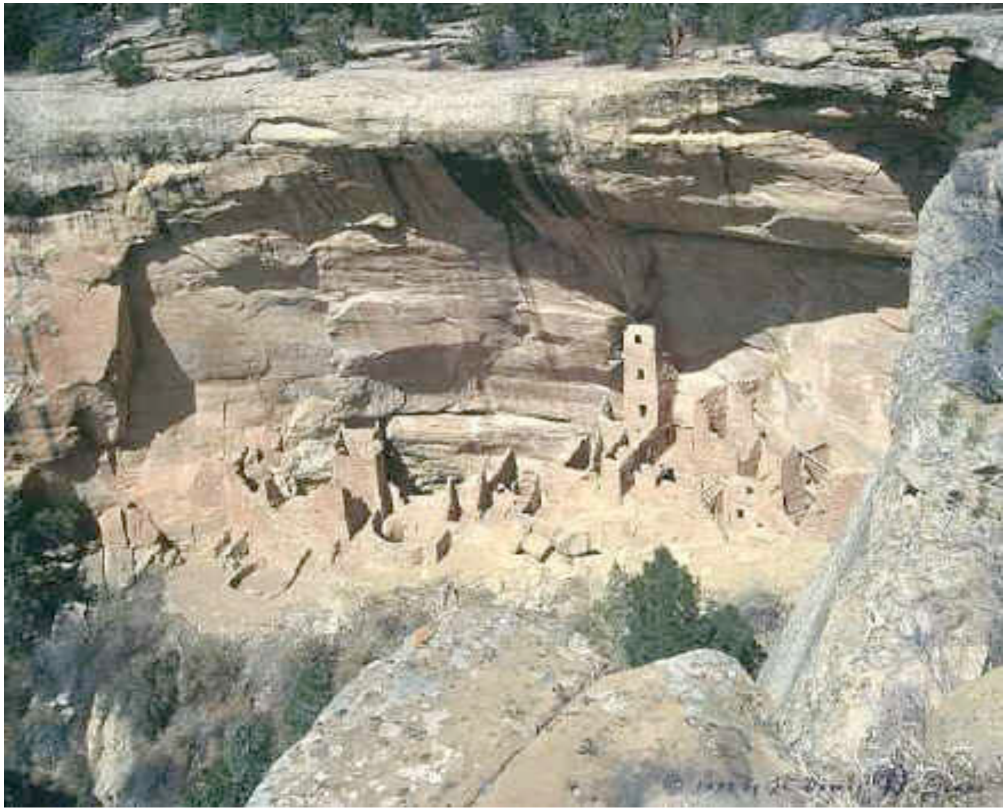
Passive Solar Design

Dr. William J. Makofske

August 2004

Passive solar has been used for thousands of years

Southwest United States



Adobe solar architecture

Passive Solar Design

- Passive solar heating is defined as using solar energy incident on windows, skylights, greenhouses, clerestories, mass walls, and thermosyphoning collectors in order to provide heating for a house. Generally such solar collection occurs passively, without the extensive use of pumps or fans typically used in active solar collector systems. However, the distribution of the energy collected sometimes uses small fans to redistribute the energy throughout the house. Because heating is needed only over the colder part of the year (Sept. to May), passive solar design must also eliminate unwanted solar heat gains during the summer. The use of techniques to eliminate solar gains and to cool a house with the use of active systems is often referred to as passive cooling

Types of Passive Systems

- Direct Gain
- Trombe Wall or Mass Wall
- Sunspace or Greenhouse
- Thermosyphoning
- Roof Systems

Direct Gain Systems

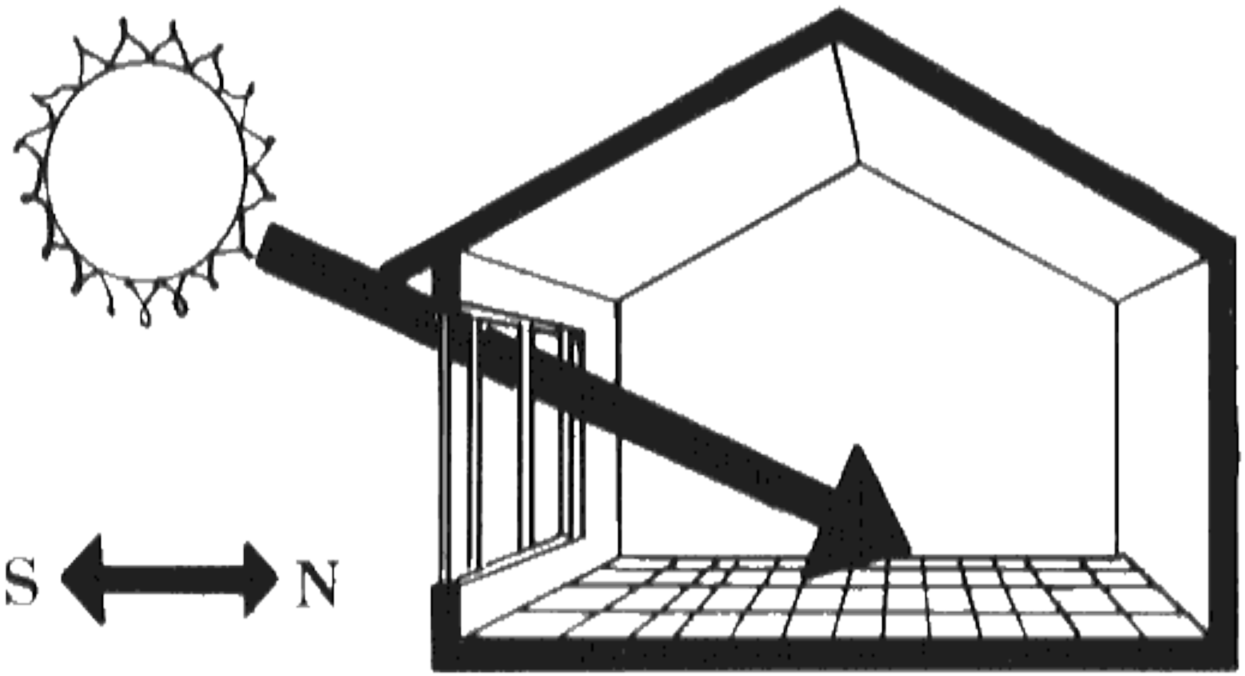
- Sunlight incident on transparent surfaces allows the energy to enter the living space directly and is called Direct Gain. South facing windows thus form the basis for the simplest type of solar heating system. With some simple guidelines, this design is the cheapest and best way to incorporate solar into a house.

Direct Gain Passive Solar Design

- Surfaces should be generally facing south (to within 20 degrees)
- Overhangs should prevent unwanted summer gains (2 ft typical at 40 degrees latitude)
- Window area should be 8-12% of the house floor area if no extra thermal mass is added
- This amount of passive solar gain should provide no more than 40-50% of the yearly heating load
- More area may be possible if additional thermal mass is added.

- PRECAUTIONS
- Excess window area can result in a loss of privacy, too much glare, underheating and overheating
- Movable insulation should be designed to be easy to install and use

