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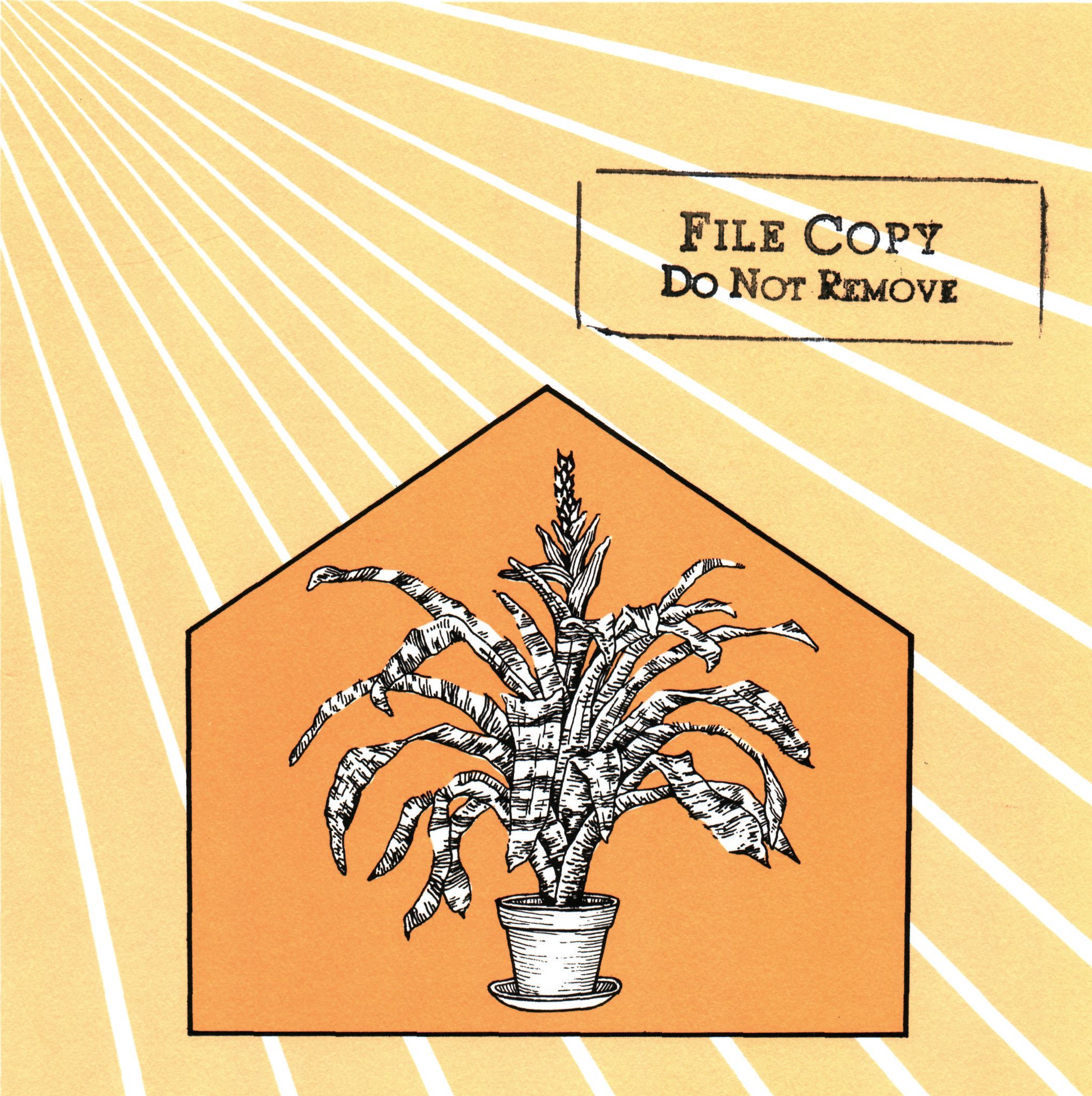

SOLAR GREENHOUSES for the HOME

COOPERATIVE EXTENSION
Northeast Regional Agricultural Engineering Service

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The Solar Greenhouse

Growing flowers and vegetables in your own greenhouse can be an enjoyable as well as useful hobby. The joy of seeing a cutting develop into a beautiful geranium or tomato seeds grow to produce delicious fruit gives a rewarding sense of accomplishment. However, a home greenhouse is very costly if it costs $1 per square foot of floor area to heat it. Interest in both plant production and energy conservation over the last few years has resulted in most hobby greenhouses being built of solar design.

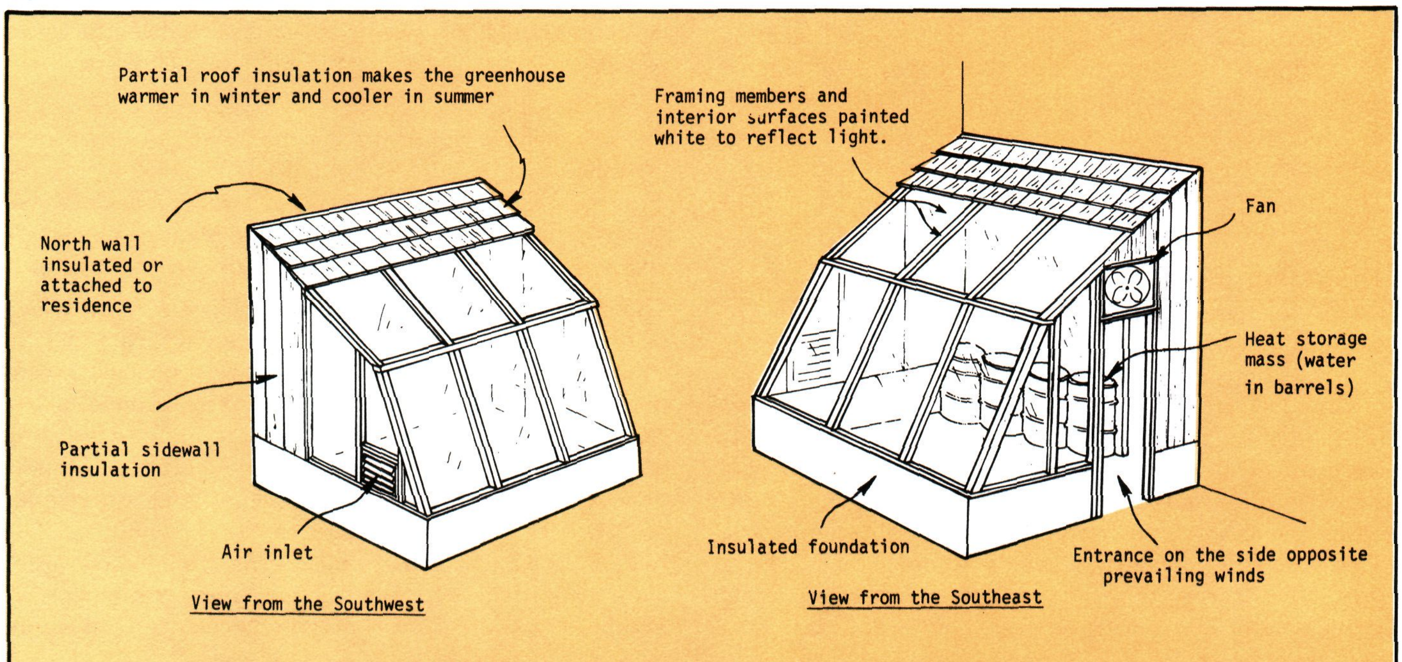
WHAT is a SOLAR GREENHOUSE?

The **conventional** greenhouse, designed primarily to capture light, tends to overheat on sunny days, lose more heat than it gains on cloudy, windy or cold days, and lose heat rapidly each day after sundown. **Solar** greenhouses differ from conventional greenhouses in that they are designed to both collect and retain solar energy, and thus reduce the use of fossil fuels for heating. If improperly ventilated, any greenhouse will overheat.

Glass and plastic are poor insulators, losing more than ten times as much heat as a well-insulated wall. Areas of the greenhouse that don't receive direct sunlight, such as the north wall and roof, and foundation, can be insulated to retain heat. Insulated interior walls and framing members are painted white to reflect light. A large thermal mass, usually water or rock, is placed in the greenhouse to absorb and store the excess day heat; at night, this heat emanates from the storage into the greenhouse. Night insulation systems using blankets, panels or shutters are often provided to reduce heat loss through the glazing.

The principles of solar energy can be applied to a full range of structures, from cold frames and other devices in the garden to the full scale permanent greenhouse. The greenhouse can be freestanding, but most typically it is attached to the residence or other building for convenience of access, simplified construction, and potential supplemental heat for the residence. If possible, the attached greenhouse should enclose a window, and/or a door connected to the house.

Figure 1. Typical solar greenhouse components



Where the conventional greenhouse is generally operated year round, using a large amount of fossil fuel to maintain optimum growing conditions, the solar greenhouse adapts to nature and is designed for a more specific or limited purpose. In the design stage, the choice must be made between obtaining maximum plant production or maximum supplemental heat production for the house.

TYPICAL USES of the SOLAR GREENHOUSE

The Sunspace

During the winter, the sunspace collects heat for the residence. While not as efficient as a standard flat plate solar collector, it does collect heat, extend the residence living space and provide limited, season-extending growing conditions in the spring and fall. Plants are usually container-grown.

The sunspace often has vertical windows, little non-south facing glazing, and reduced need for ventilation compared with a plant-growing greenhouse. A large mass for heat storage is not required, as heat produced in winter is delivered to the residence, sometimes by a thermostatically controlled fan. Generally no auxiliary heat is provided.

Extended Living Space

An attached greenhouse, separated from the house by sliding glass doors may be used as an extension of home living space. During cold, sunny weather, extra heat from the greenhouse supplements the heating system and heat from the house heats the greenhouse at night. Plants are container-grown year round. Energy conserving measures are used during the winter and shading during the summer. No storage is necessary during the cold months as the house takes all the extra heat, but storage may be used in spring and fall when extra heat is available. Supplemental heat or heat from the home is often needed in winter.

Season Extender

The season extender greenhouse is used primarily to extend the outdoor growing season by several months in the spring and fall. Garden vegetables can be started early in the spring. When transplanted outdoors they reach maturity sooner. In the fall, crops can be transplanted from the garden into large containers to continue harvest after frost. Insulation, night blankets or insulation panels and a large thermal storage are needed to retain the day's heat; otherwise an auxiliary heating system may be necessary. This type of greenhouse is generally not used for plant production during the coldest part of the winter. Cold frames, hotbeds and window greenhouses are other low-cost options to extend the growing season.

Year round Plant Production

The **cold** winter greenhouse without supplemental heat has similar design requirements to the season extending greenhouse, except that it is more important that the south facing glazing receive maximum sunlight during the coldest part of winter. A small auxiliary heater is needed to maintain a minimum temperature during very cold nights. In the Northeast, some leafy green vegetables will tolerate these conditions. Many ornamental crops also tolerate low light levels and cool temperatures.

A **warm** winter greenhouse using a supplemental heating system will provide optimum temperatures for maximum production. The use of solar heating principles and insulation techniques will greatly reduce the amount of fuel needed to heat the greenhouse.

PASSIVE vs ACTIVE SYSTEMS

All of the previously discussed greenhouses are heated by **passive** solar heat. In this system the greenhouse acts as the collector and heat is stored in an internal water or rock storage. The main advantages of the passive systems are their simplicity of construction, low maintenance, and appreciably lower first costs. Significantly more expensive and complex **active** solar heating systems are rarely used. They have external solar collectors and fans or pumps to move the heated fluid or air into the greenhouse or into a storage.

CHOOSING a DESIGN

The solar greenhouse design must be suited to your overall purpose, plant growing needs and to the site, with its geographic and climatic conditions. If attached to the residence, it should enhance its appearance and comfort year round, as well as increase your gardening pleasure.

Before choosing a design, develop a year round gardening plan. Familiarize yourself with the results of other solar greenhouse experiments, particularly in your geographic location. The amount of solar radiation available varies widely from region to region and the plant growth rates will be proportionate to the amount of available sunlight.

The information in this booklet will help you decide which plant growing structure is best for you, as well as help in choosing, designing, constructing or retrofitting a greenhouse. The section on controlling the environment offers suggestions on heating, energy conservation, ventilation and humidity control. Cold frames, hotbeds, window greenhouses and indoor lighting are included in a chapter on smaller scale alternatives to the greenhouse. The section on plants discusses plant requirements and problems associated with the passive solar greenhouse. A number of plans for plant growing structures and equipment are also included.

Solar Heating Principles

Solar energy reaches the Earth's surface by direct radiation and by diffuse sky radiation, reflected from clouds and atmospheric dust. Diffuse radiation also includes radiation reflected from adjacent ground or building surfaces. The relative proportion of total radiation from these sources varies widely in each climate. Hot-dry climates with clear skies enable a large percentage of direct radiation to reach a building while up to 40 percent of the total radiation received may be diffuse in temperate and humid climates. In northern areas, low winter sun reflection off snow may result in a greater amount of incident radiation on vertical walls than in warmer, but cloudier, areas. Because of different types and amounts of radiation and different heating demands, the design of optimum solar heating components will vary in each locale, and with the particular use of the greenhouse.

TILT of the EARTH'S AXIS

The earth rotates on an axis that is tilted 23.5° with respect to the plane of its orbit around the sun. This tilt is the primary cause of seasonal changes.

