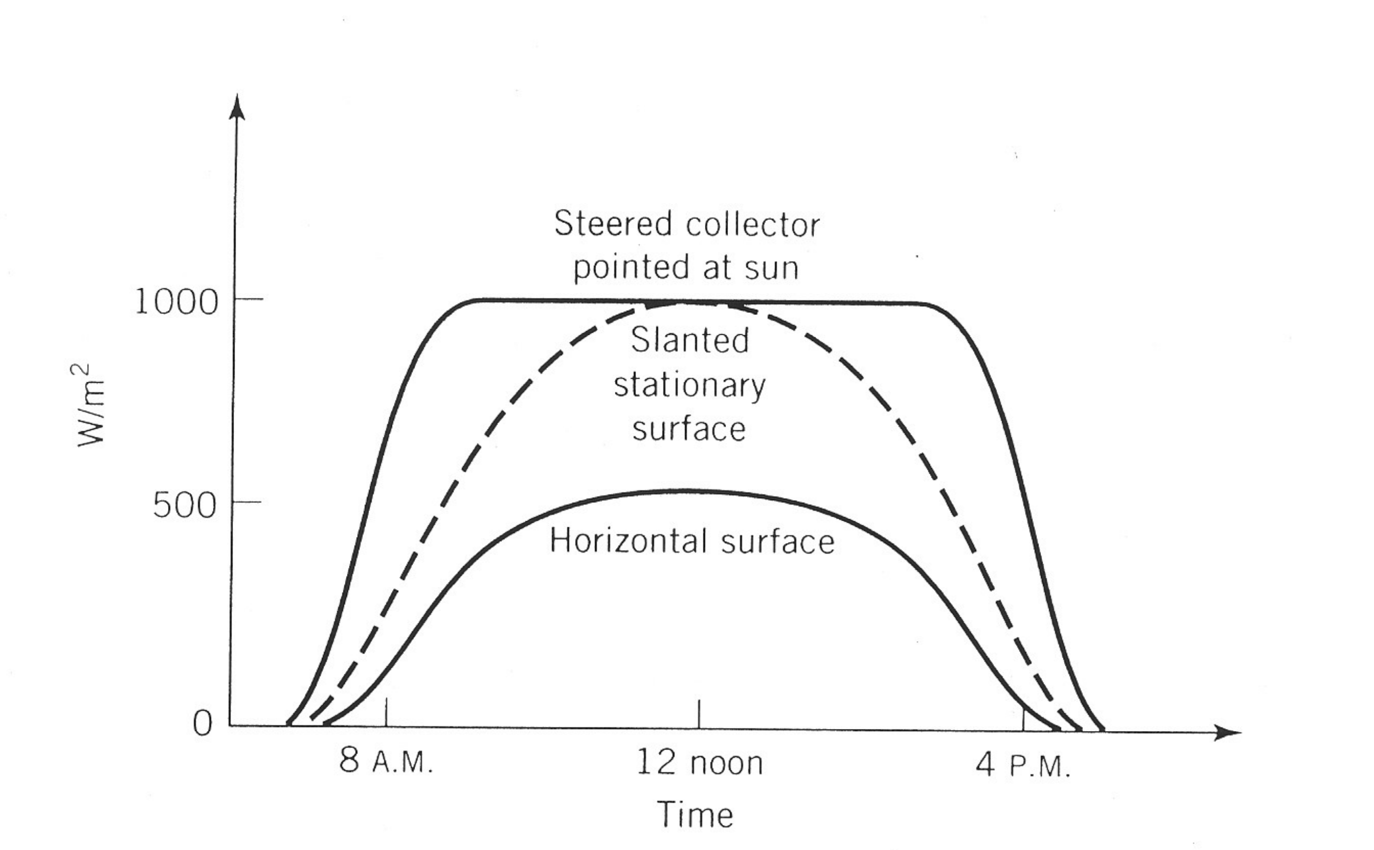


FIGURE 6–34

Calculating collector tilt angle from the horizontal for space heating.

For a fixed panel, make sure it points south (in the Northern Hemisphere.)

Increased Solar Collection by proper tilting of panel.