A Simple Direct Gain System



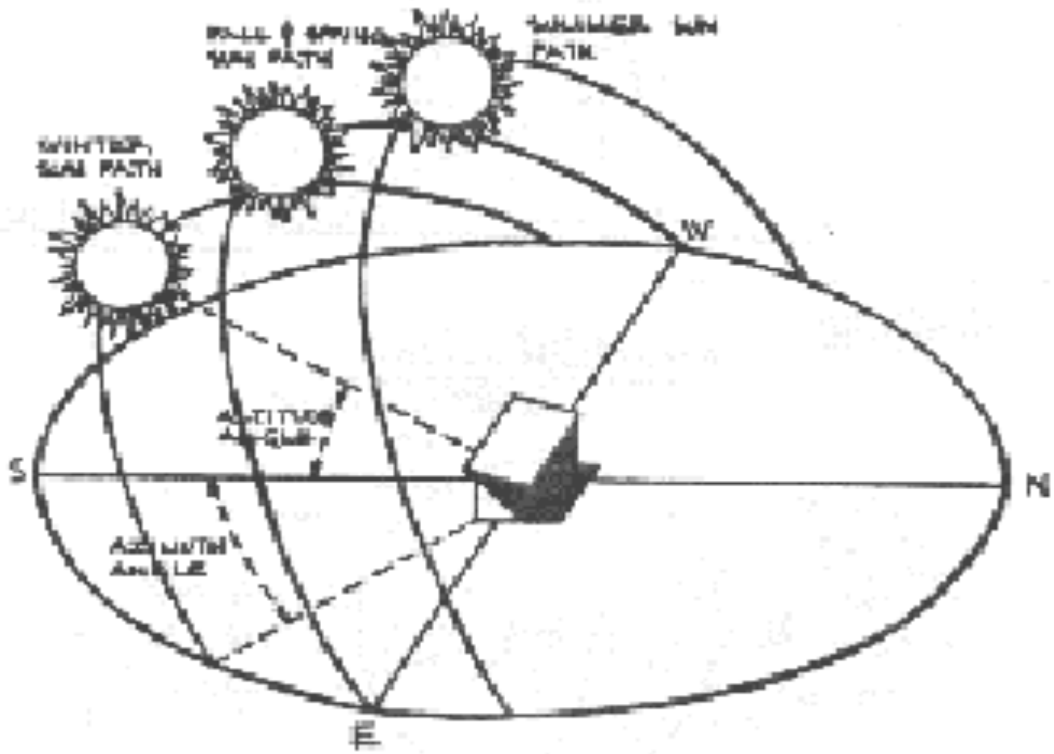
A Simple Direct Gain Home

Good design is based on combining several elements and ideas

- Knowledge of seasonal changes in sun path
- Landscaping in the site plan
- Overhangs
- Appropriate use of thermal mass
- Energy efficient design for the thermal envelope

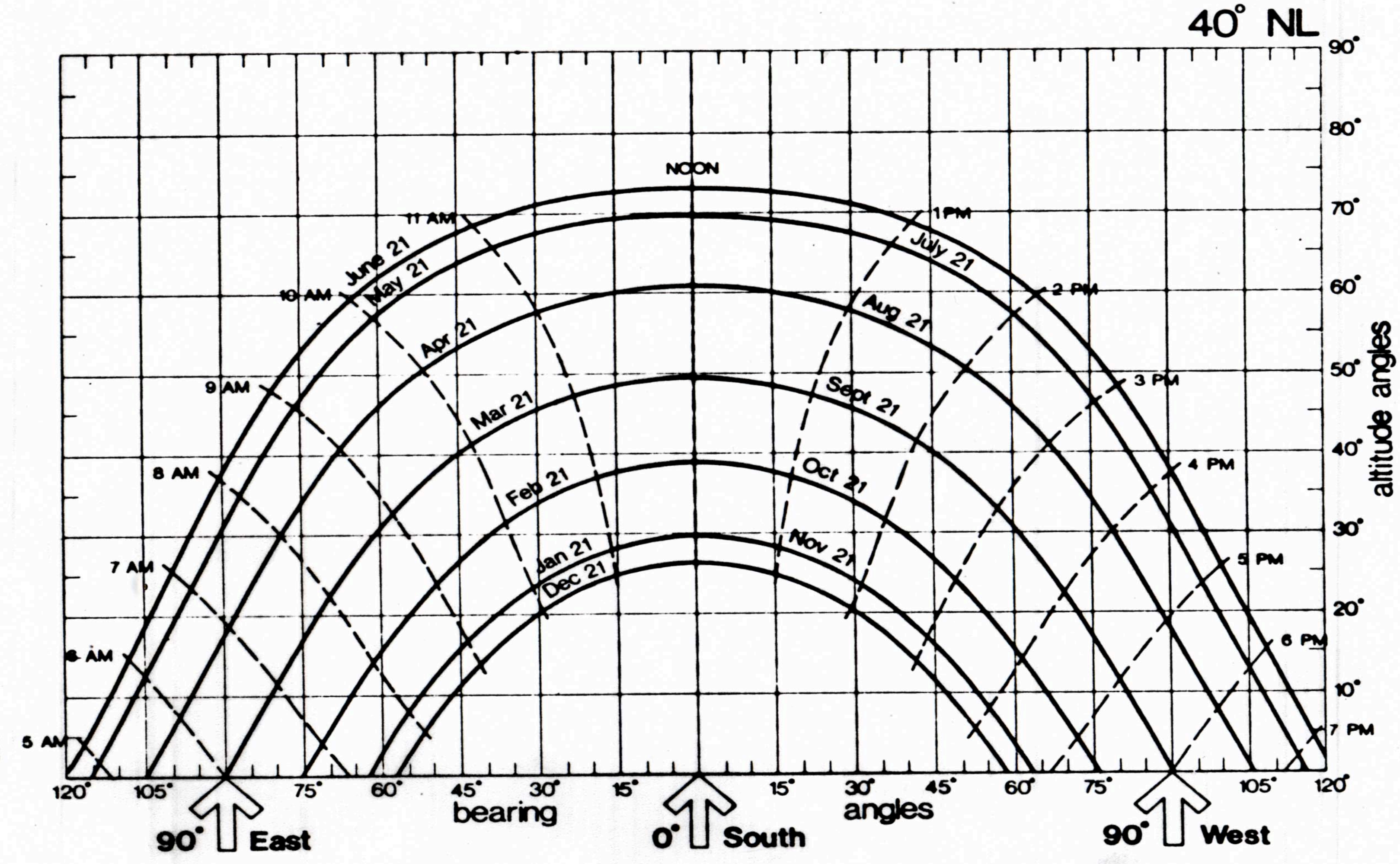
The Sun’s Seasonal Path

This path is hemisphere and latitude dependent



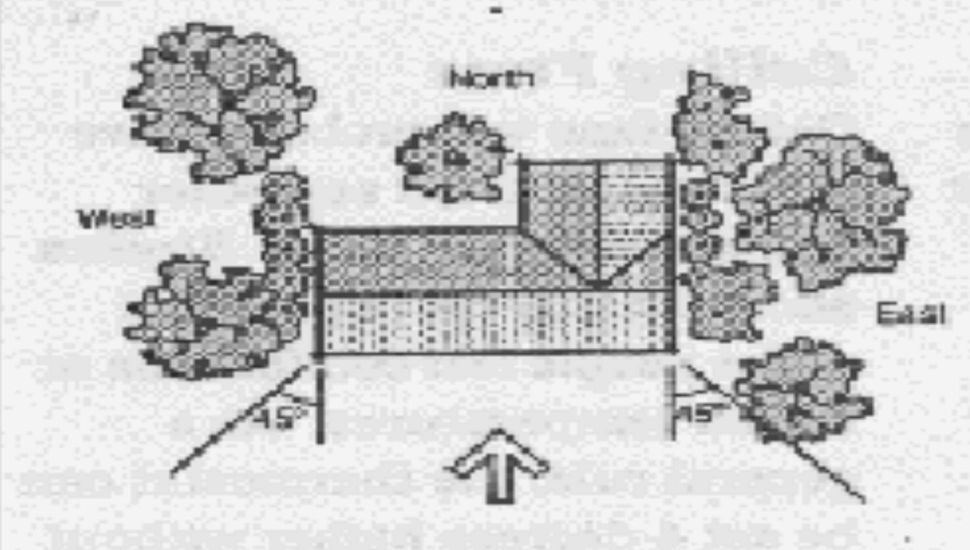
40 Degree Latitude Sun Chart

showing altitude and azimuth angles for different months of the year and times of the day