Figure 3. Types of solar radiation

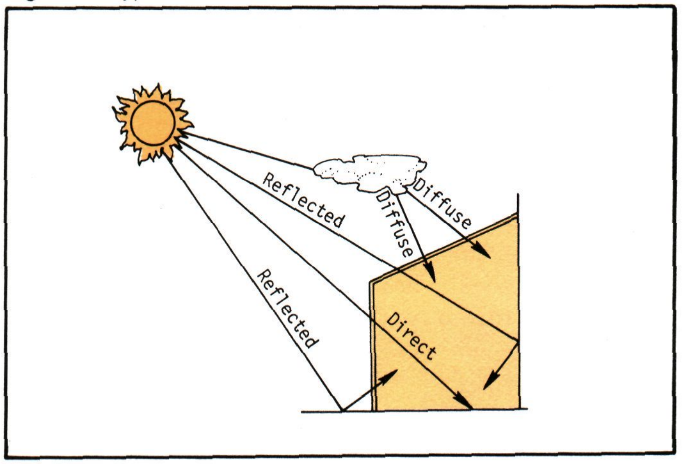
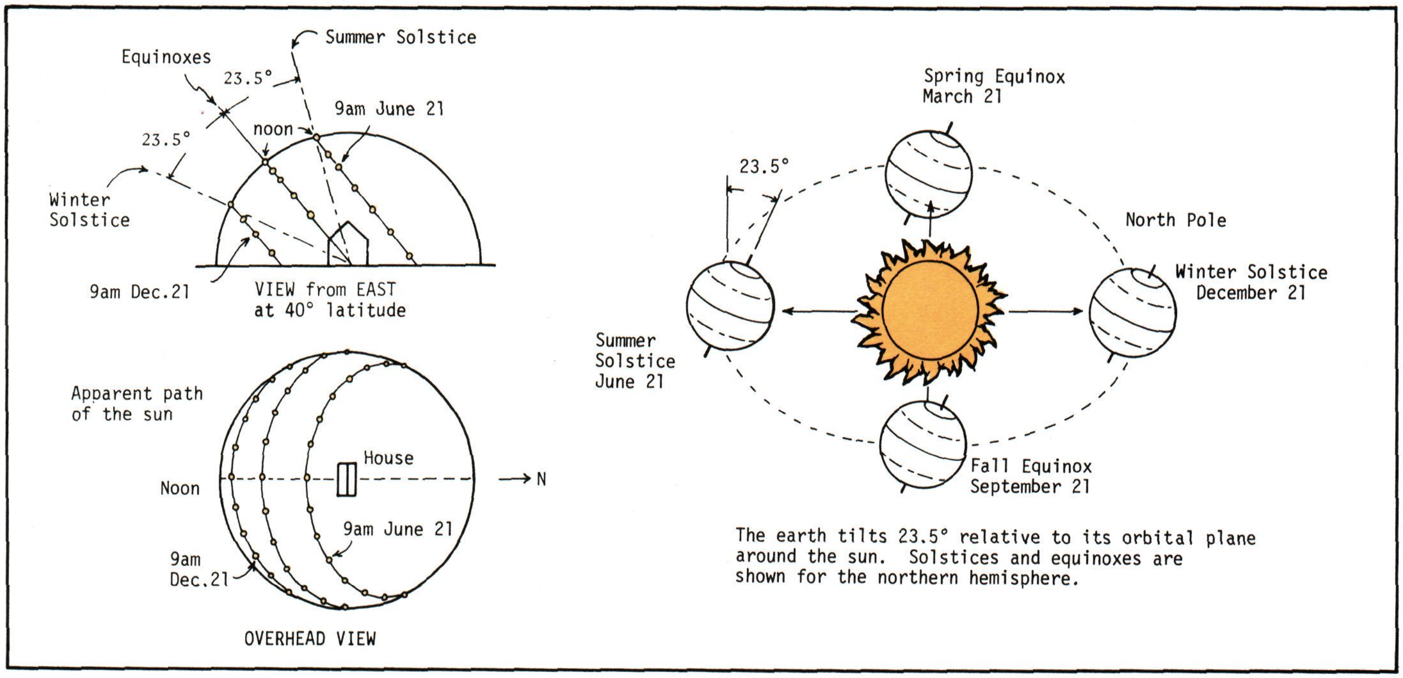


Figure 2 shows the position of the sun on the first day of summer, winter, spring and fall at 40° north latitude. Note that little useful radiation is available before 9:00 A.M. in the winter. Also, because the sun's angle is very low, more radiation is lost because it must travel through more atmosphere.

Figure 2. Diagram of the earth's path

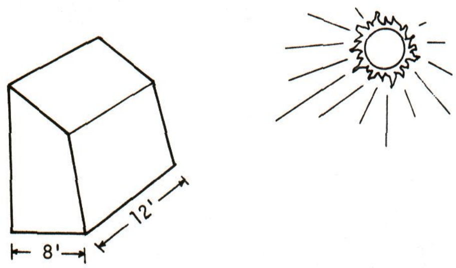


SOLAR INTENSITY

Solar radiation maps for January and July illustrate the variation of solar energy received on a horizontal surface. During the summer the Northeast receives almost as much radiation as the South. During winter months the picture is quite different; most of the northern areas receive less than half the radiation of the South. (Figure 4).

Local conditions also affect sunlight. In areas where fog or smog are common, values may be reduced significantly. Shade from trees or adjacent buildings also will reduce solar radiation.

For example, consider a conventional 8′ x 12′ glass greenhouse. If it must be maintained at 60°F over a 24 hour period with an average outside temperature of 30°F the heat loss would be about 310,000 Btu's (equal to about 3 gallons of fuel oil burned at average efficiency). Assuming an average solar daily input of 600 Btu/sq. ft., the heat gain will be 26,000 Btu per day, or less than one-tenth what is needed.



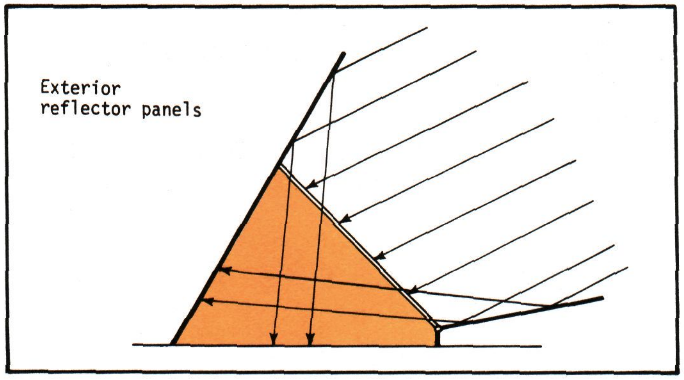
Now consider a well insulated solar greenhouse of the same dimensions. The daily heat loss using the same temperatures amounts to about 45,000 Btu per day. Solar gain with this design will be about 23,000 Btu's, still not enough to provide all the greenhouse heating needs for the day.

On a sunny winter day, however the solar input is 1400 Btu per square foot per day or more. Then the sun provides all the greenhouse heating needs—if the house is well insulated and the heat can be stored.

SUNLIGHT for PLANT GROWTH

Light is often the limiting factor to plant growth. Any solar greenhouse will work better in the southwestern U.S. where more sunlight is available than in the middle Atlantic states or the Northeast. To reflect more light to plants, it helps to paint framing members and insulating walls white. Walls may also be covered with aluminum foil-faced building paper.

External reflector panels located above, in front of, or to the side of the greenhouse, if angled properly, will reflect light into the structure. Sometimes these reflectors can be made part of external insulating panel, but they must be designed to withstand the weather.



ORIENTATION

To receive the most sunlight, the major glazed area should face south or 5° to 10° east of south. The slightly eastern orientation allows the morning sun to clear any condensate a bit earlier. Slight variations of up to 20 degrees from true south reduce the energy received by less than 5 percent. Even when the greenhouse faces southeast or southwest the reduction is less than 25 percent.

Use a compass to check the direction your greenhouse will face; but remember to correct for the declination between magnetic north and true north. You can also use a property map or a local subdivision map to orient your greenhouse or observe the position of the sun at solar noon when it is located at true south.

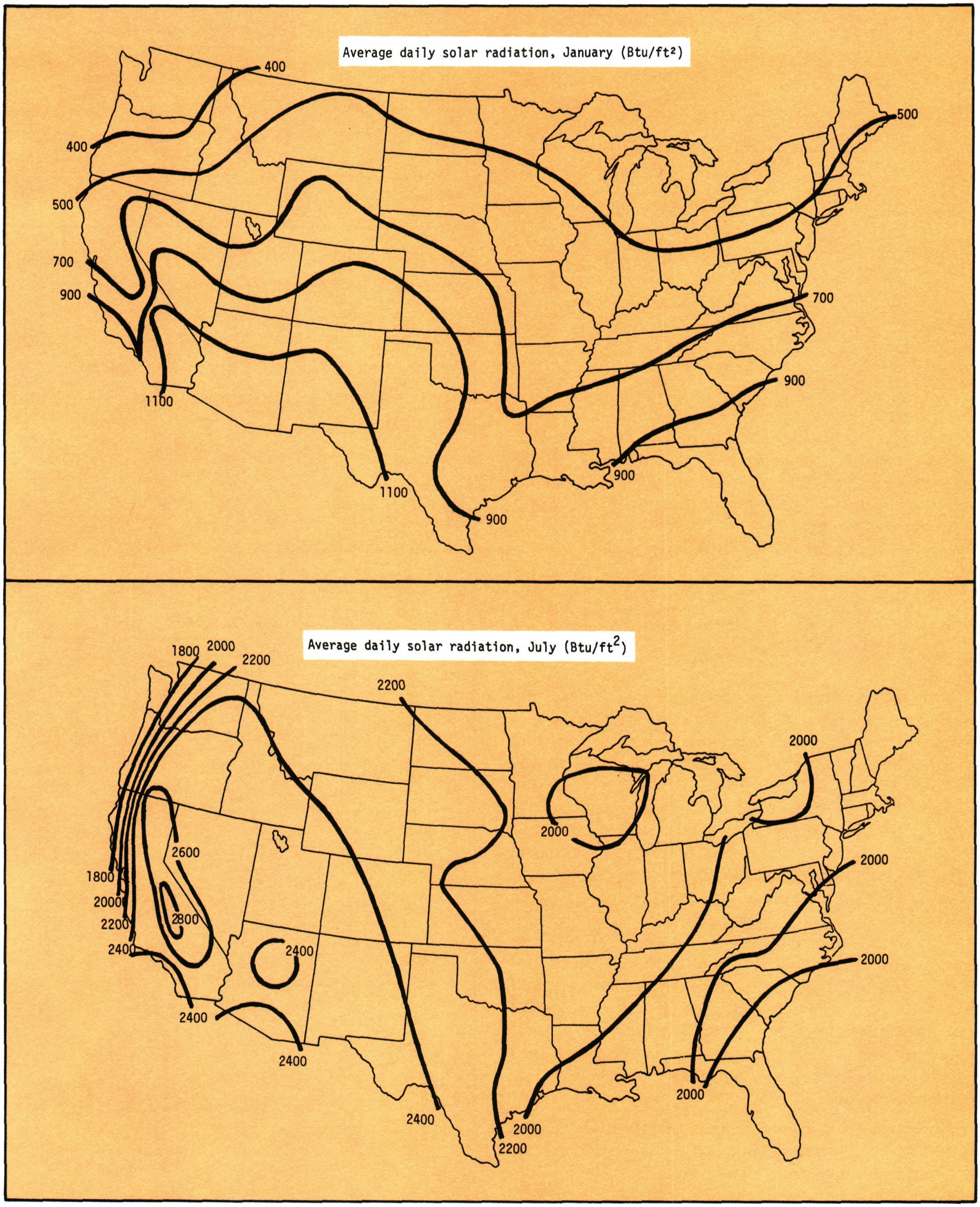
To find solar noon find your longitude on a road map, atlas or globe. Then multiply by 4 to obtain the number of minutes that solar noon occurs before or after noon standard time.

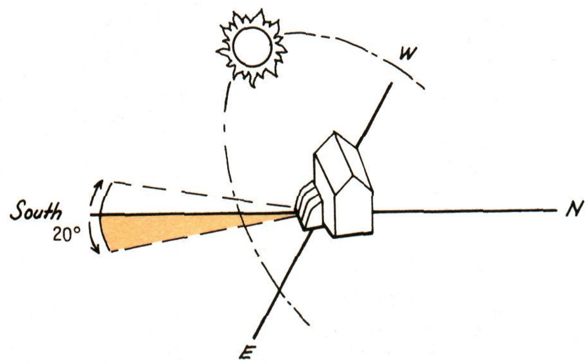
To find solar noon:

1. Find your longitude on a road map, atlas or globe.
2. Subtract 75 from longitudes in the eastern time zone.
   Subtract 90 from longitudes in the central time zone.
   Subtract 105 from longitudes in the central time zone.
   Subtract 120 from longitudes in the Pacific time zone.
3. Multiply the remainder by 4 to obtain the number of minutes that solar noon occurs before or after noon standard time.

For example, find solar noon for a greenhouse near Hartford, Connecticut which is at 72.6° west longitude. First subtract 75 to obtain -2.4°; then multiply by 4 to get -9.6 minutes. Therefore solar noon occurs about 10 minutes before noon Eastern Standard Time (10 minutes before 1 pm Eastern Daylight Time).

Figure 4. Solar radiation maps for January and July





Percentage of solar gain available as the site moves away from true south.