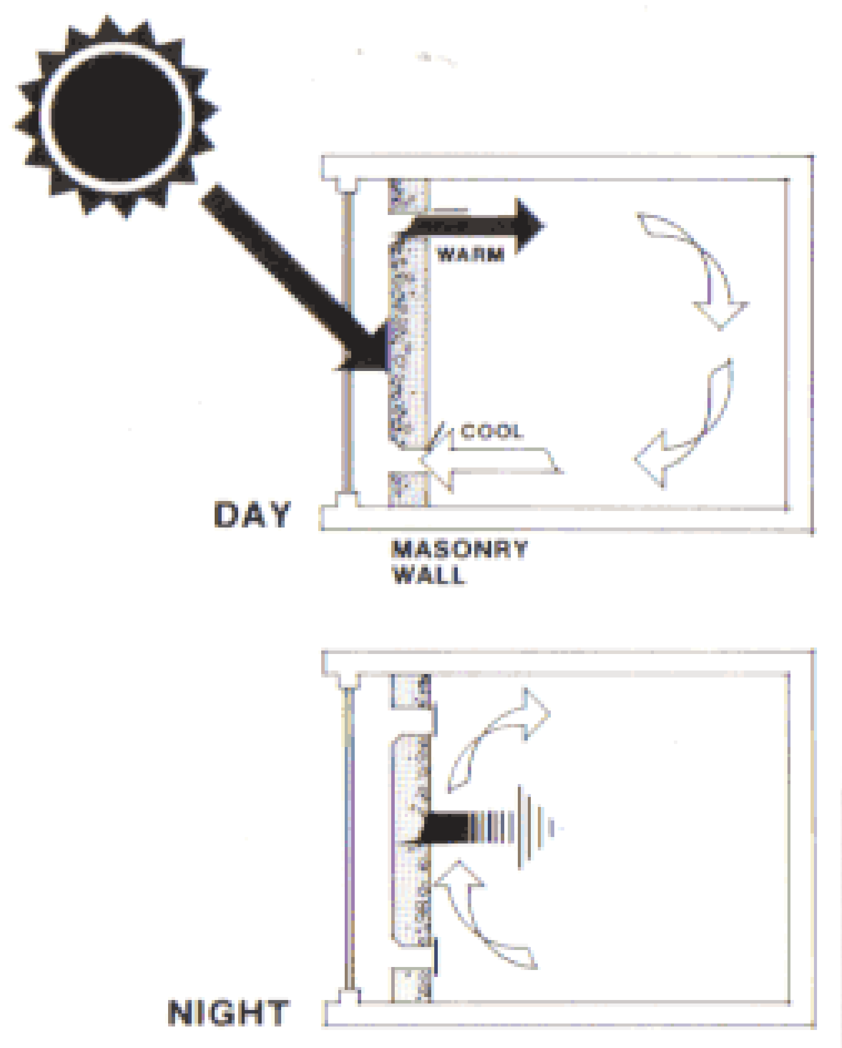


Solar Heating: Passive System

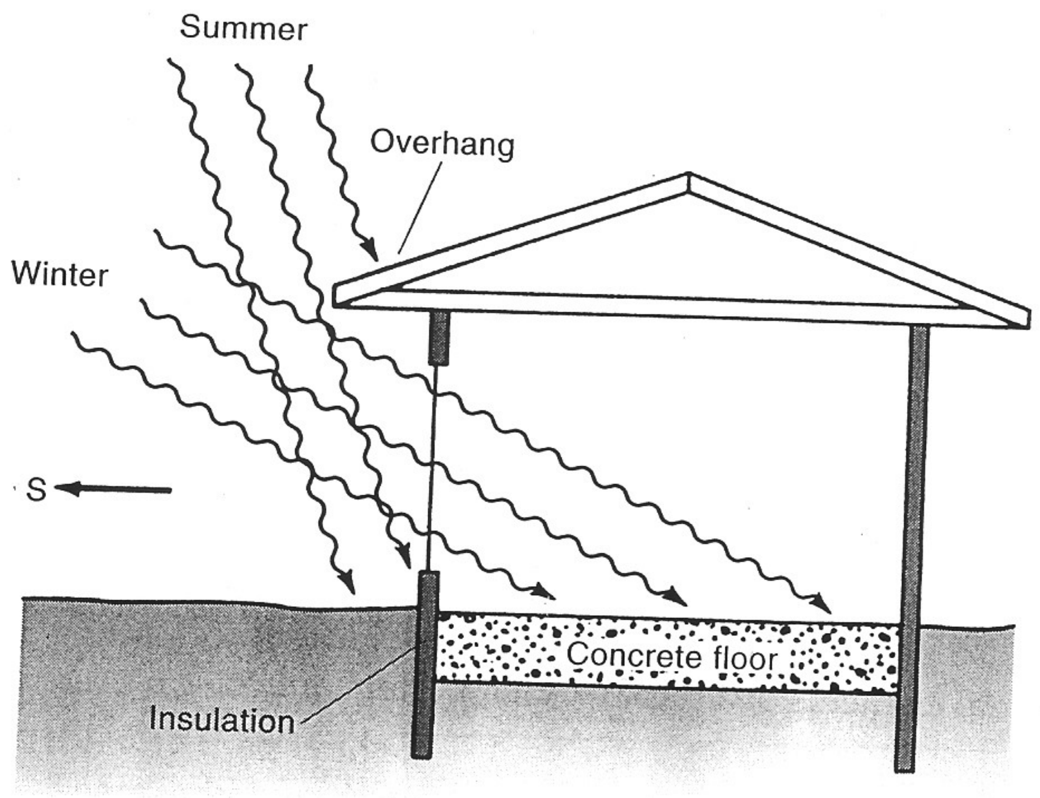
- Use natural convection currents and architectural features to circulate heat:
- No external energy required, but very little flexibility.