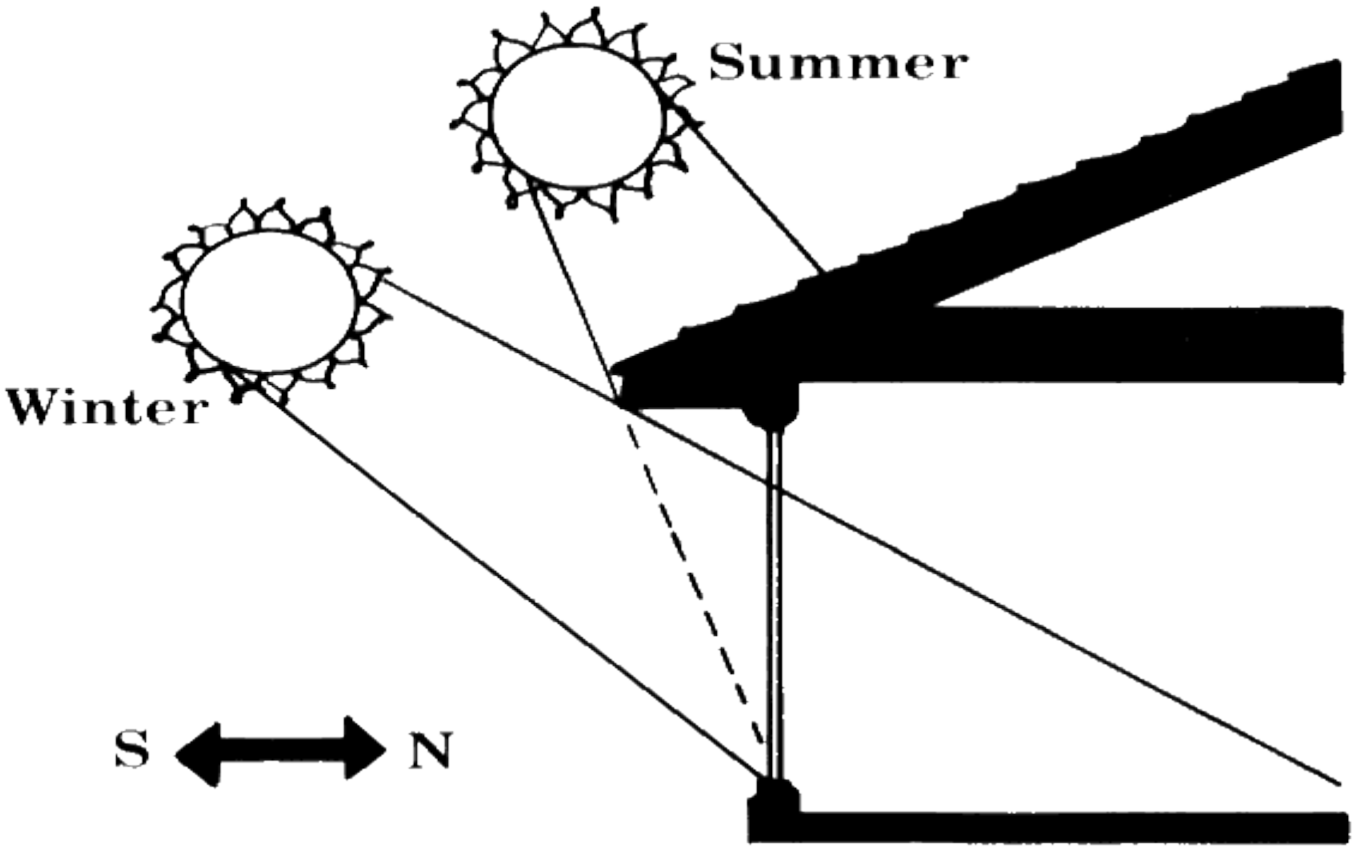
Site Plan

Don't shade the south, except for overhangs, but do shade the east and west sides. Decks, porches and carports also may be used to shade.



Landscaping for Summer Shade
Trees and other landscaping features may be effectively used to shade east and west windows from summer solar gains.

Overhangs on the South Side



Simple Patio Provides Shading to the south side (What's wrong with this picture?)

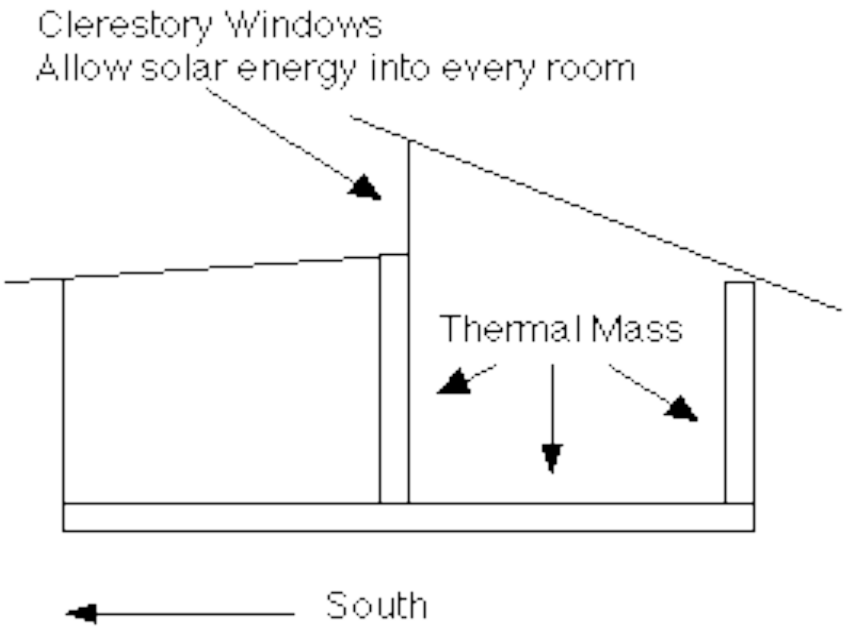
photo credit: National Renewable Energy Laboratory

Example of House with South Overhangs

Thermal Mass

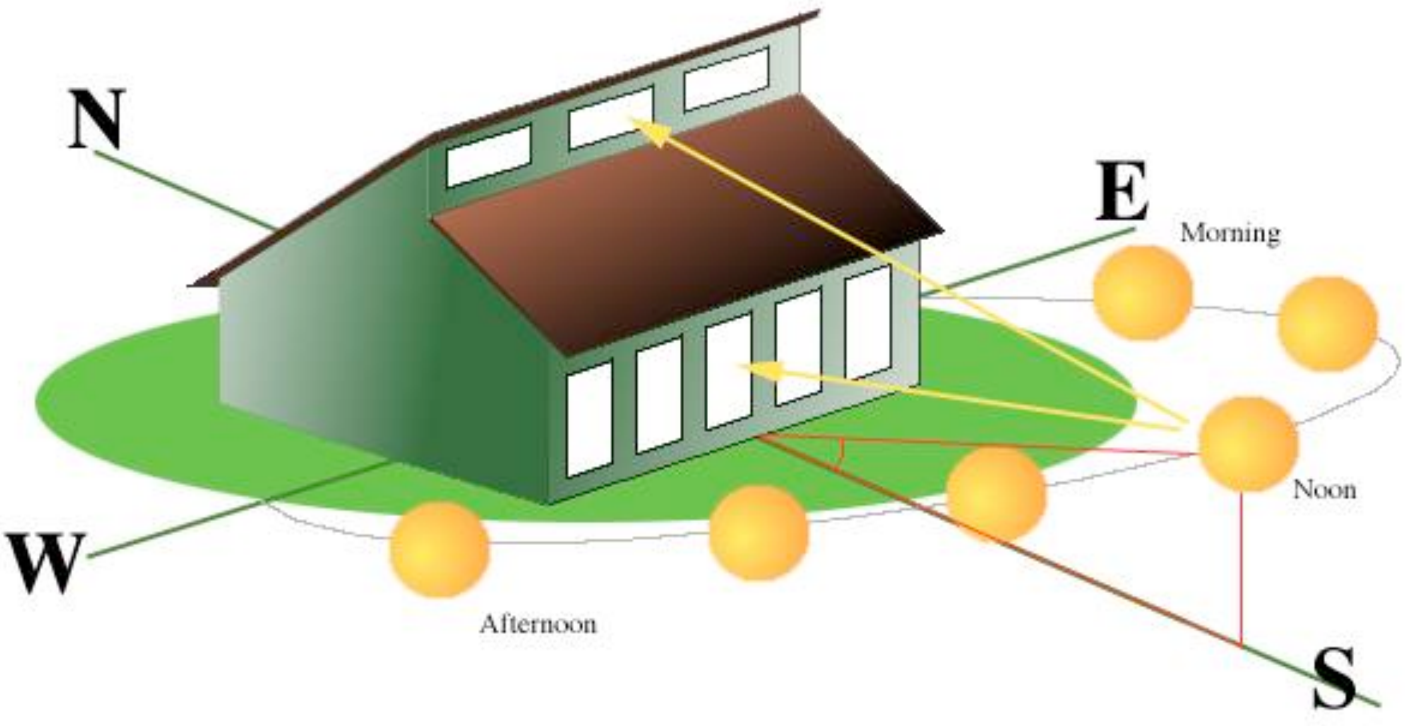
Some provided by normal wallboard and furnishings and also by slabs, mass walls, fireplaces, etc. In the southwest, adobe can provide extensive mass.