True South	100%
20° East or West	95%
30° East or West	90%
45° East or West	72%

If you have to orient your greenhouse more than 30 degrees from south, glaze most of the endwall that receives the greater hours of sunlight and fully insulate the opposite endwall.

SLOPE of SOUTH FACING GLAZING

The maximum amount of energy passes through the glazing when it is perpendicular to the sun's rays. With a particular design this only occurs for an hour or so on two days of the year, once in the spring and once in the fall. The rest of the time part of the energy reflects off the surface. If the greenhouse will be used all winter long, the angle of the south-facing glazing will be determined for the period of January and February when the combined effect of temperature and reduced solar radiation is most severe. Other factors, such as weather patterns (e.g. foggy mornings in spring, etc.), physical site factors, obstructions and horticultural considerations, will also influence the design. One rule of thumb is to add 15° to your latitude to get the desired slope. For northern areas the best roof angle is between 35° and 65° from the horizontal. If a large percentage of the solar radiation in your area is diffuse, choose an angle from the lower end of the range so that the inside of the greenhouse is exposed to a greater part of the sky dome.

Table 1 shows that even a vertical wall effectively collects solar energy, especially during the winter. If you are designing your own greenhouse, use the following guidelines when selecting the angle.

Table 1. Total daily insolation on a clear day at 40°N Latitude, Btu/ft^2/day.

	Slope of Roof or Side Wall from Horizontal					
Date	0°	30°	40°	50°	60°	Vertical
Jan 21	948	1660	1810	1906	1944	1726
Feb 21	1414	2060	2162	2202	2176	1730
Mar 21	1852	2308	2330	2284	2174	1484
April 21	2274	2412	2320	2168	1956	1022

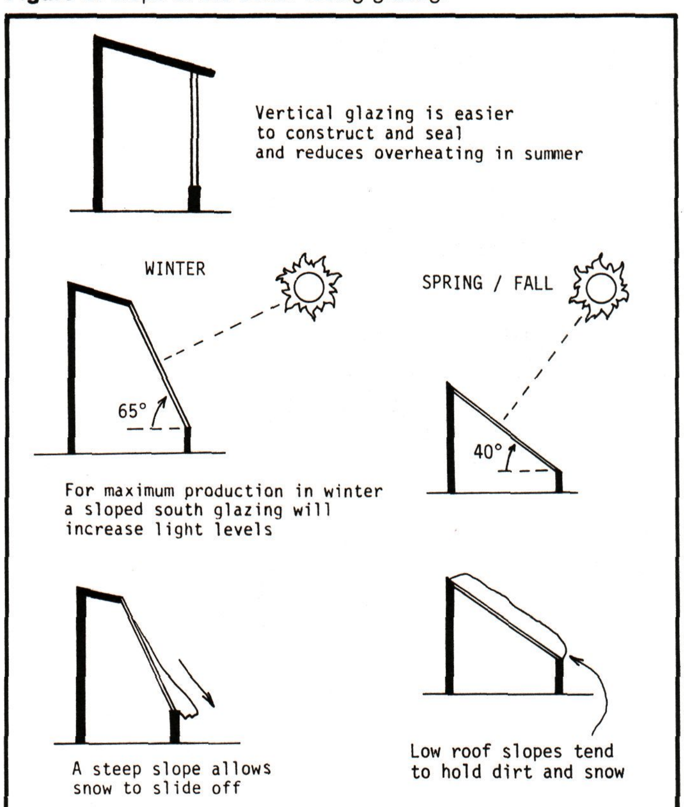
Use a steep angle:

- in areas where there is a greater percentage of direct sun,
- for narrow greenhouses,
- for greater solar collection during the winter,
- for less overheating during the summer.

Use a shallow slope:

- in areas with cloudy weather,
- in wide houses,
- in a greenhouse built for spring and fall use,
- to allow an attached greenhouse to fit under the eave,
- to reduce heat loss.

Figure 5. Slope of the south-facing glazing.



SOLAR GREENHOUSE COMPONENTS

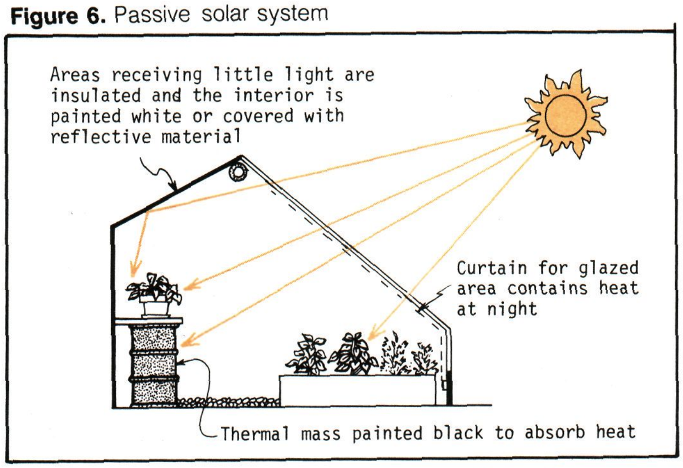
A true solar greenhouse depends on heat captured and stored during sunny days to keep it warm during the night and on cloudy winter days. In most parts of the northern U.S., however, the temperature in such a greenhouse will drop to near or below freezing during extended periods of cloudy cold weather. Clearly, some form of back-up heat is needed if plants are to survive and grow.

Solar Heating: Passive, Active, Hybrid

The three basic solar heating systems include either passive, active or hybrid designs. In a **passive** system the building and its components collect and store the solar energy. No blowers, pumps or electrical equipment are used. This is usually the most cost effective way to use energy from the sun. Water barrels or rock walls typically store heat for a passive system used in greenhouses.

Active solar systems typically have separate solar collectors and either pumps or blowers to transfer heat via liquid or air from the collectors to a separate storage. The same or additional pumps or blowers may be needed to remove the heat from storage and distribute it within the greenhouse. A blower and duct system that transfers heat from the ridge of the greenhouse to a rock bed is an example of an active system.

Figure 6. Passive solar system



A **hybrid** system may combine some of the features of both the active and passive systems. In an attached hobby greenhouse with a passive collector-storage wall of five gallon cans, a small fan may be installed to transfer heat to the house. The equipment cost and energy used to run the fan is small compared to an active system.

The Collector

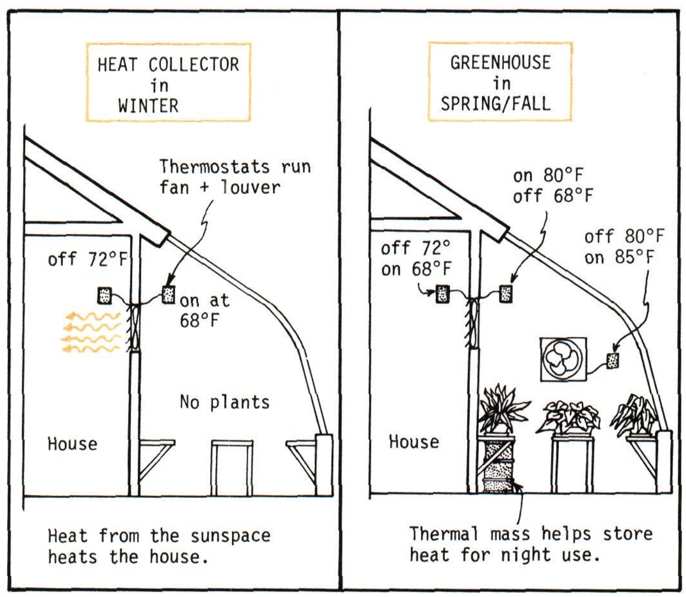
A collector converts incident solar radiation (insolation) into thermal energy to heat air, water or other media. Greenhouses are natural solar collectors and, through modification, can store heat trapped during the day for later use at night.

A greenhouse-collector has several advantages over an external collector. Construction costs are less, little additional land is required and little heat loss occurs in the transfer of heat from the greenhouse or storage to the house.

A greenhouse has several deficiencies as a collector. At times, it must be vented to remove excess heat and lower humidity levels to prevent disease. Insulation, internal blankets and double glazing should be used to hold the small amount of heat collected more effectively.

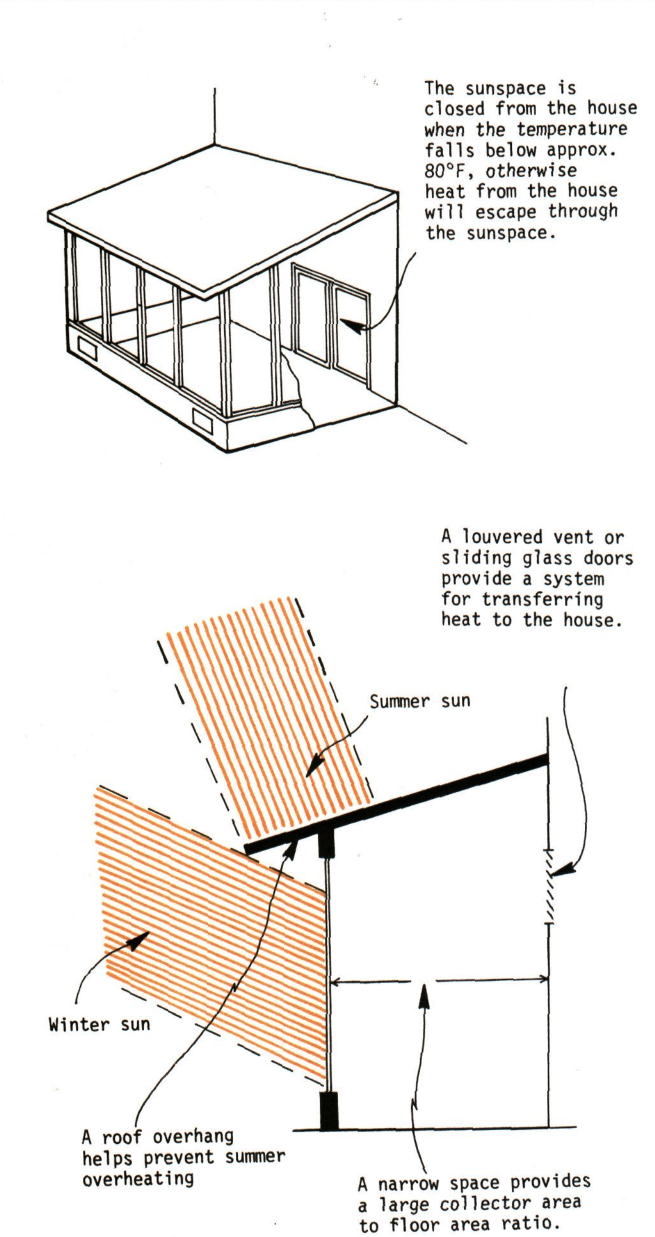
On the other hand, an external collector, oriented to face the sun directly, captures a higher percentage of the sun's heat and requires no venting. In its simplest form, an external **flat plate collector** is a large piece of black material set to absorb the sun's rays. Heat is then transferred to an anti-freeze solution, water or air passing over or through it. More heat can be collected by covering the front of the collector with more than one layer of glass or transparent plastic, and insulating the back. Most external collectors have a high initial cost and are not used to heat the hobby greenhouse.

Sunspaces are operated as solar collectors, so few, if any, plants are grown in them. On sunny days a sunspace may become quite hot. Then at night or whenever the temperature in the space drops below 70° to 75°F, it is typically closed from the house. Otherwise heat from the house will escape through the sunspace. But closing the sunspace at night often allows it to become quite cold. Thus it is not well suited to grow plants during the heating season.



Several studies have shown that a typical sunspace delivers about 25% of the energy available from the sun. Transmittance losses, reflection off the glazing, and shading by the structure account for as much as half the losses. Heat that passes out through the glazing and losses in transferring the heat to the house account for the remainder.

Figure 7. The sunspace



During the heating season from October through April, much of the Northeast can expect modest levels of light. In this time, a typical south facing sunspace with 100 square feet of glazing will have 15 to 30 million Btu of radiation fall on it. About 5-8 million Btu of this energy can be collected, which is the heating equivalent of 50-80 gallons of fuel oil.

Sometimes a fan is installed to circulate warm air from the sunspace into the residence. It should have a diffuser and a louver or damper that closes by gravity. Calculate the fan capacity in cubic feet per minute by dividing an estimate of the volume of the sunspace by 2.

A sliding glass door may be used instead of a fan. The door is opened when the sunspace is warm and closed at night. A sunspace that is used as living space must either have large roof and side vents or a fan that brings in outside air to cool it on sunny days.