Examples of Passive Solar Elements

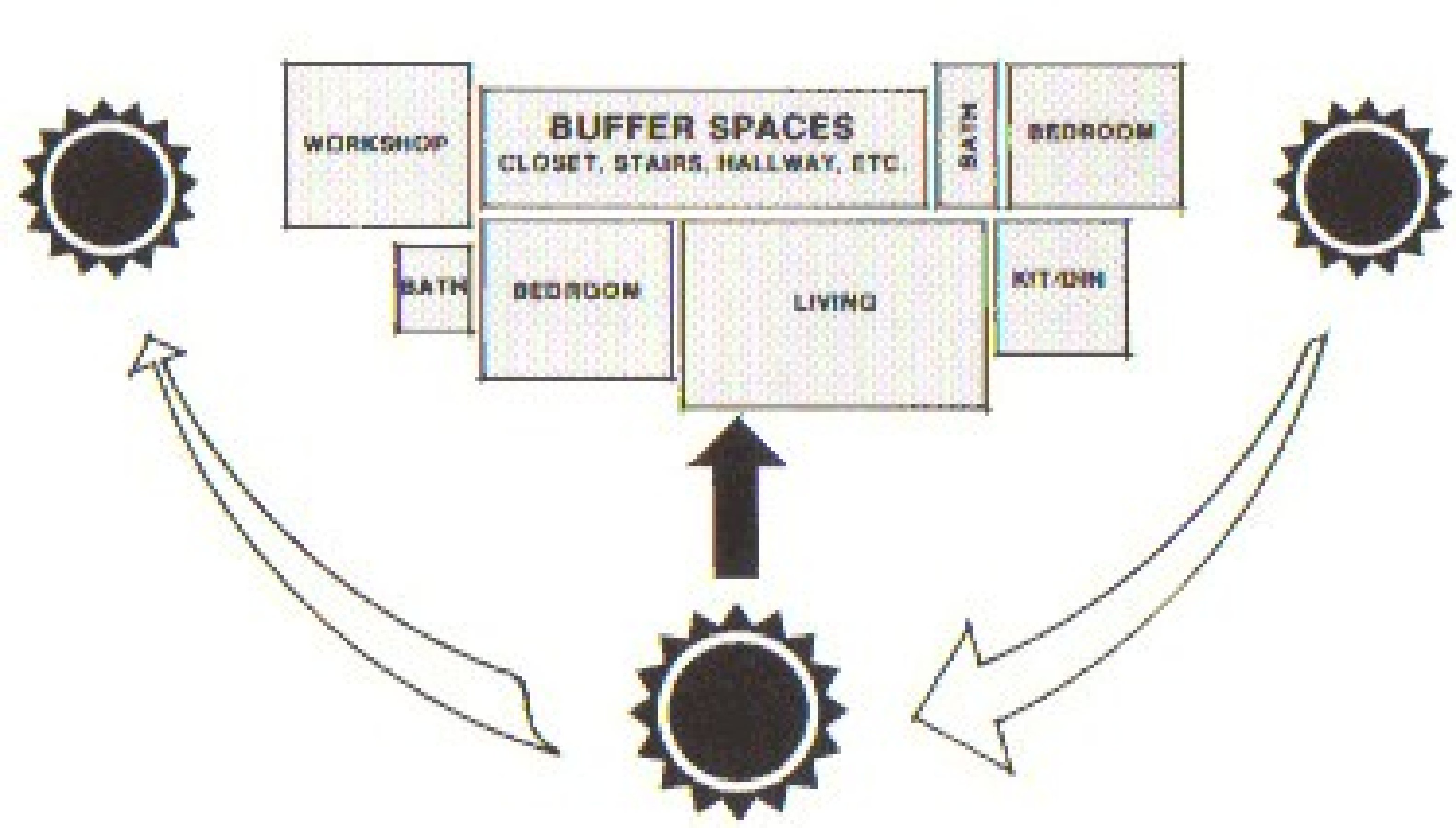
- Trombe Wall



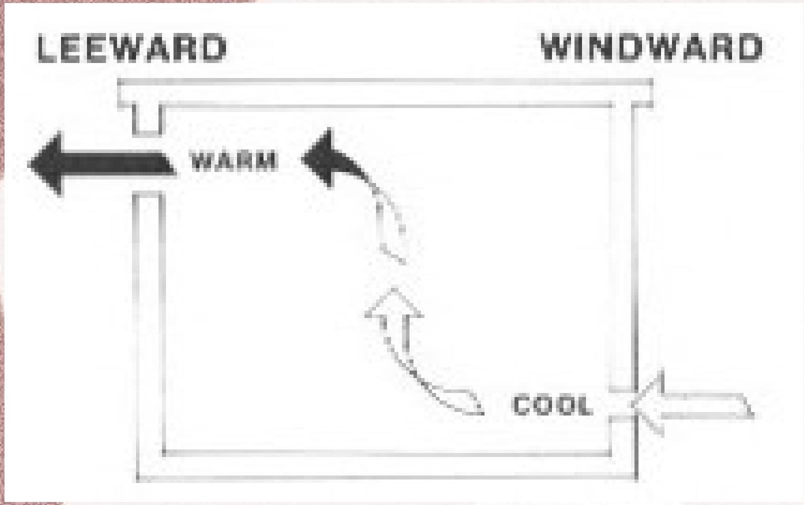
Roof overhang and thermal mass flooring/walls