Clerestory is also direct gain



- Excellent for bringing daylighting to northern spaces (deep houses)
- Can use north wall masonry heat storage
- Overhang over clerestory window shades in summer

Example of Clerestory House



The Clerestory Design

The shape can be repeated for deep or commercial buildings

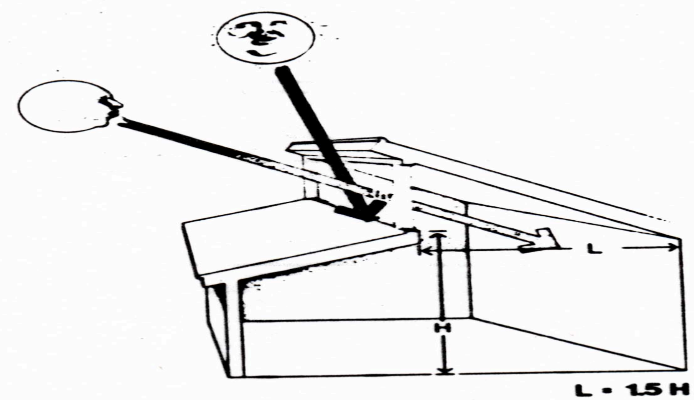
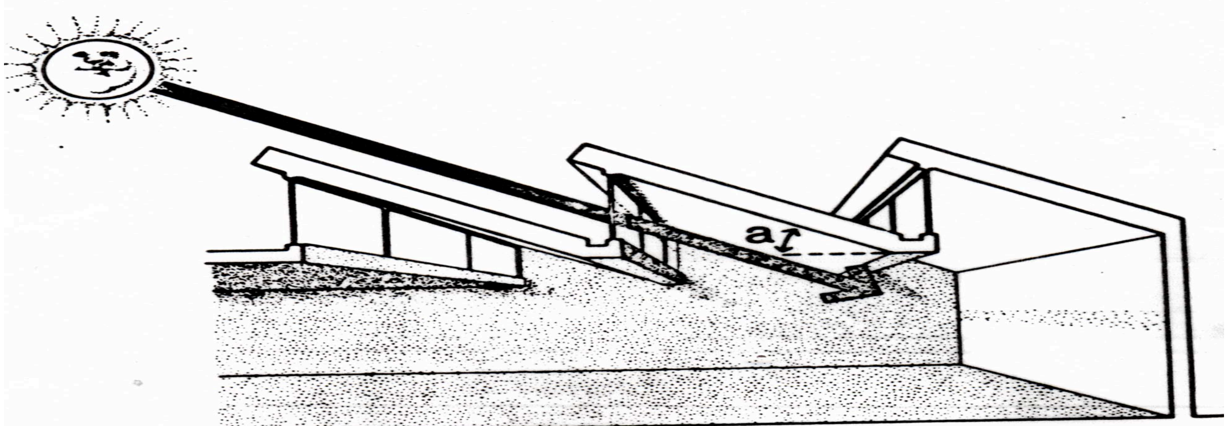


Fig. IV–10b: Clerestory location.



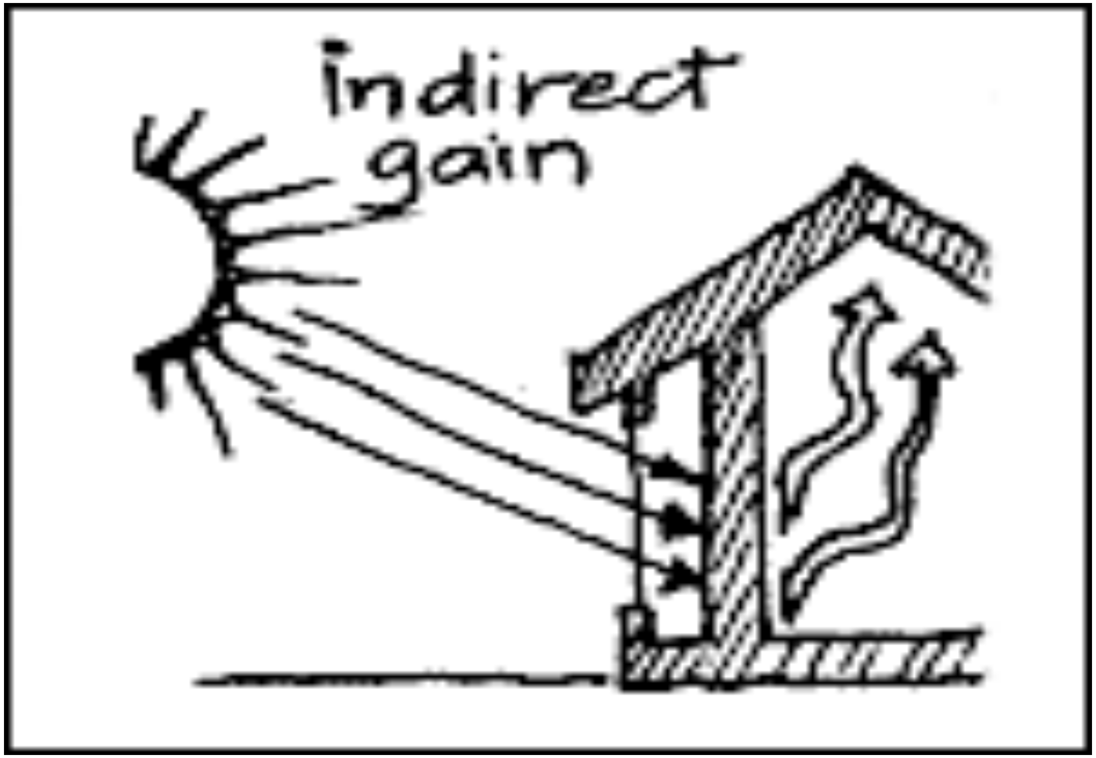
ANGLE a – ALTITUDE OF THE SUN AT NOON ON DECEMBER 21
EXAMPLE: AT 36°NL ANGLE a – 36°

Thermal Storage Walls or Trombe Walls

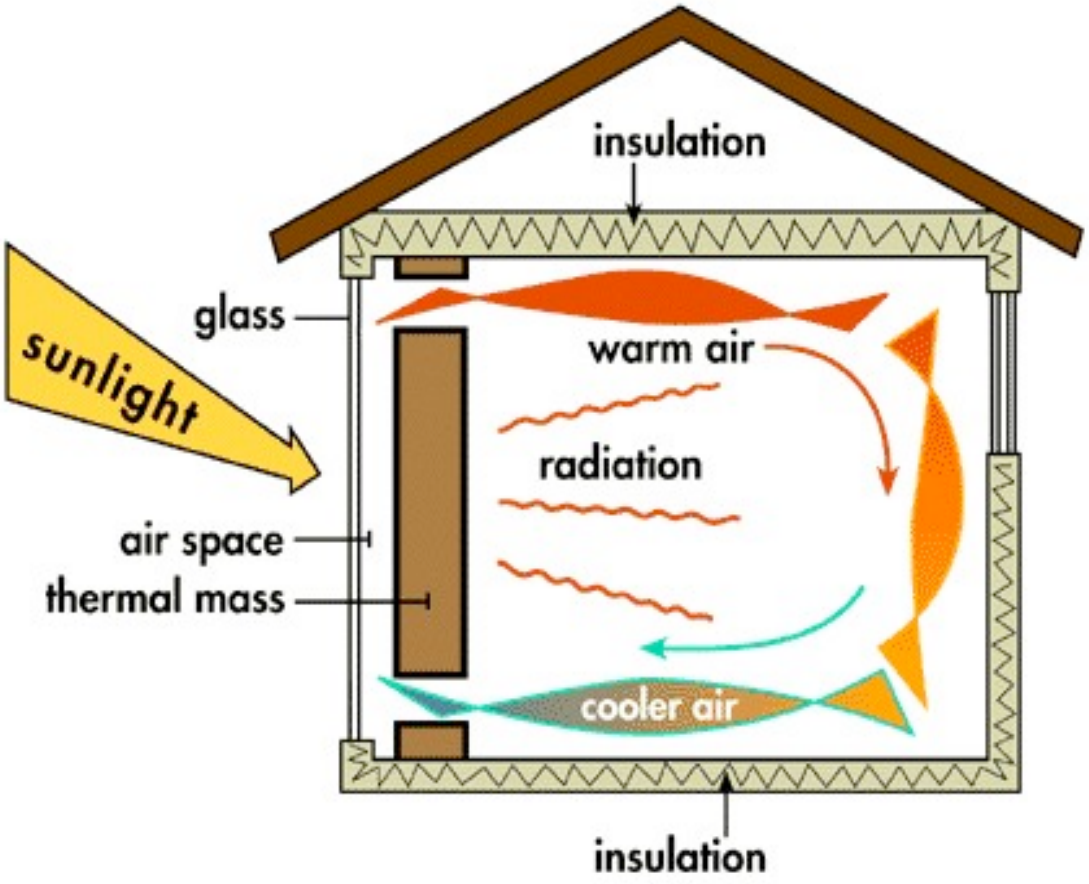
- **Advantages:**
- Eliminates glare
- Lowers temperature swings in room
- Vents allow partition of energy into daytime and nighttime heating
- Sun hits entire mass