Heat Storage

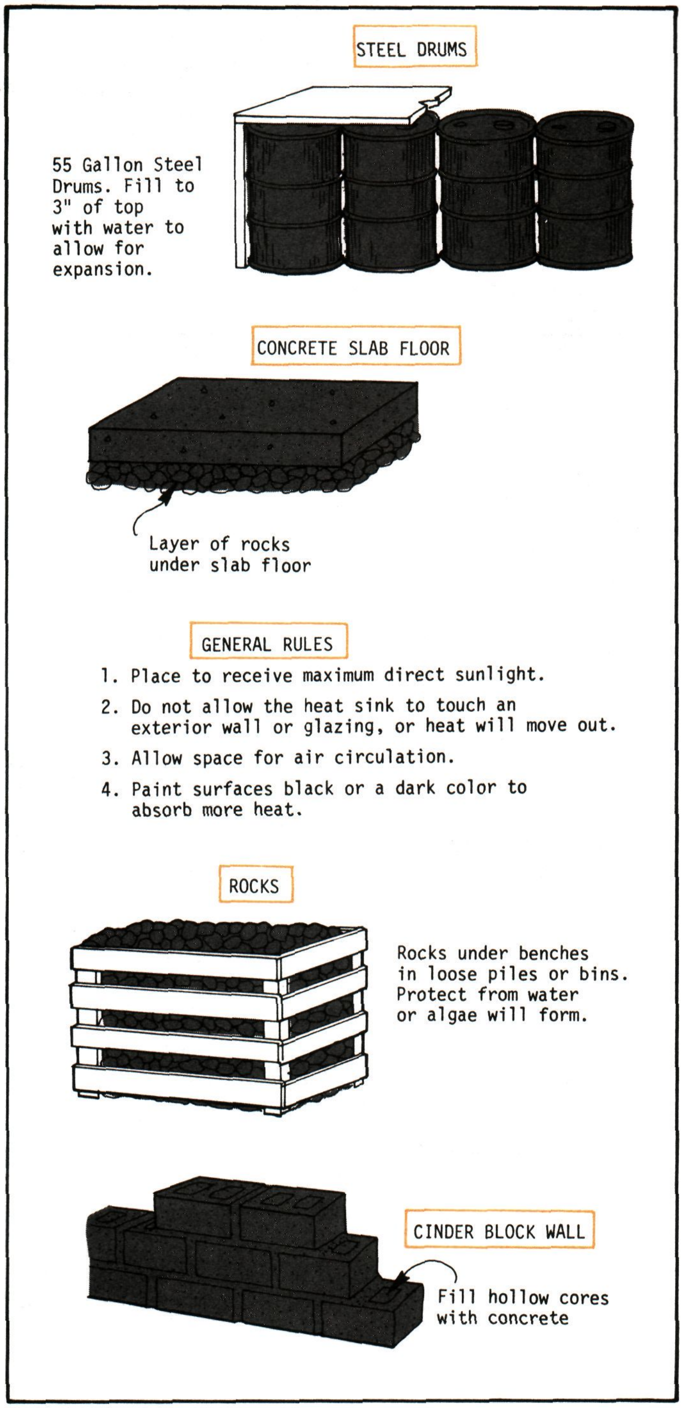
Heat collected is normally stored for later use by warming a material such as a brick or concrete wall, water, small stones, or a material that changes phase. Pound for pound, water can store more heat than any commonly available material. One Btu of heat will raise the temperature of a pound of water 1°F. This value is called specific heat. Rock, iron, or aluminum have specific heats of about 0.2 Btu or less per pound of material per °F temperature rise.

Table 2. Heat capacities of materials at room temperature.

Material	Specific Heat (Btu/lb-°F)	Unit Weight (lb/cu ft)	Volumetric heat capacity (Btu/cu/ft-°F)	Volumetric heat capacity (Btu/gal/°F)
Water	1.00	62.4	62.4	8.3
Steel	0.12	489.0	58.7	
Aluminum	0.21	171.0	35.9	
Concrete	0.16	140.0	22.4	
Window glass	0.20	162.0	32.2	
Brick	0.22	123.0	27.1	
Crushed rock	0.23	105.0	24.2	
Sand	0.19	95.0	18.0	
White fir	0.65	27.0	17.6	
Used motor oil	.50	6.1	28.1	3.0

Phase Change Materials. Heat is stored by melting a solid at a set temperature. When heat recovery is needed, the liquid freezes at that set temperature releasing the heat of fusion. Two common phase change materials used for storage of solar heat are Glauber's salt and calcium chloride hexahydrate. Glauber's salt has a melting point of 88-90°F and a heat of fusion of 108 Btu/lb. Calcium chloride hexahydrate has a melting point of 81°F and a heat fusion of 82 Btu/lb. A much smaller volume of a phase change material is required to store the amount of heat available in a greenhouse.

Figure 8. Types of solar heat storage



Deciding on a storage volume is as difficult as sizing the collectors. A rock bed for an air system must be larger than a water tank for the same heat storage capacity. Many small stones in a given area have more surface area than a few large ones; so for a given air velocity, more heat can be transferred to the smaller stones in a given time. Stones should all be about the same size, washed, and fairly round for best results. A concrete aggregate mix of sand, pebbles, and rock is not good for solar heat storage because it has a high resistance to air flow.

Small 3/8 inch stones work well in large, shallow (2 to 3 ft deep) beds, while larger, 3/4 to 1 1/2 inch stones have less impedance to air flow in deeper beds.

For low temperature applications, the temperature of the storage unit will rise only 20° to 30°F during the day. The storage should have enough capacity to heat the greenhouse for an average winter night.

Example: Sizing a Heat Storage

For example, a well insulated solar greenhouse, with 150 square feet of double wall south facing glazing, loses about 100 Btu per hour per degree temperature difference between inside and outside. If the average outdoor temperature for the 14 hour overnight heating period is 20°F and the inside temperature is 45°F, about 42,000 Btu will be needed (120 Btu/hr x 25°F x 14 hours). Storage for that much heat can be provided with 168 one gallon cans, 34 five gallon cans, 3 fifty-five gallon drums or a 2 ft x 3 ft x 14 ft rock bed. The storage is assumed to cool 30°F (from 80° at night to 50° in the morning (Table 3). There is some storage of heat in the soil, benches and plants that will help heat at night. This will tend to reduce the amount of water or rock storage needed.

Table 3. Heat capacity of water storage containers.[1]

	Water Temp., °F	Heat Capacity, Btu 55 Gal. Drum	5 Gal. Square Can	1 Gal. Can
Passive Systems	60	4590	420	80
	70	9170	830	170
	80	13760	1250	250
	90	18340	1670	330
Active Systems	100	22930	2090	420
	110	27520	2500	500
	120	32100	2920	580

[1]Assumes minimum greenhouse temperature of 50°F and uniform water temperature throughout containers which is usually not true in larger containers.

The amount of heat that is collected in the storage will also depend on how many plants are in the greenhouse. In a greenhouse full of plants, about 50 percent of the solar energy entering is used to evaporate water from the leaf and soil surfaces. For this reason a greenhouse used as a sunspace should not have any plants if maximum collection is desired.

Storage Location

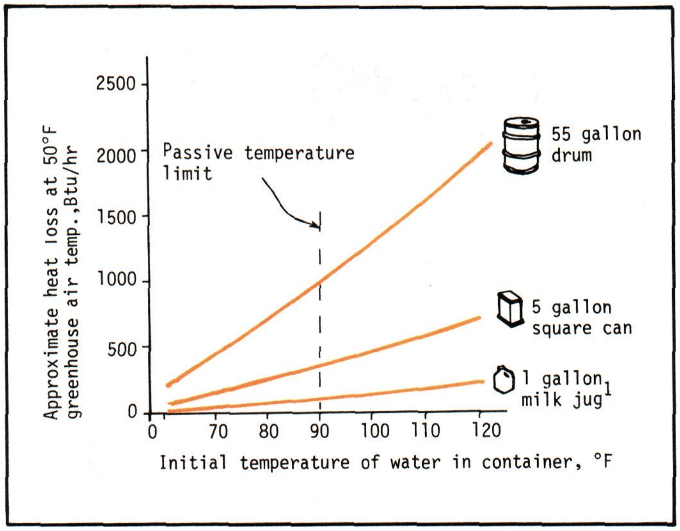
There are several advantages to locating the heat storage inside the greenhouse. Any heat lost from the storage still heats the greenhouse, no losses occur when heat is circulated from the storage to the greenhouse, and little additional land is required for the storage. Locate the storage to receive maximum direct sunlight.

Heat Transfer

The amount of heat transferred to the greenhouse from a hot water heater or storage tank is almost proportional to the area of the heater or tank surface and the water temperature. Values for typical passive storage containers are shown in Figure 9.

This ratio for a 55 gallon drum, 5 gallon square can and 1 gallon can is 0.23, 0.94 and 1.5 square feet per gallon respectively. A one gallon can will loose its heat about 6 times faster than a 55 gallon drum. For example, a one gallon container may release its heat in 3 hours whereas a 55 gallon drum takes about 20 hours to lose its heat. Generally the five gallon size, if they are stacked tightly, or the 55 gallon drums work best because they hold more water per unit of surface than the 1 gallon containers.

Figure 9. Amount of heat given off by different water storage containers



[1]Plastic milk containers may deteriorate rapidly when exposed to direct sunlight.

Controls

An active system such as a rock storage with blowers or a water tank with external collectors requires a control system. Controlling everything to operate at the right time or temperature is a challenge. The transfer fluid should not be circulated to the collector at night or when there is not enough sunlight to heat it. Water or air should not be circulated from storage to the greenhouse if storage temperatures are lower than greenhouse temperatures.

Greenhouse Design and Construction

GREENHOUSE TYPES

The **attached greenhouse** is popular because it blends well with the home and landscape. Its other advantages include:

- Costs less to build because it shares a wall with the house.
- Is more convenient to maintain; access is from the house.
- Helps insulate the wall of the house, but only if it is insulated or closed off at night.
- Can add heat and moisture to the house.
- Has convenient access to water, heat and electricity, if needed.
- Can be built to extend the living space of the home.

Disadvantages of the attached greenhouse include:

- Summer overheating.
- Temperature control is sometimes difficult unless fans are used for ventilation.
- Pests can be introduced to the residence.

Freestanding greenhouses are generally more expensive, but allow more flexibility than the attached styles because they can be larger and located to receive more sunlight. Many different shapes are available.

The **pit greenhouse** is built partially below ground (4′ or so), often attached to another building, roofed with transparent material that faces south, and normally heated only by the sun. It may be less expensive to build and heat than many of the above ground styles, if the cost to excavate and provide drainage are not too high. The surrounding earth will keep it cool, but usually above freezing if the glazing is covered with insulating blankets at night. In winter, snow will not slide off the roof. Ventilation is poor so this greenhouse is not best for summer use. Properly installed drain tile or a sump pump should be installed for drainage.

Figure 10. Pit greenhouses

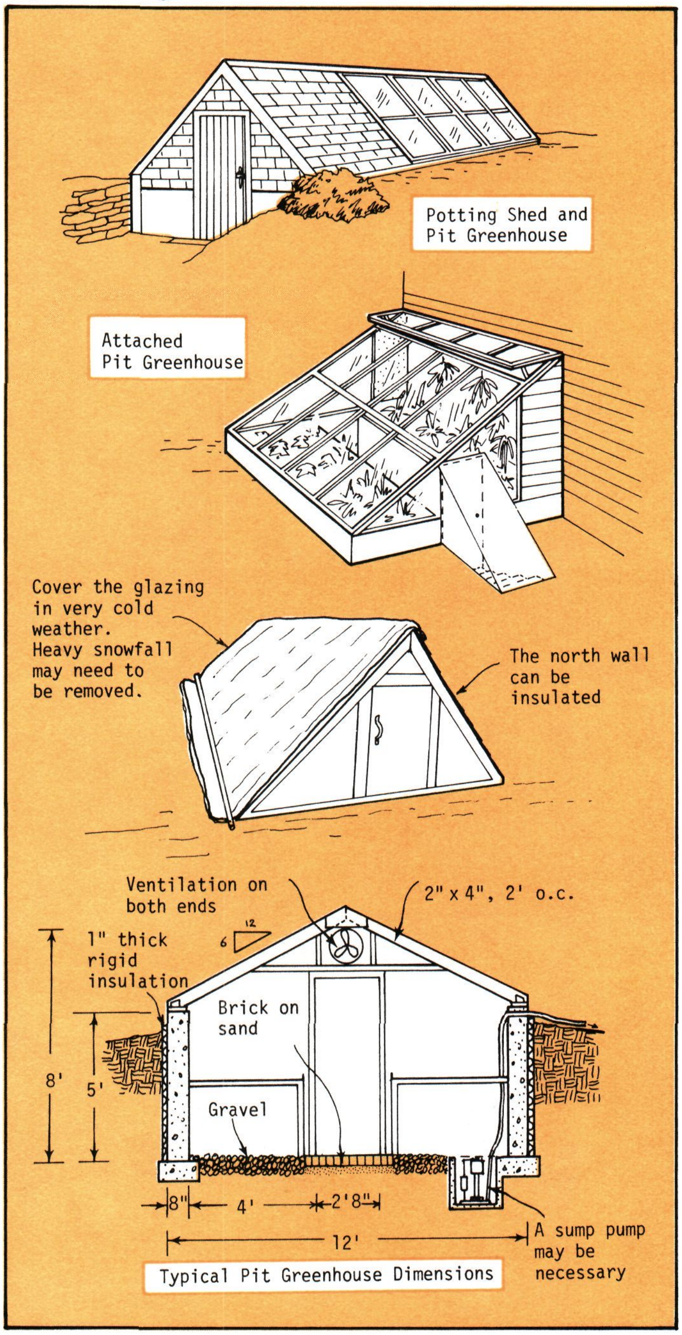
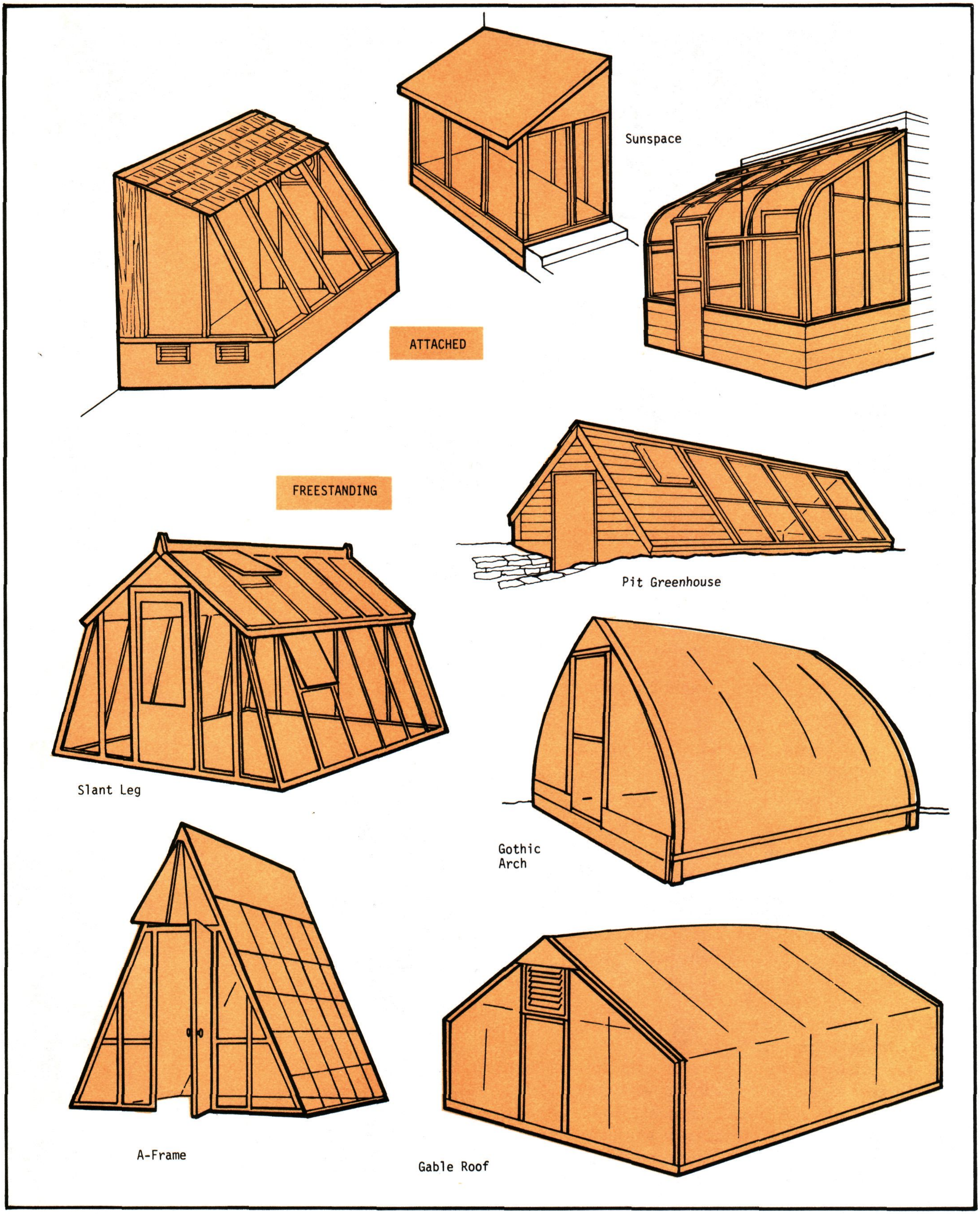