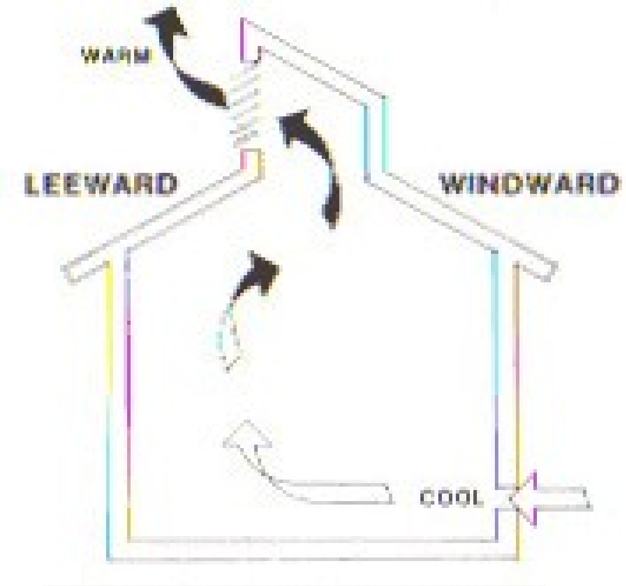


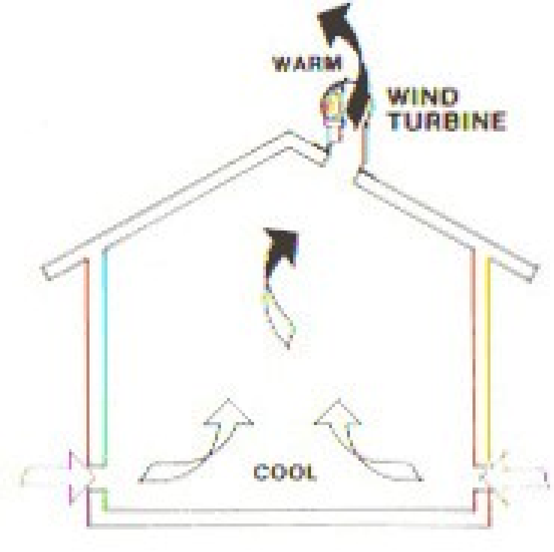
Room Arrangement



Natural Ventilation

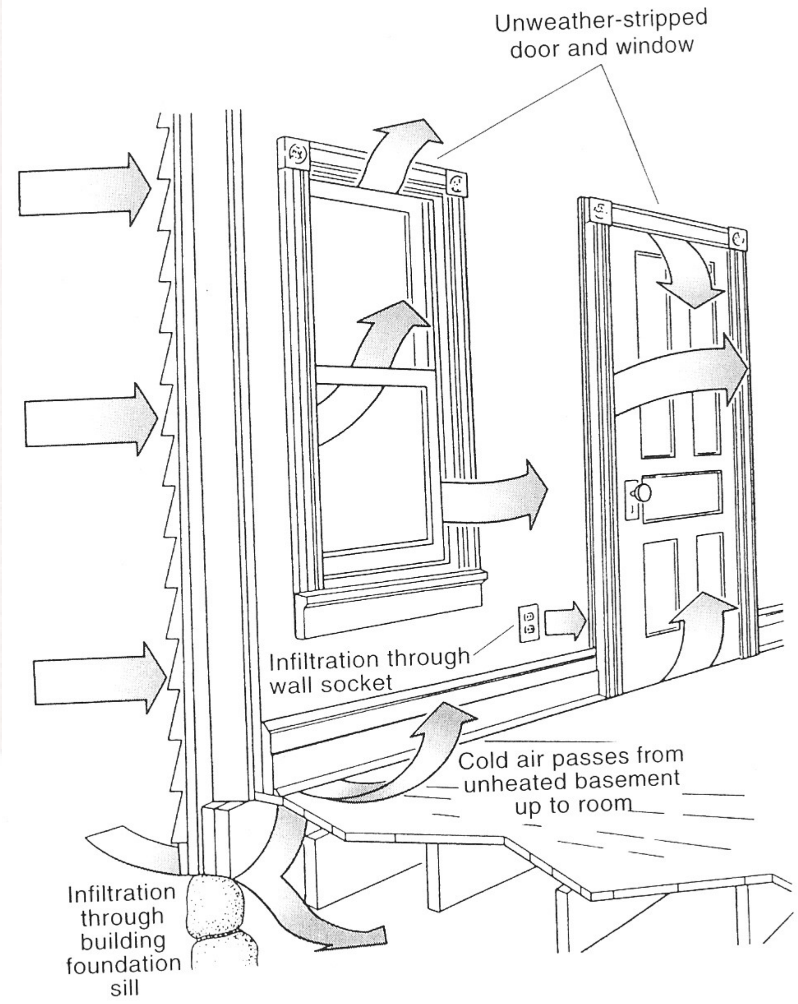






Insulation

- Reduce the flow of energy into/out of house.
- Reduce air infiltration by sealing cracks
- About 50% of energy loss through infiltration