- **Precautions:**
- More expensive and less efficient than DG
- More difficult to reduce nighttime losses
- Best for sunnier climates
- Occupies valuable space in building

Trombe Wall Diagram



Trombe Wall with Vents



Operation of Trombe Wall

- Sunlight hits the darkened mass wall and absorbed heat moves slowly across the wall
- The inside surface temperature peaks 6-8 hours after the midday outside surface peak
- Operational vents allow optional controlled air circulation into the space during the day
- Overhang reduces wall sun exposure during the warmer months

Kelbaugh House in Princeton, NJ
Greenhouse plus Trombe Wall plus Direct Gain

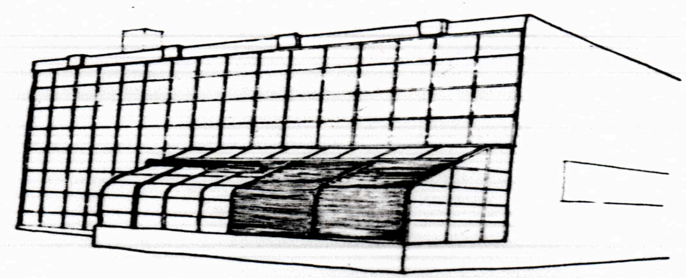


Figure 3-14. Doug Kelbaugh's House: Trombe Wall and Greenhouse

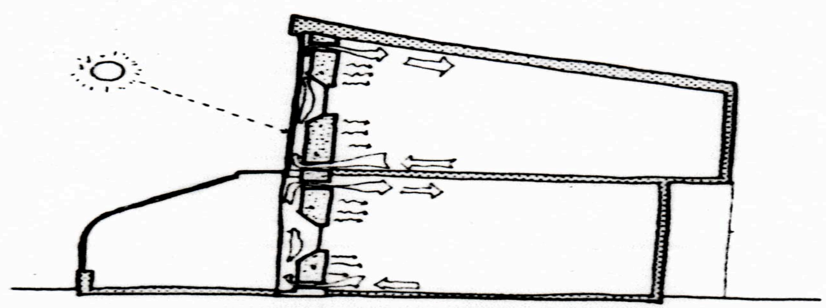


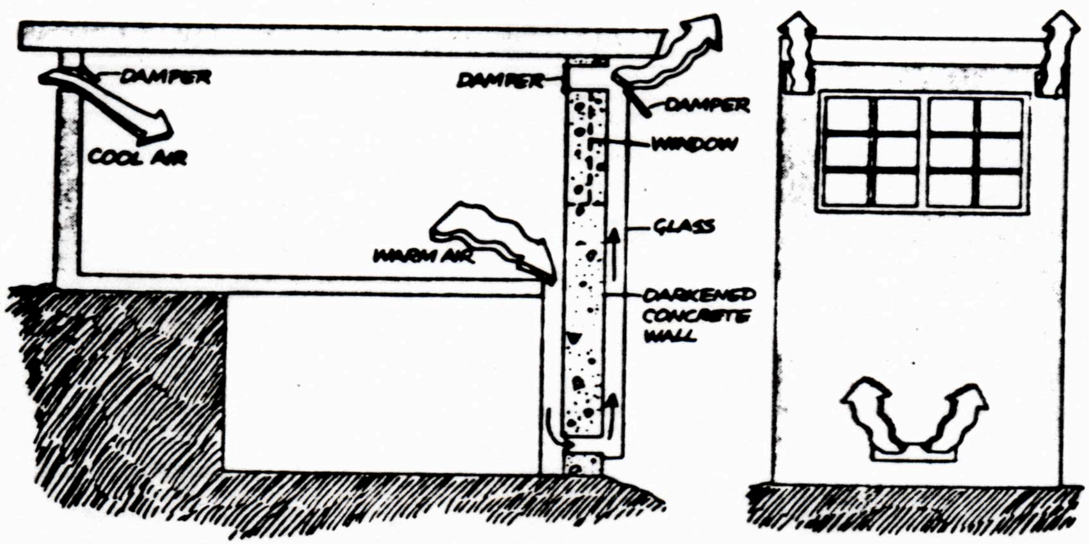
Figure 3-15. Doug Kelbaugh's House: Winter Operation

Trombe Wall – added features

- Vent added to outside at the top can drive warm air out in the summer and bring cooler air from a north vent
- Trombe wall can be used as part of a south-facing greenhouse
- Trombe wall concept may be retrofitted to existing houses with brick or stone construction

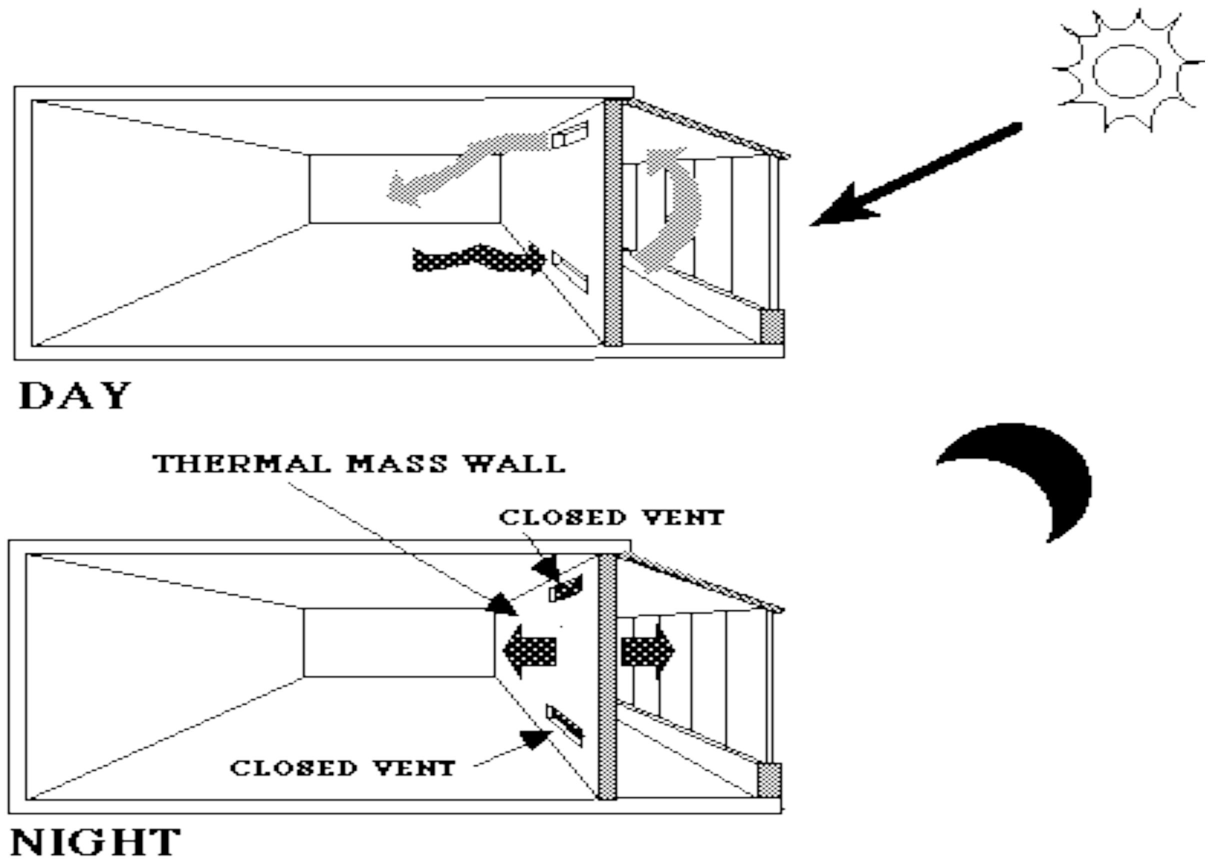
Trombe Wall Venting in Summer

Sun hitting the bottom drives the hot air up to the open vent



Cross-section and front view of solar heating and cooling system in the 1974 Odeillo Residences—summer operation.