Figure 11. Greenhouse types



CHOOSING a SIZE

Usually available space and cost, more than need or desire, dictate greenhouse size. All too often this problem leads to the purchase of a flimsy, tiny box that never seems to function properly as a greenhouse. Temperatures fluctuate rapidly in a small greenhouse and heat losses can be almost as high as in a larger house. A 6′x6′ greenhouse can better be replaced by a 3′x6′ hotbed at a quarter of the price and a tenth of the fuel cost.

When choosing a size, ask yourself how you will use the greenhouse. Are you really an avid gardener who can use the space a greenhouse offers? Can you spend the time needed to maintain it? If you are an avid gardener and have a choice, select a size somewhat larger than you think you will need. If you are only starting a few seedlings for the summer garden, perhaps a hotbed is a better choice. Remember that costs of heat, plants, fertilizer and your time will soon exceed the initial cost of the greenhouse itself.

Length depends on available space and money, but 10′ is minimum for a freestanding house. Attached houses are sometimes smaller. Small greenhouses are often proportioned so that length does not exceed twice the width. If you are building the greenhouse primarily as a sunspace or heat collector, a long narrow space is generally desirable. This gives a large collector area to floor area ratio.

Small greenhouses often do not have enough headroom and are hard to work in. Taller houses heat and ventilate more uniformly, so they require little or no more heat than the shorter house. Eave height of gable roof houses should be at least 5 1/2′ and ridge heights at least 8′. Doors should be 24″x72″ or larger. Standard doors are 32″ or 36″ wide and 78″ high.

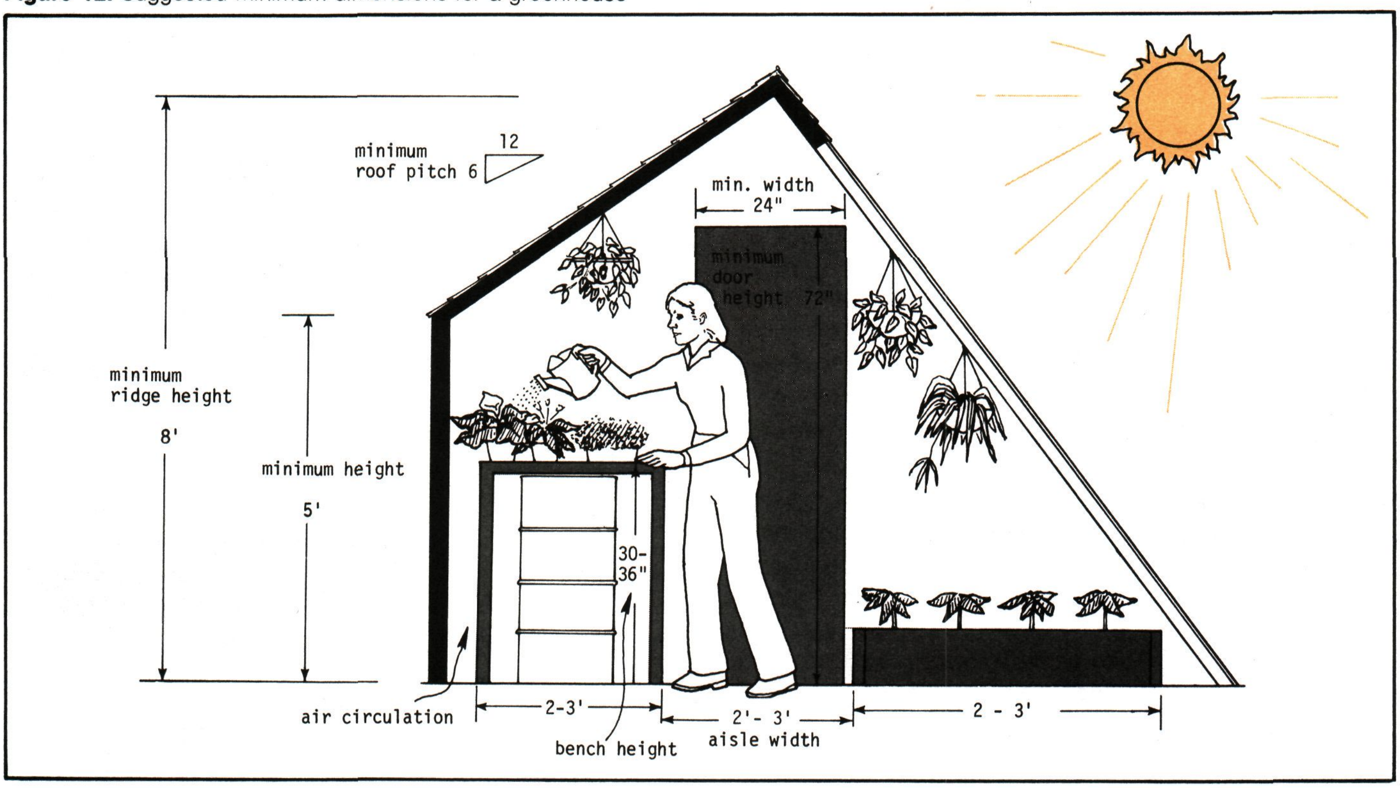
Figure 12 shows typical widths for aisles and benches. Add at least 6″ to each side for air circulation around solid benches or heat storage devices. Minimum outside width for a greenhouse with two side benches and a center aisle is 6 1/2′. Eight feet is better.

COVERING MATERIALS

The sun radiates both visible and invisible wavelengths of energy. Most greenhouse crops grow best in light whose wavelengths fall between 400 and 700 nanometers. This waveband is called photosynthetically active radiation or PAR. Greenhouse glazings readily transmit these short waves of visible light.

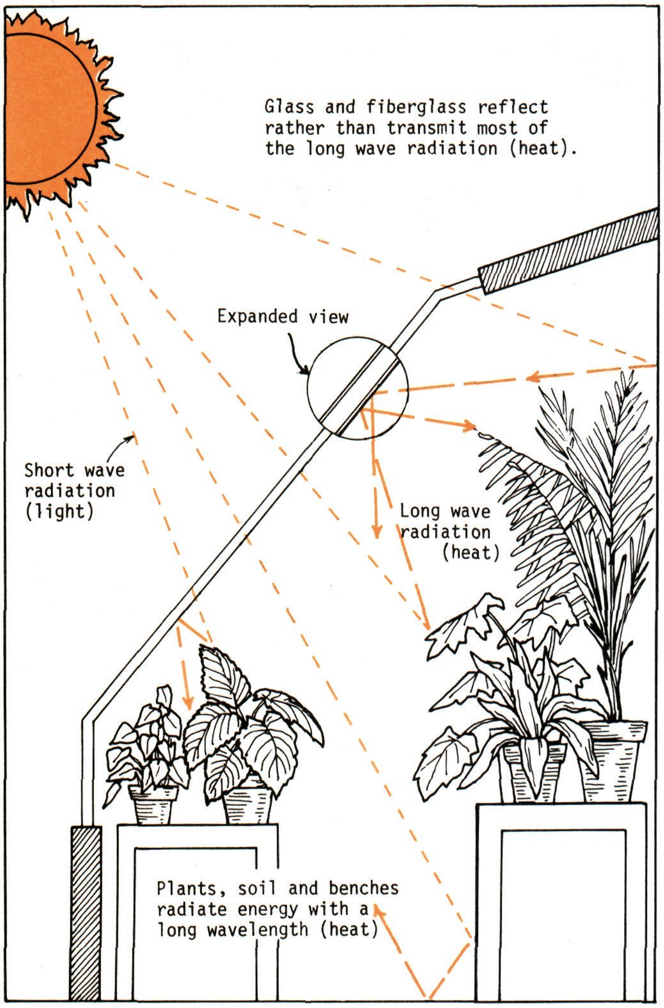
Plants and soil also radiate energy, but with a very long wavelength. Glass and fiberglass reflect, rather than transmit most of this long wave energy. This property of glass is called the "greenhouse effect." Some plastics, particularly polyethylene, transmit a large portion of this long wave radiation. This property causes polyethylene covered houses to cool faster at sunset. However, water condensation on the polyethylene reduces this radiant heat loss.

Figure 12. Suggested minimum dimensions for a greenhouse



Greenhouses also trap heat because they are an enclosed space. Only about a quarter of the temperature rise in a greenhouse is due to the greenhouse effect. The remaining 3/4 of the temperature rise is due to the air being trapped in an enclosed space.

Figure 13. The greenhouse effect



Glass is the standard against which other covering materials are measured. Glass houses are attractive, permanent, and expensive. Glass is durable but breakable, so double strength or tempered glass normally is used for greenhouses. Tempered glass is stronger and on widely spaced supports allows more light to enter. Glass-covered houses should be built by a greenhouse manufacturer or purchased in kit form because they are difficult to fabricate.

Sunspaces are often built using windows or sliding glass doors. They are readily available in several sizes. Wood framed windows provide more insulation than metal ones, and are preferred.

The proportion of radiation which enters the greenhouse depends on both the chemical composition and the thickness of the transparent material. The normal glass and plastic used for greenhouses not only reduce the intensity of solar radiation but also have a selective effect and allow only certain parts of the light spectrum to penetrate. Common glass transmits only radiation with wavelengths between 320 nanometers (nm) and around 2800 nm. Visible light ranges from 360 nm to 760 nm.

Most glass contains iron which absorbs light. Low iron glass transmits about 90% of incoming solar radiation while typical window glass transmits 83%.

A large variety of **plastic glazings** are available. Generally plastics are resistant to breakage, lightweight and relatively easy to install. Most plastics, however, degrade under sunlight. Quality plastic glazing varies widely, so it is important to buy a greenhouse grade plastic, preferably with a written guarantee of its life. Characteristics of various plastics are listed in Table 4.

Polyethylene, fiberglass and patterned glass diffuse or scatter light while polycarbonate, acrylic, polyester and float glass are clear and allow radiation to pass through directly. Diffuse light can benefit plants both by reducing excess light on the upper leaves, and by increasing the amount of light reflected into the lower leaves. Too much direct sunlight on the upper leaves can overheat the plant and thus reduce photosynthesis. In the South or West, fiberglass glazing reduces heat stress which may reduce plant growth. In the Northeast and coastal Northwest, sunlight often is diffused by clouds, so diffusing glazings offer little benefit in these areas during the winter.