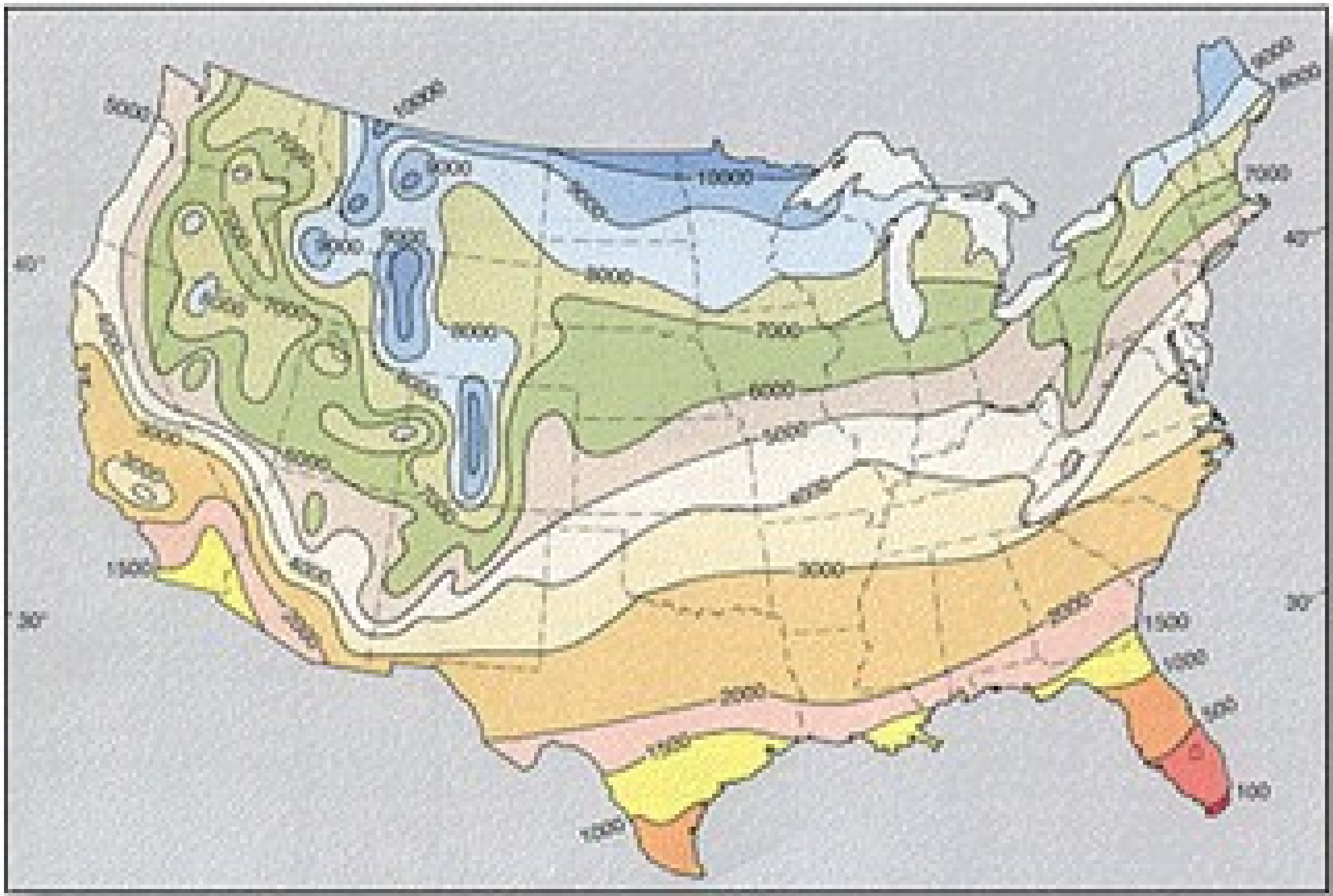


Heating Degree Days:

- In general, no additional heat is required if $T > 65^\circ F$.
- Definition:

  Heating Degree Day (DD) = $65^\circ - T_{avg}$

Average DD for US.



- HDD can be added over periods of time to provide a rough estimate of seasonal heating requirements. In the course of a heating season, for example, the number of HDD for New York City is 5,050 whereas that for Barrow, Alaska is 19,990. Thus, one can say that, for a given home of similar structure and insulation, around four times the energy would be required to heat the home in Barrow than in New York. Likewise, a similar home in Los Angeles, California, whose heating degree days for the heating season is 2,020, would require around two fifths the energy required to heat the house in New York City.[4]

Insulation:

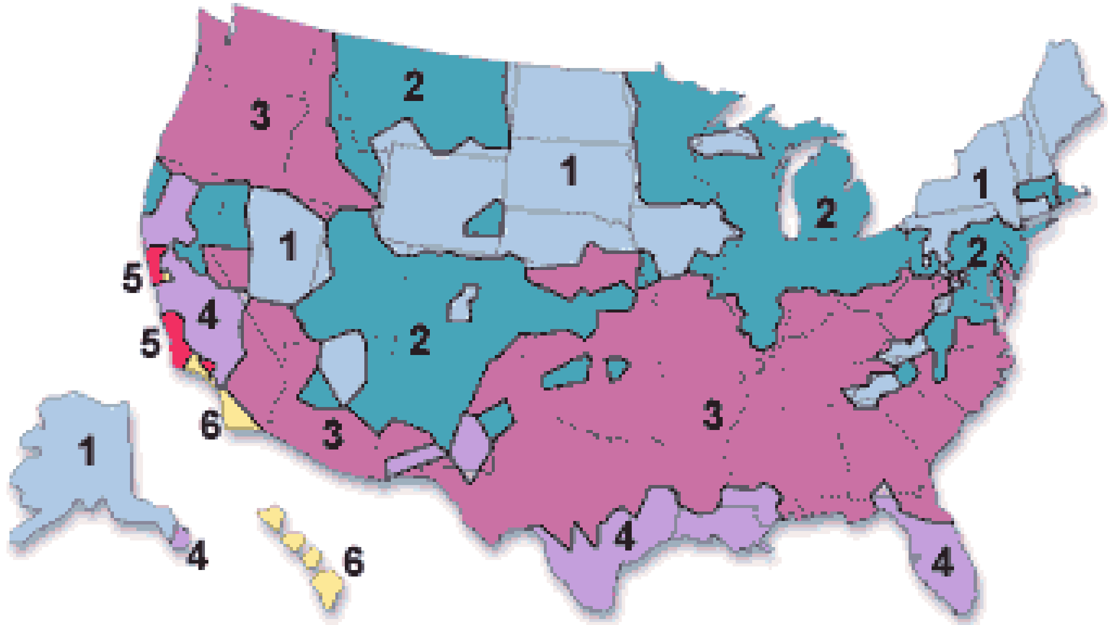
- The amount of insulation used in construction depends on the expected number of DD in a given region.
- Measured in terms of R value,
- R is the thermal resistance. (Recall conduction discussion)

Table 5–2 R-VALUES OF COMMON BUILDING MATERIALS*

Material	Thickness	R-Value (ft²-hr-°F/Btu)†
Hardwood	1″	0.91
Softwood	1″	1.25
Plywood	½″	0.62
Concrete block	8″	1.04
Common brick	1″	0.20
Sheetrock (gypsum board)	½″	0.45
Fiberglass insulation	3½″	10.9
Fiberglass insulation	6″	19.0
Expanded polystyrene board	1″	4.0
Expanded polyurethane board	1″	6.3
Cellulose insulation	1″	3.7
"Thermax" or "High-R" sheathing	1″	8.0
Flat glass	⅛″	0.88
Insulating glass	¼″ air space	1.54
Insulating glass	½″ air space	1.72
Wood subfloor	25/32″	0.98
Hardwood floor	¾″	0.68
Nylon carpet	1″	2.0
Tile		0.05
Asphalt roofing shingle		0.44
Asbestos shingle		0.21
Steel	1″	0.0032
Copper	1″	0.0004
Wood siding (lapped)	½″	0.81

*ASHRAE, "Handbook of Fundamentals"

†In the metric system, the units for R are m^2-°C/W; R(metric) = R(English) × 0.57



Zone	Gas	Heat Pump	Fuel Oil	Electric Furnace	Attic	Wall (A)	Floor	Crawl-space (B)	Base-ment
1	✔	✔	✔		R-49	R-18	R-25	R-19	R-11
				✔	R-49	R-28	R-25	R-19	R-19
2	✔	✔	✔		R-49	R-18	R-25	R-19	R-11
				✔	R-49	R-22	R-25	R-19	R-19
3	✔	✔	✔	✔	R-49	R-18	R-25	R-19	R-11
4	✔	✔	✔		R-38	R-13	R-13	R-19	R-11
				✔	R-49	R-18	R-25	R-19	R-11
5	✔				R-38	R-13	R-11	R-13	R-11
		✔	✔		R-38	R-13	R-13	R-19	R-11
				✔	R-49	R-18	R-25	R-19	R-11
6	✔				R-22	R-11	R-11	R-11	R-11
		✔	✔		R-38	R-13	R-11	R-13	R-11
				✔	R-49	R-18	R-25	R-19	R-11

Example of Heat requirements

Heat loss through a wall of area A .

$$Q = \frac{A}{R} \times DD \times 24\ hr$$

Example, 1000 ft^2 house, with 6000 DD

Wall area $(33\mathrm{ft} \times 10\mathrm{ft}) \times 4 = 2320\mathrm{ft}^2$

$$R = 15\ ft^2 \cdot hr \cdot {}^{o}F Btu$$

$$Q = \frac{2320}{15}(6000)(24) = 22.3\ MBtu$$