SUNSPACE CONCEPT
with mass wall added

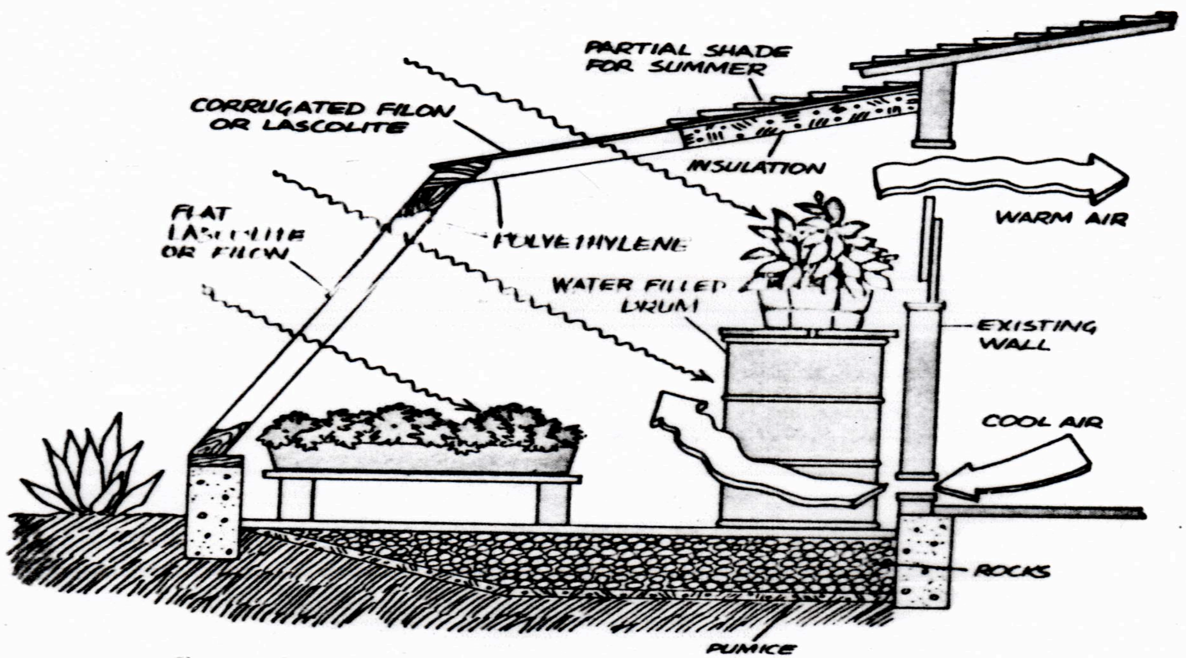


Attached Greenhouses or Sunspaces

- Advantages:
- Lower temperature swings in adjacent living space
- Flexible – can be operated in many modes
- Provides additional living or growing space
- Works well in late winter and spring when standard overhangs block direct gain through windows

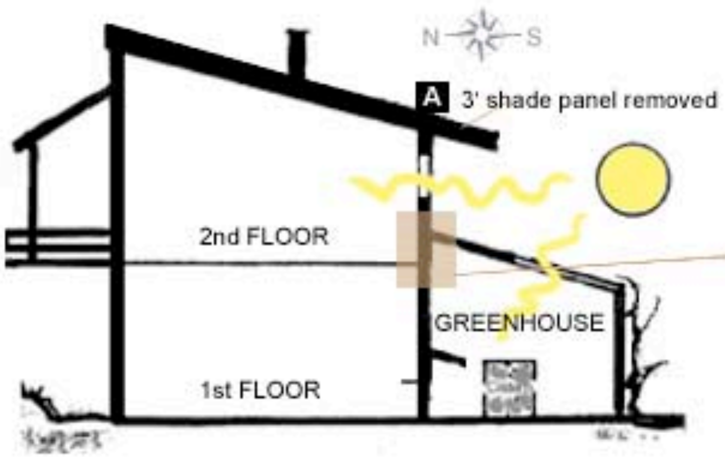
- Precautions:
- Price moderate to high
- Thermal performance depends greatly on how it is operated

Solar Greenhouse with thermal mass in the floor and in water barrels

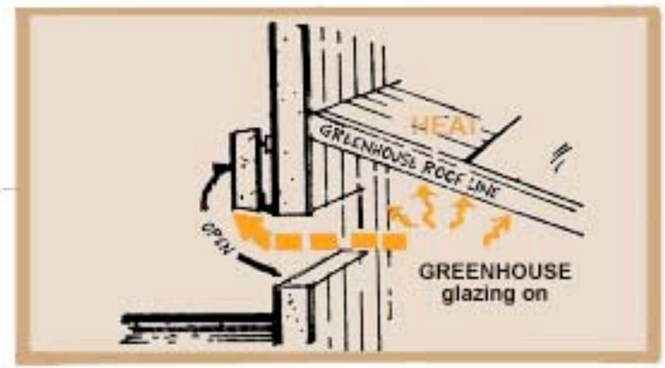


Cross section of Solar Sustenance Project greenhouse—daytime operation.

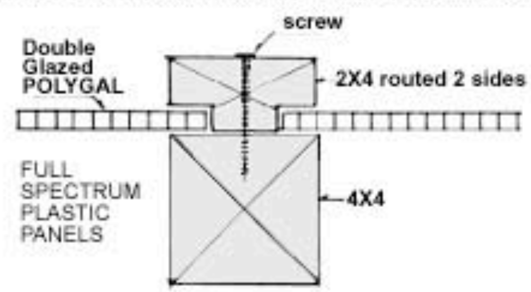
The Sun House: Passive Solar
Passive Heating



WINTER



CROSS SECTION GREENHOUSE PANEL SUPPORTS



PASSIVE HEATING: The attached greenhouse on the south side passively heats the 2nd floor so well that you can blow dry your hair in front of the floor vents on sunny days.

- Super insulation in ceilings: R-35
- Super insulation in walls:
- North & south walls: R-30
- 2nd floor east wall: R-50
- 2nd floor west wall: R-50 and no windows
- 1st floor walls: R-45

3 WOOD STOVES provide supplemental winter heating, and we now use 1-2 cords a year. We use one cord when the greenhouse panels are all up, 2 cords if they don't all go up.
In 2002 this costs us $180 per ocrd.
$30 per month for wood.

•Back to Sun House •Back to Passive Solar

We slide the **PLASTIC PANELS** into the routed out 2"x4"s in October and remove them in May. After 18 years, some panels have hail pits in the first layer, but most are the original panels. Several panels broke lengthwise in strong windy weather in 2001, and were the first to be replaced.

The **WOODEN SHADE PANELS** **A** come down in winter and are stored inside where the plastic panels are stored in summer.