Acrylic is very transparent, very resistant to weathering and breakage, and can be used as a curved panel. However, *acrylic is very expensive, flammable and easily scratched.* The long-wave thermal radiation absorption and the ultraviolet radiation transmission of acrylic is higher than glass. This means you could get a sun tan in an acrylic but not in a glass greenhouse. Ultraviolet radiation keeps plants shorter by suppressing cell elongation.

Double-layer acrylic glazing has some advantages when used for greenhouse glazing. It is a translucent material that transmits about 83 percent of the light and reduces heat loss by 30 to 40 percent of that through a single layer.

Polycarbonate. Double-wall polycarbonates (Qualex and Tuffak Twin-wall) transmit 75-80 percent of the light and offer the same 40% energy conserving properties as other double-walled materials.

Polycarbonate panels usually are more flexible, resist impact better, and because they are thinner, are less expensive than acrylic panels. Thin polycarbonate panels can be bent during construction to fit a curve while the same thickness of double layer acrylic would have to be heat formed. Acrylic maintains high transparency throughout its life while polycarbonate starts turning yellow and losing transparency within a year. The manufacturer of Qualex suggested that it will lose about one percent light transmission per year over its approximately 10 year life.

Table 4. Comparison of characteristics of glazing materials with supporting framework.

General Type	Comments	Typical Trade Names	Light (PAR) Transmittance (%)	IR Transmittance (%)	Estimated Lifetime (years)	$/ Square Foot
Glass	**Advantages** Excellent transmissivity Superior resistance to heat, U.V., abrasion Low thermal expansion/contraction Readily available Transparent **Disadvantages** Difficult to site fabricate Low impact resistance unless tempered High cost Heavy	Double Strength	85	<3	25+	0.75-2.00
		Insulated Units	71	<3	25+	3.50-7.00
		Low Iron	90-92	<3	25+	0.90-2.25
Acrylic	**Advantages** Excellent transmissivity Superior U.V. & weather resistance Won't yellow Lightweight Easy to fabricate on site **Disadvantages** Easily scratched High expansion/contraction Slight embrittlement with age High cost Relatively low service temperatures Flammability	Plexiglass Lucite Acrylite	93	<5	20+	2.00-3.00
		Double Wall Exolite Acrylite SDP	83	<5	20+	2.50-4.00
Polycarbonate	**Advantages** Excellent service temperatures High impact resistance **Disadvantages** Poor weatherability & U.V. resistance (yellows) Scratches easily Not readily available High expansion/contraction	Lexan Tuffak A Poly Glaz	87	<6	7-10	3.00-4.00
		Double Wall Tuffak twinwall Qualex	75	<6	5-7	1.75-3.00
Fiberglass	**Advantages** Low cost Strong Superior weatherability only when Tedlar coated Easy to fabricate and install **Disadvantages** Susceptible to U.V., dust & pollution degradation Yellows with age High expansion/contraction rate	Lascolite Filon Glasteel Kalwall	75-85	<10	10-15	.85-1.75
		Doublewall roof panels	70		7-12	5.00
Laminated Acrylic/Polyester film	**Advantages** Combines weatherability of acrylic with high service temperature of polyester Good transmissivity **Disadvantages** Non-reversible, Acrylic must be installed to the outside Susceptible to wind flapping Only 4' width available	Flexigard	87	9.5	10+	.45-.70
Polyethylene film	**Advantages** Inexpensive Easy to install Readily available in large sheets **Disadvantages** Short life Low service temperature Cats LOVE to climb on it	Visqueen	>85	80	8 months	.02
		Monsanto 602 (U.V. resistant) Tufflite III	87	80	2 years	.06
		Monsanto 603		80	3 years	.08
Weatherable Polyester film	**Advantages** Excellent transmissivity High service temperature **Disadvantages** Only available in 26" to 60" widths Low impact resistance U.V. degradable unless treated	Llumar Mylar Melinex	85-88	>30	7-10	.50-1.00

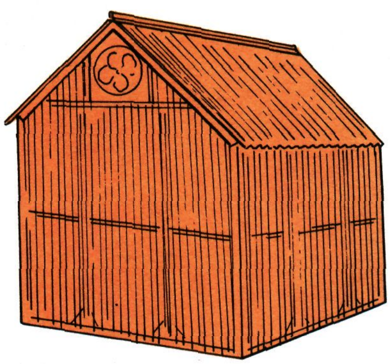
Note: Much of the technical information in this chart was taken from Manufacturer's data. Actual field performance may be different. Costs are accurate as of April 1981 from regional distributors. Local prices may vary.

Fiberglass. Houses covered with fiberglass reinforced polyester panels (FRP) are durable, attractive, and moderately priced. FRP is more resistant to impact than glass. It transmits slightly less light than glass and weathering further reduces light transmission. It is not completely transparent, and therefore not as attractive as glass. Fiberglass is not a good glazing for growing crops with high light requirements in areas with less than 40% sunny days in the winter.

Panels are easier to cut and fit than glass and they can be used to cover almost any house. Either corrugated or flat panels are available. Corrugated panels require commercial sealing strips to stop drafts between corrugations. Flat FRP is attractive but needs support every 18" to 24" or it sags. Supports create more shade. Fiberglass, like many plastics, sustains a flame and burns quickly when it's windy. Fortunately, except for heaters and propane torches, little flame producing or flammable material is used in greenhouses. But be careful with fire near fiberglass.

Only buy fiberglass that is made for greenhouse use. Store fiberglass vertically and in a dry, well ventilated area. Moisture caught between sheets of fiberglass can cause staining. Acrylic or fluorocarbon (Tedlar) coated fiberglass is best and should last for 10 years or more. Do not use colored or lower grade panels. Plants do not receive enough light through colored panels and low grade panels darken rapidly with age.

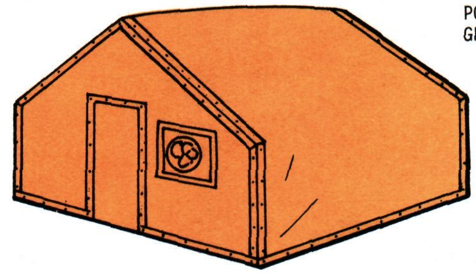
FIBERGLASS
GREENHOUSE



Polyethylene film used to cover greenhouses is inexpensive, but temporary. Polyethylene houses are less attractive and need more maintenance than other styles. Clear polyethylene, 4 or 6 mils (0.004" to 0.006") thick, is used because it is readily available and inexpensive. Unfortunately it is easily destroyed by ultraviolet (UV) radiation from the sun.

Polyethylene treated with a UV inhibitor will last 12 to 24 months longer than untreated. Several companies now offer UV inhibited (Monsanto 602 or 603, Ethyl Visqueen, and Arco Tufflite 3) film that lasts 2 to 3 years as a greenhouse cover.

The wider the sheets of glazing material and the fewer structural framing members needed for support, the greater the light transmission will be. The low structural shading factor and low initial cost account for the high popularity of polyethylene film.



POLYETHYLENE
GREENHOUSE

Heat loss can be reduced by 30 to 40% by applying two layers of plastic film. However, two layers transmit 87% of 87% or 75% of available light when new. Because of its rapid degradation by sunlight, transmission through two layers may be down to 65% after a year or two. The framework lowers transmission even further. In the North where low winter light already limits growth, most crops will not produce quality growth through the second winter.

Polyester films (Mylar, Melinex, Llumar) transmit well initially, but sunlight rapidly degrades them. Polyester tends to tear and run when punctured. It is stiff, manufactured only in narrow widths, and may not be locally available.

Acrylic laminated to polyester (Flexigard) provides UV radiation breakdown and tear resistance. The acrylic side must be on the outside or radiation source. This material is strong, has good light transmission and a moderately long life. At present its major limitations are stiffness, narrow 48 inch width, and some loss of light transmission over time.

Polyvinyl fluorides (PVF) films have become available for greenhouse glazing. They have been used for glazing flat plate solar collectors. They are ultraviolet resistant, have high transmittance, high impact resistance and high tensile strength. They tear easily if punctured and are relatively expensive.

Fluorocarbons. Tedlar PVF and Teflon FEP are two fluorocarbons which have potential as greenhouse covers. They both have excellent visible light transmission and long service life with very little loss of transmission over time. Teflon has poor tear resistance and is much more expensive than Tedlar. Tedlar has excellent weatherability, is easy to clean, is relatively strong and has low long wave radiation (heat) transmission. Tedlar has been used for solar collector covers for over 10 years. Based on accelerated weathering studies in Arizona, it has a potential of 20 years or more of useful life. This makes it the lowest cost cover per square foot per year of useful life.

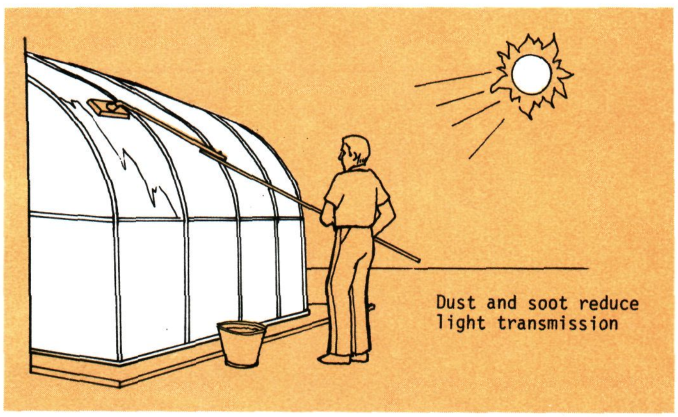
Vinyl is a clear plastic film which, when reinforced with a polyester scrim, is used with many tent style greenhouse kits. Vinyl is electrostatic and attracts smog and dirt, so light transmission can be rapidly reduced by surface contamination. Cleaning is difficult and may have to be done often. Vinyl lasts 2 to 5 years and is more expensive than polyethylene in the same thickness.

Glazing Management

Light energy is often the most limiting factor for midwinter growth of many flowering and fruiting plants. Low midwinter light is due to three factors: 1) short days, 2) low external light levels, and 3) loss of light through the glazing and structure.

Loss of light through the glazing and structure is substantial. The 80 to 90% light transmission values reported for various glazing materials are based on the light entering perpendicular to the surface and do not include losses due to the changing angle of the sun and to the structural framing. Light reaching the upper leaves of plants in an older glass house is usually about 65% of the outdoor light level. If the glass is dirty between laps and partially covered with shading compound and the frame bars and trusses are in poor condition, the light intensity may be as low as 40% of outside.

Dust and soot also absorb light. In a year, light transmission may be reduced 4 percent in a non-industrial area and up to 50% in an industrial area with heavy pollution.



Installing Glass

If you purchased a glass greenhouse kit, information on installing the glass will be found in the instruction manual. Installation generally consists of laying a bead of putty on the sash bar, inserting the glass, installing the holding clips, and attaching the bar cap.

If you purchase an old wood greenhouse to rebuild it, you must first clean the bars. A scraper, chisel or router can be used to remove the old paint and putty. Be sure to protect your eyes. Then prime the bars with a coat of high quality exterior primer paint.

To install the glass, place a bead of putty on the sash bar and lay the glass in place. If you are using old glass, place warped glass with the bow up. Start at the front wall and allow the glass to extend over the sill slightly. Lap the next pane 1/4 to 1/2 of an inch over the lower one. Place one bead or point on each end of the glass to prevent it from slipping down and three on each side to hold it in place.

When all of the glass is in place between a set of bars, trim the putty above and below to leave as little as possible exposed to the weather. Complete the job by painting all woodwork, and sealing the putty with paint.

Replacement patio door units also make an attractive glazing. They may be sealed with silicon caulk and held with a narrow batten strip attached by screws or nails.

Installing Fiberglass Reinforced Panels

Corrugated fiberglass panels may be installed several ways. The corrugations on roof panels should slope down so water will run off. Sidewall panel corrugations can run either direction.

Fasten with special aluminum- or zinc-coated, screw-shank or ring-shank, nails, 1 3/4" long, with fiberglass or neoprene washers attached. Predrill nail holes in the fiberglass about 8" apart or through the top of every third corrugation to keep water out.

Roof panels should be supported and nailed to cross supports or purlins every 2 1/2' to 3' length. Corrugated wall panels can be supported every 4' or so. Use corrugated foam-plastic filler strips under the edge or ends of panels to reduce air infiltration. Flat roof panels should be supported on the sides and every 18" to 24" across the roof. Wall panels can be supported every 2' to 3'.

Corrugated sheets should overlap 1 to 1 1/2 corrugations at the sides. Use clear, flexible sealer (generally sold by the fiberglass supplier) where panels overlap. Sometimes houses are designed to nail the sides of panels to the frame. This design is somewhat stronger and tighter than one with panels just fastened to the crossbraces. Because the frame must be carefully measured and built so nails can be driven through the top of a corrugation and into the frame, this construction method is not used often.

Installing Single and Double Layer Polyethylene

Using the air inflation method two polyethylene sheets are fastened to the house so the edges are sealed. A small fan forces the layers apart creating a dead air space. Polyethylene may also be fastened with 1" to 1 1/2" spacers to make a double layer with an existing cover of glass, fiberglass, acrylic or other rigid cover.

Some people use wood spacers to hold the poly film apart because an inflation fan costs $15 to $20 a year to operate.