Sunspace
(What's wrong with this picture?)

photo credit: Andersen Windows

Sunspace

photo credit: Andersen Windows

Convective Loop Heaters

- Advantages:
- Reduces glare and protects privacy
- Inexpensive and easy to incorporate into existing homes
- Can be isolated from the living space at night
- No thermal mass needed if area < 10% of floor area

- Precautions:
- Not a normal part of the façade of houses
- Good design and construction needed to ensure proper airflow and thermal isolation at night
- Warm air is difficult to store in thermal mass than direct sunlight

Details of Thermosyphoning Collector

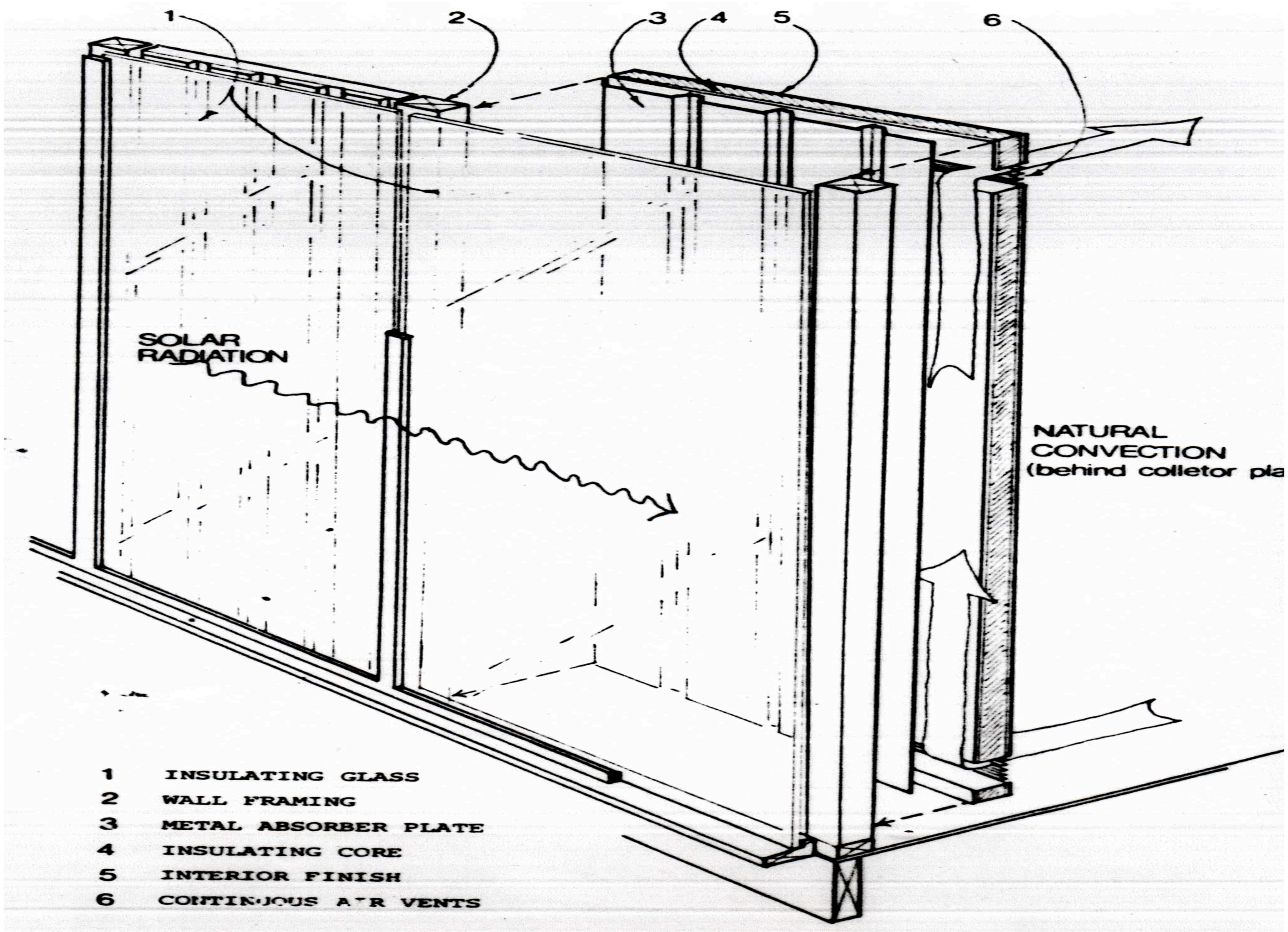
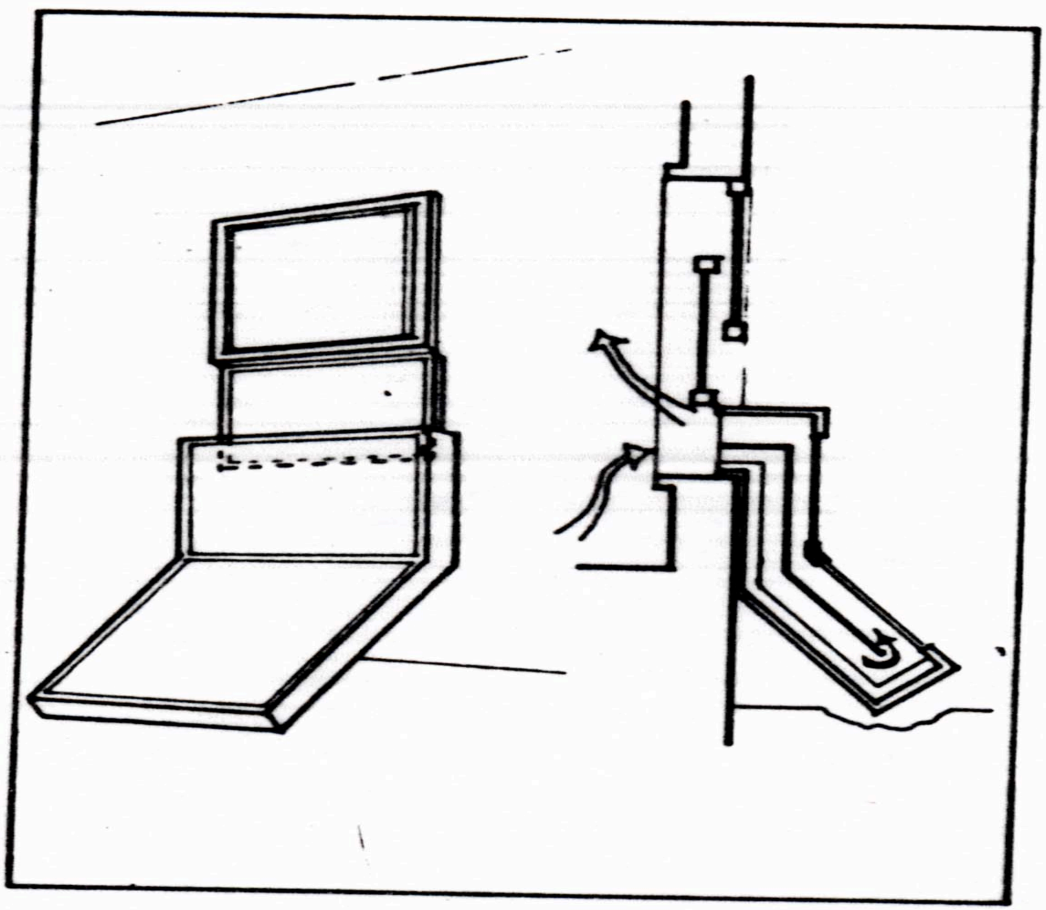


Figure 3-24. Thermosiphon Air Panel

Window Convective Loop Heater



Thermal Storage Roofs

- **Advantages:**
  - Provides both heating and cooling
  - Provides low temperature swing in the building
  - Can provide 100% of heating and cooling in milder climates

- **Precautions:**
  - Structural support for heavy mass expensive
  - Most easily used in 1 story buildings
  - Typically 50% size of floor area
  - Least acceptable design in earthquake prone areas

Thermal Roof Concept

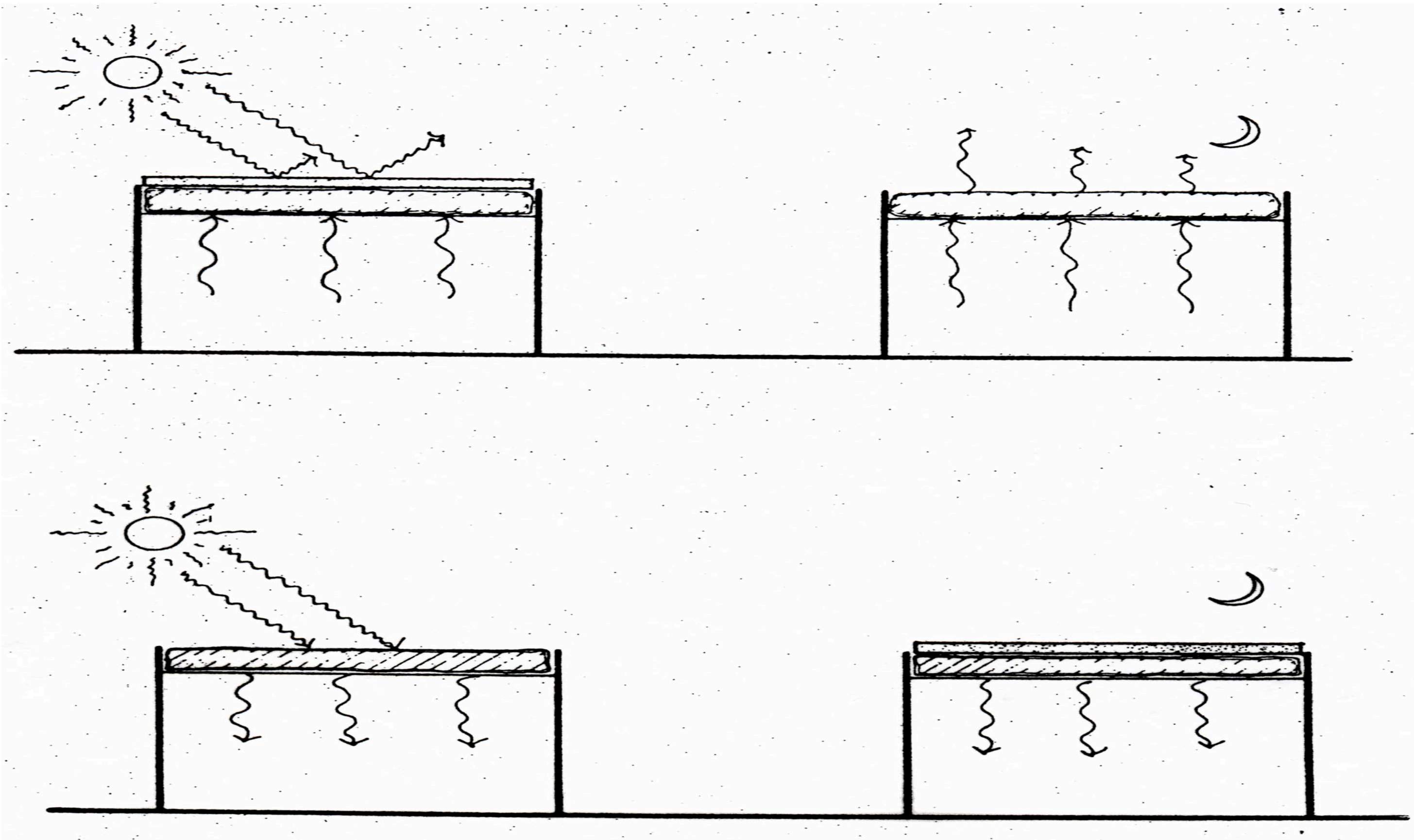


Figure A-4: "Skytherm"R sthermal storage roofs -- summer and winter operation (HON).

How to Determine Performance

The heat collected from glazing (or a window) is the sunlight that gets **through** the window. This varies throughout the day and season because of

1. Angle of the sun (which determines reflection losses) and also depends on

2. Number of glazings or panes, typically 1-3

The Solar Heat Gain Chart

- The solar heat gain chart tells you what enters the house on a daily or monthly basis
- For a sunny day, the solar energy collected per day is the product of I, the clear day solar heat gain or insolation value in Btu/ft2, times T, the transmission of the window (T=1 for single pane, = 0.86 for double pane, etc.), and times A, the area of the window in ft2.

Solar Heat Gain Chart

SOLAR HEAT GAIN FACTORS FOR 40°N LATITUDE, WHOLE DAY TOTALS Btu/ft^2/day (Values for 21st of each month)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	118	162	224	306	406	484*	422	322	232	166	122	98
NNE	123	200	300	400	550	700*	550	400	300	200	123	100
NE	127	225	422	654	813	894*	821	656	416	226	132	103
ENE	265	439	691	911	1043	1108*	1041	903	666	431	260	205
E	508	715	961	1115	1173	1200*†	1163	1090	920	694	504	430
ESE	828	1011	1182	1218*†	1191†	1179	1175†	1188†	1131	971	815	748
SE	1174	1285	1318*	1199	1068	1007	1047	1163	1266	1234	1151	1104
SSE	1490	1509*	1376	1081	848	761	831	1049	1326	1454	1462	1430
S	1630*†	1626†	1384†	978	712	622	694	942	1344†	1566†	1596†	1482†
SSW	1490	1509*	1370	1081	848	761	831	1049	1326	1454	1462	1430
SW	1174	1285	1318*	1199	1068	1007	1047	1163	1266	1234	1151	1104
WSW	828	1011	1182	1218*†	1191†	1179	1175†	1188†	1131	971	815	748
W	508	715	961	1115	1173	1200*†	1163	1090	920	694	504	430
WNW	265	439	691	911	1043	1108*	1041	903	666	431	260	205
NW	127	225	422	658	813	894*	821	656	416	226	132	103
NNW	123	200	300	400	550	700*	550	400	300	200	123	100
HOR	706	1092	1528	1924	2166	2242*	2148	1890	1476	1070	706	564

*month of highest gain for given orientation(s)

†orientation(s) of highest gain in given month

SOURCE: ASHRAE, *Handbook of Fundamentals*, 1970; Koolshade Corporation.

Monthly Solar Heat Gain

For a month, the solar heat gained in Btu is

= I x #days/month x fraction sun x T x A

where I, T and A are the same as before, and the fraction sun is the fraction of sunshine that is available for that month (includes clear and cloudy weather)

Question?

What is the solar heat gained by a house in the month of January if there is 200 ft2 of double glazing facing south and the fraction of sunshine is 50%.

Answer

From the solar heat gain chart, the insolation value in January for a window facing south is 1550 Btu/ft2.

Thus, using the relationship

I x #days/month x SF x T x A gives

1550 Btu/ft2 x 31 x 0.5 x 0.86 x 200 ft2

= 4,1300,000 Btu

Of course, the more important question is, for a given house, what size south window is needed to provide a desired percentage of the yearly heating load?

To do this, we need to use the Heat Loss Value, H, of the house and the heating degree days, DD, for the year in order to determine what the seasonal heat loss value Q for the house where Q = H x A x DD. Then we can use

$$\text{Area (ft2)} = \frac{\text{fraction solar desired x Q}}{\text{100,000 Btu/ft2}}$$

Question?

How much south facing window is needed to provide 40% of the seasonal heat load of a house with a heat loss value H of 3 Btu/ft2/DD, a floor area of 2000 ft2, in a 5000 DD climate?

Answer

The seasonal heating load for the house is

$$Q = H \times A \times DD$$

$= 3$ Btu/ft2/DD x 2000 ft2 x 5000 DD

$= 30{,}000{,}000$ Btu

A(ft2) = 0.4 x 30,000,000 Btu/ (100,000 Btu/ft2)

= 120 ft2

Only 8 south facing windows of 3 ft x 5 ft size would provide 40% of the heat needed for this house

Passive Solar Design Style

The effectiveness of solar heating does not depend on the style (Cape Cod, Colonial, modern, contemporary) of house that you design. Houses may be small and simple, or spectacular, the solar concept being applied is the same as is shown in the following examples. Of course, the smaller the house, the less resources and cost will be needed to build and maintain it.

High Mass Adobe House

Direct Gain Solar House

photo credit: National Renewable Energy Laboratory

High Mass Desert House

Adobe Sunspace High Mass House

Clerestory Direct Gain House

Point House in California Coast

Point House from the Windward Side

Direct Gain Solar House

photo credit: National Renewable Energy Laboratory

Summary of Passive Solar Performance Guidelines

Solar gain can be found on a daily or monthly basis. Over a season, roughly, each ft2 of south facing surface will provide 100,000 Btu of solar gain. Since 1 gallon of oil (140,000 Btu) burned at 70% efficiency is also 100,000 Btu, we can say that each ft2 of south facing collector surface saves a gallon of oil over the heating season.

Matching Solar Area to House

The solar area should be matched to the seasonal heat loss of the house, Q.

Q = H x A x DD where this A is the heated floor area of the house in ft2

Then the solar area is found from

A(ft2)=fraction solar* x Q(Btu)/100,000 Btu

* fraction solar < 0.4 for sun tempered house

or greater than 0.4 depending on added mass

South Facing Window Advantages

The Clear Winner

- Provides views to south
- Provides good daylighting
- Provides high collection efficiency
- Long lifetime
- No maintenance (other than cleaning)
- No extra cost
- Automatic collection and distribution of energy
- No integration with backup system needed
- No thermal storage needed if window area $< 10\text{-}12\%$ of floor area
- Movable insulation can provide privacy and reduce nighttime losses if needed

Credits

- Many of the illustrations are from the Passive Solar Design Handbook, Vol. I and II, U.S. DOE, 1980.