Figure 14. Fastening details for fiberglass reinforced panels

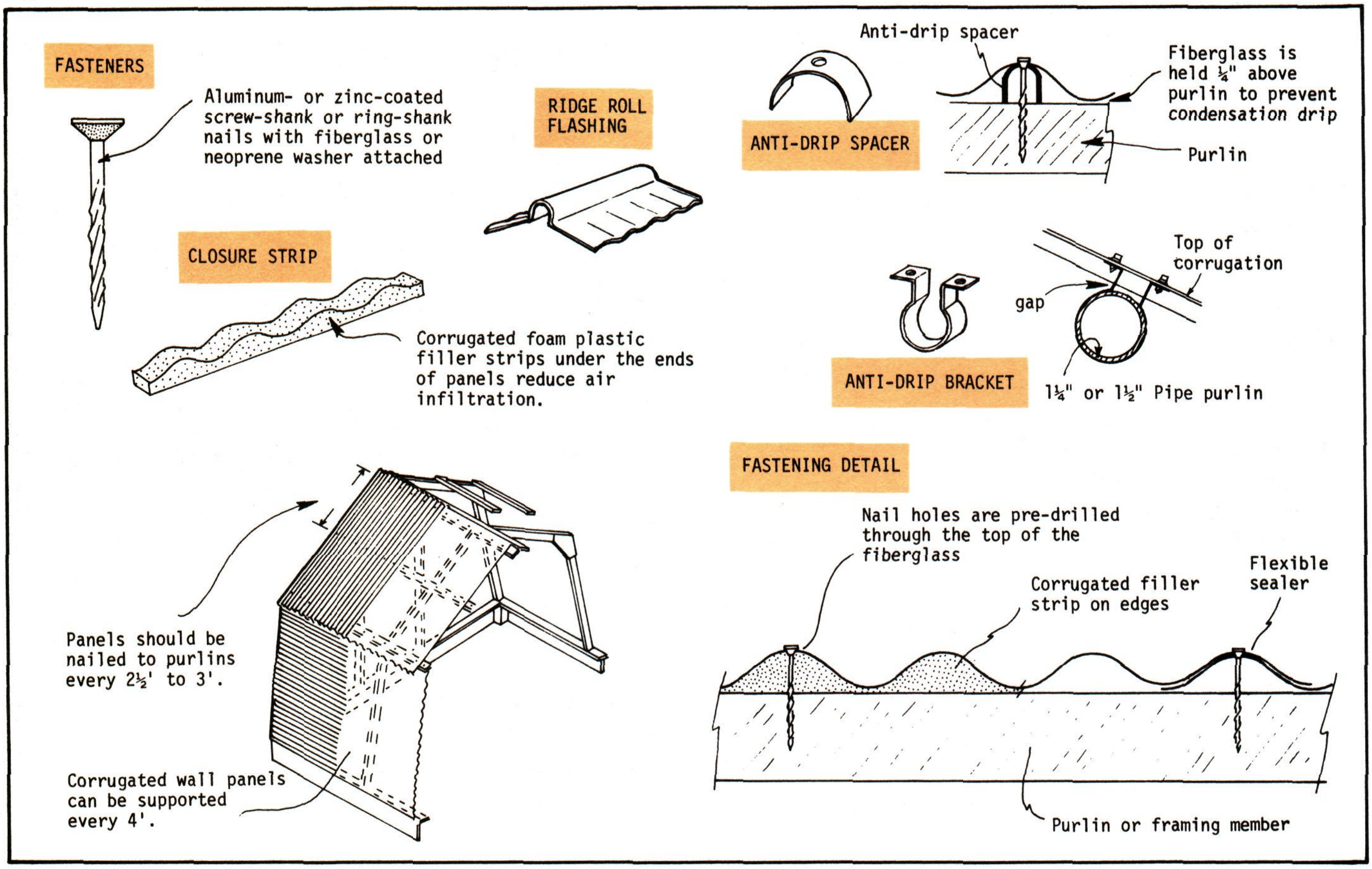
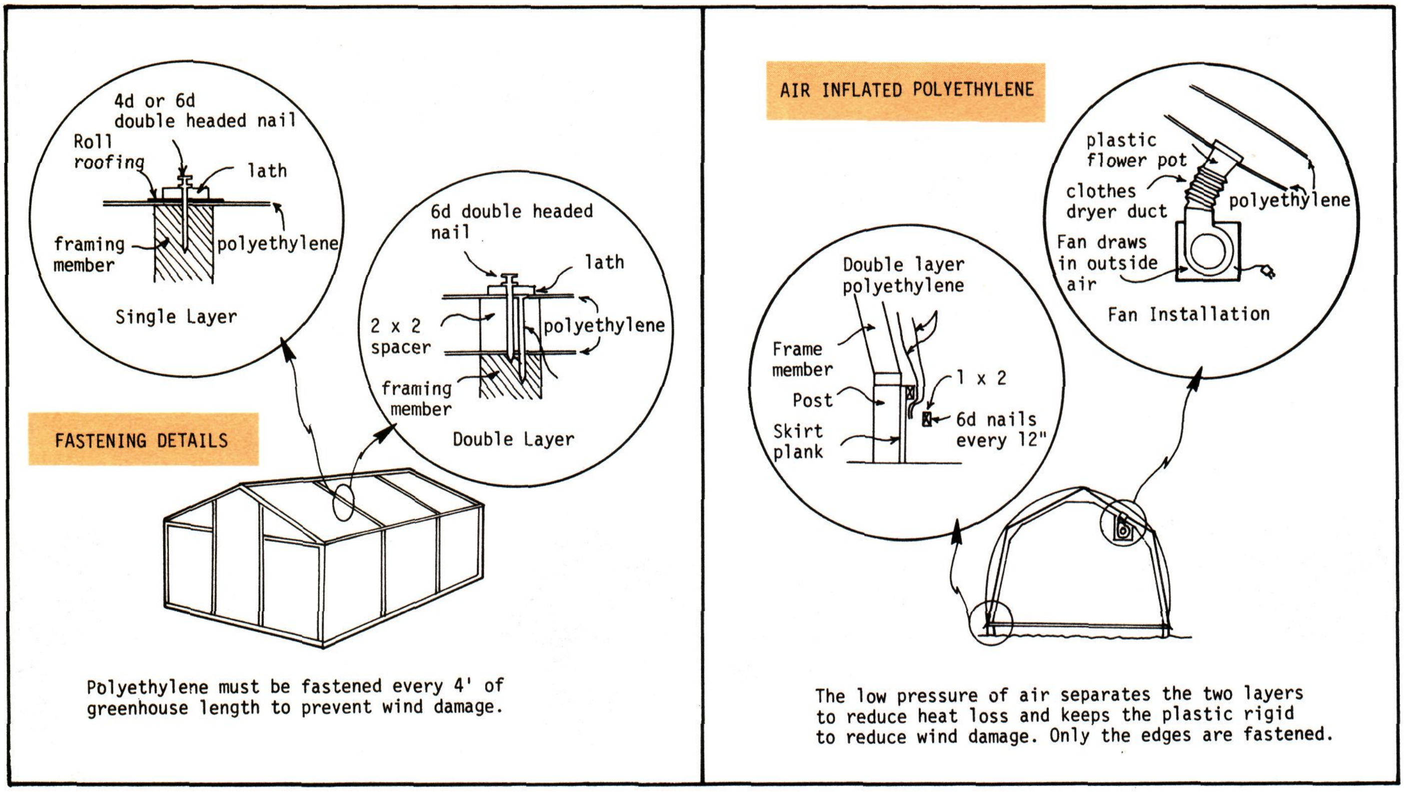


Figure 15. Installation details for polyethylene



FRAMES

The materials selected influence the greenhouse life expectancy as well as its appearance and integration with the residence design. Metal frames, either aluminum or galvanized steel, are attractive and require little maintenance. **Metal** is a poor insulator, so these frames lose heat more rapidly than wood frames. Steel without protective galvanizing is not recommended for greenhouse frames because it requires regular painting to prevent rust.

A **wood** frame is often the first choice for those who design and build their own greenhouse. Wood is easy to work with and costs less than other materials. High greenhouse humidities and constant exposure to water mean that wood requires more maintenance than metal.

Wood, and particularly wood that touches the ground, should be pressure treated with a preservative. Those with various combinations of copper, chromium and arsenic are suitable for greenhouses. Cuprinol, Erdalith, Wolman, Tanalith, Celcure and Osmose are typical preservative trade names. **Do not use creosote or pentachlorophenol preservatives because they release vapors harmful to plants.**

Pressure treated wood lasts 25 years or more; home soaked preservative treated wood and redwood or cedar lasts 7 to 15 years. A preservative that is brushed on is not effective.

Wood may be painted with an exterior primer and white paint to improve light levels in the greenhouse.

Use construction grade or better lumber; good lumber costs more but is easier to work with and stronger than lower grade material. Often poor lumber has more waste due to warping and large knots. Redwood and cedar are resistant to rot, insect and moisture damage; however, their cost may be prohibitive.

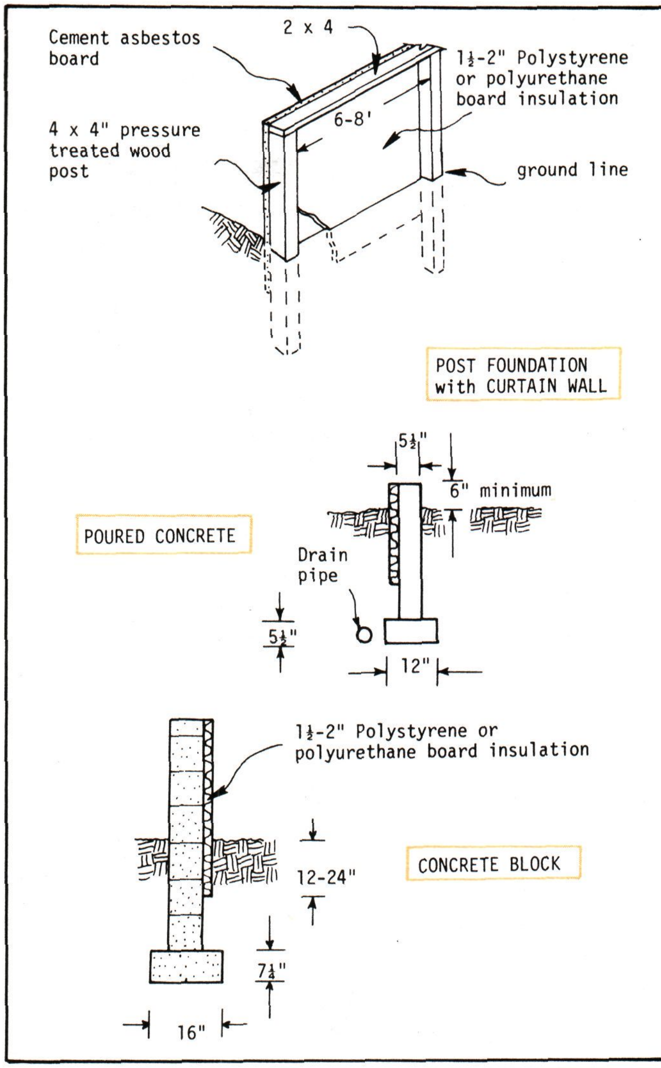
FOUNDATIONS

All greenhouses should be anchored to a solid level foundation. Pressure treated wood posts, concrete block, concrete or brick are commonly used. Building your own masonry foundation is heavy work. Most building suppliers have booklets on how to do it, if you want to tackle this job.

Pressure treated wood posts set 24″ or more in soil or concrete make simple, low cost foundations for small greenhouses.

Brick, stone, redwood, pressure preservative treated plywood and cement asbestos board can be used for sidewalls. Use a material that is attractive and integrated with the residence design. The wall can be extended to bench height and insulated with 1″ thick polyurethane or 1 1/2″ polystyrene board to reduce heat loss. Extend this insulation at least one foot into the ground.

Figure 16. Typical greenhouse foundations



FLOORS

A greenhouse whose floor is the ground itself has the soil to store solar heat. Any gravel, concrete, or brick laid on top does not store more heat; these materials just improve the walking surface.

Heat storage is different for a sunspace that is level with the living space. In this case, the floor is raised above the ground and heavily insulated underneath. A masonry floor may be added on top for heat storage. For example, a 3 1/2″ thick concrete and tile floor may store 100 Btu per square foot on a sunny day.

Low cost floors or walkways include:

- four inches of crushed rock
- brick, either mortared or set over a 2 to 4 inch deep sand base

- flagstone, brick, tile or concrete walkways with soil or gravel under the benches.

Any greenhouse needs good drainage. The drainage system installed around most homes will usually handle irrigation water from an attached greenhouse. A raised sunspace normally needs no drainage because the plants in it are typically grown in containers.

PURCHASING CHECKLIST

The easiest way to get a greenhouse is to contract with a greenhouse builder or local contractor. Some companies now specialize in solar designs. Many of the older greenhouse companies are developing new designs or adapting existing designs to the solar concept. Write for catalogs from several companies before deciding. Also try to attend an energy fair or solar show where companies exhibit their models.

If you have a location where you can't fit a standard model or are building a new home and planning to incorporate a solar greenhouse as part of the structure you may want to hire an architect to develop a special design. Try to see some examples of the architect's work and talk to former clients before choosing one.

Before signing a contract for a new greenhouse, use this checklist:

☐ 1. What will the builder provide? What do you have to provide?

___ *Building permit.* Is one needed?

___ *Foundation.* Does the builder want you to have this built?

___ Will it be fully insulated?

___ *Erection.* Who is responsible for modifications to your home?

___ *Benches and Beds.* Are these included?

___ *Utilities.* Who is responsible?

___ *Electricity.* Is the main service entrance large enough for the extra load?

___ *Water.* Where will the hose faucet(s) be located?

___ *Alarm.* Is a high/low temperature alarm included?

___ *Clean up.* Who has this responsibility?

___ *Landscaping.* Is this part of the contract?

☐ 2. Is the starting and completion date specified?

☐ 3. Will the builder supply you with references?

☐ 4. Is the builder insured?

☐ 5. Does the contract include written specifications for the materials to be used?

☐ 6. How is payment to be made?

☐ 7. Does the contract contain a payment "hold back clause?" Does the lender (if one) require a completion certificate?

☐ 8. Does the contractor provide a warranty on the quality of the materials and workmanship? A detailed contract will generally result in fewer problems during construction but may increase the price because the builder will have fewer options in material purchases and erection procedures.

GREENHOUSE KITS

If you own and like to use a few basic hand tools, you may want to purchase a greenhouse kit. All the materials for the structure except the foundation are usually included. You may have to purchase energy conserving materials and solar storage components separately from a local greenhouse supplier. If you can't locate one in the telephone business pages, ask your local garden center or florist where they purchase supplies.

Masonry foundation construction involves excavating, forming and pouring footings and walls, and then backfilling. It is heavy work that is usually best left to a contractor who has the necessary forms and equipment to do this job. Pressure treated wood foundations are another choice.

The greenhouse is usually delivered to you in packages containing pre-cut and pre-drilled parts. An instruction manual leads you through the step-by-step assembly. A hobby greenhouse, once the foundation is in, can usually be completed in a weekend.

GREENHOUSES BUILT from PLANS

This is a rewarding project that will take several weekends or a week of your vacation. It can also save you some on the cost. Plans are available for many types and sizes of solar greenhouses. Some are shown in Section VII of this booklet, others are available from sources listed in most gardening magazines.

After you have decided on the set of plans that you will follow, make any necessary modifications then list the materials needed; include quantity, size and quality of each item. Take the list to two or three lumber yards to get cost estimates. Some items such as glazing, blowers, fans and heaters may have to be ordered from a greenhouse supply company.

After the materials arrive, lay out and mark them indicating use and location. Refer to the plans and the construction pointers in the next section to aid you in completing the project.

THE GREENHOUSE INTERIOR

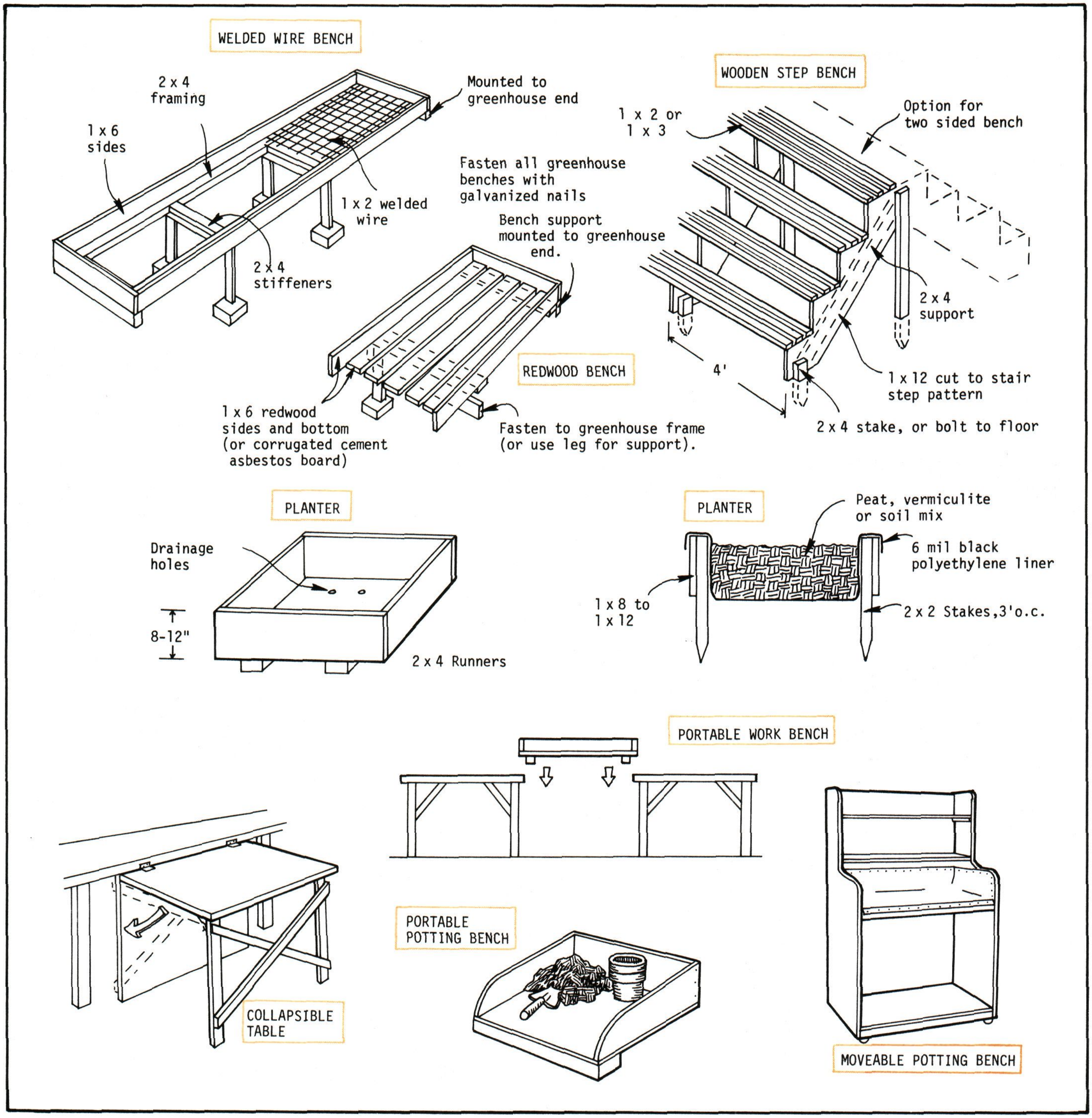
Benches

Benches raise the plants to a more convenient working height. Plants are better handled in containers than planted directly into soil in the benches. Bench growing media need periodic pasteurizing, require heavy construction, and are more difficult to manage.

Benches should be only as wide as you can reach. Side benches can be 2′ to 3′ wide. Center benches that are reached from both sides may be as wide as 6′. Standard bench heights are 30″ to 32″, but they can be modified to suit your height.

A portable or hinged workbench can be lifted when not in use to let light reach plants placed under it. If the work area is stationary there is a tendency to put plants and materials on it, and its usefulness is lost.

Figure 17. Benches, beds and workbenches



Beds

Growing beds can be built as movable boxes or fixed permanently to the greenhouse floor. Beds are often used along the south side to allow more sunlight to reach both the plants and storage at the rear.

A bed worked from one side should be less than 3′ wide. A center bed can be up to 6′ wide. To have enough soil for good plant growth, make the bed 8″ to 12″ deep.

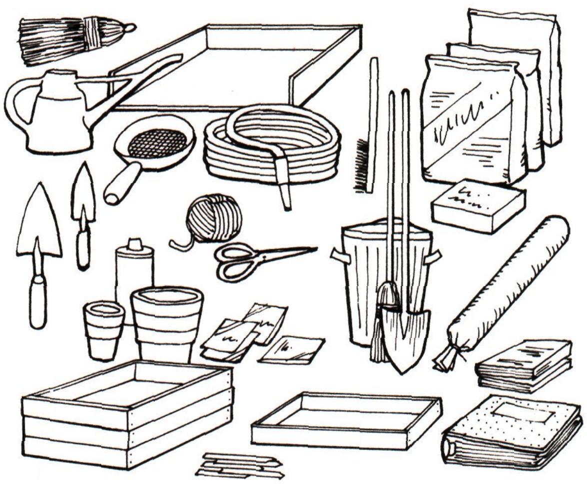
Lumber for beds and benches should be treated with a preservative to keep it from rotting. Remember not to use creosote and pentachlorophenol wood preservatives because they release vapors that are toxic to plants.

Shelves

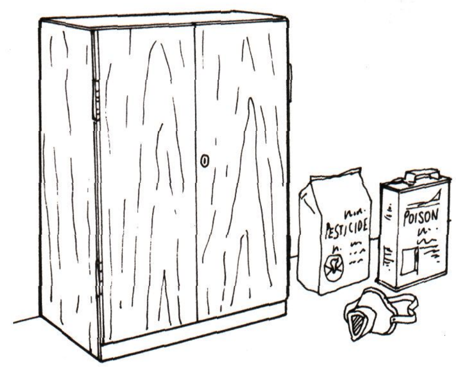
The space above the rear benches or storage may be used to grow plants. Hanging baskets can be suspended from the ceiling or shelves can be attached to the rear wall. Preservative treated boards, usually 1″ x 12″ and supported by shelf brackets spaced up to 3′ apart, work well.

Storage for Supplies

Greenhouse plants require tools, fertilizers, chemicals, containers, potting soil materials, etc. You will need to plan a storage area for all these materials when you plan the greenhouse. The high humidity of the greenhouse, which is beneficial to plants, ruins tools and chemicals. Greenhouse storage should be separate but nearby. If the greenhouse is heated, extra space for storage in the greenhouse means more costly heating. A potting bench in the storage area is handy to mix growing media and fill pots.



Caution: Pesticides and other chemicals should be kept in a separate, locked cabinet. Also, always keep a first-aid kit handy.



Controlling the Environment

SUPPLEMENTAL HEAT

If the greenhouse is to be maintained warm enough for good plant growth during the entire winter, supplemental heat is generally necessary. Several types of heaters are available.

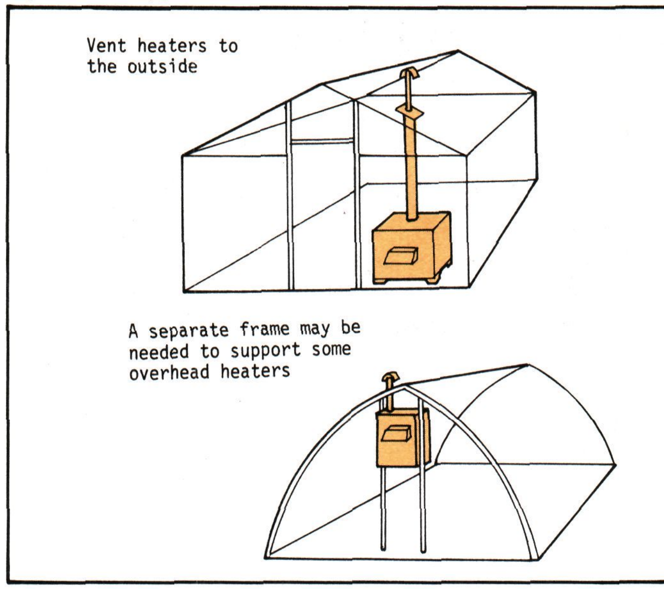
The **electric heater** is convenient, clean, efficient, and easy to install; but electric energy is more expensive than other fuels. The heater should have a built-in thermostat and circulation fan. Adequate electrical supply and wiring is required, and the size of the existing electrical service may limit the number of new branch circuits which can be added to service the greenhouse.

Space heaters are commonly used to heat small greenhouses. Some are completely self contained units with fan and heat exchanger that burn either natural gas or fuel oil. Others, not commonly used in small greenhouses, have a fan and heat exchanger but use hot water or steam from a central boiler as the heat source. Space heaters are often hung overhead, but some fit through the wall so little space is lost and no special venting is required. The frame of some small greenhouses may not be strong enough to support an overhead heater; a separate frame or mounting bracket can be used instead. Units with fans that blow air horizontally give more uniform temperature distribution than heaters that blow air vertically.

Caution: Fuel burning heaters must be vented to the outside because some of the products of combustion are toxic to both people and plants. Be sure air for combustion comes from outside the greenhouse. Portable oil fueled space heaters, such as used on construction projects, should not be used in greenhouses.

Small kerosene, propane or natural gas burners are sold to heat small greenhouses. These low cost, handy units have no fan or thermostatic control, so temperatures fluctuate and are less uniform than in houses with more expensive heating systems. Even these small heaters should be vented to the outside. In tightly constructed houses these heaters can use enough oxygen to cause incomplete combustion which generates toxic gases. In addition, water vapor, formed as part of any combustion process may cause high humidities and potential disease problems.

Figure 18. Supplemental heaters



Electrical or gas fired **radiant panels** hung over each bench or floor can be very efficient for small areas. Equipment may be expensive and hard to find, however.

Caution: Heat lamps should be suspended by chains and not by the electrical cord.

Infrared lamps have been used to heat bedding plants grown in a greenhouse in the spring. These low cost lamps are simple to install overhead so they do not require floor space. A 150 to 200 watt heat lamp suspended 32″ above the bed will heat a 3′ x 3′ area 15° to 20° above the outside air temperatures. A thermostat can be installed to turn off lamps at 45° to 50°F.

A small **wood or coal stove** can be used, if the fuel can be purchased economically. The stove should be installed to meet all safety requirements, especially distances to combustibles. Purchase a stove designed for the fuel you intend to burn. It is difficult to burn coal in a stove designed for wood.

Most small wood stoves need to be refueled every 4 to 6 hours and do not keep a fire overnight. A wood stove can be used to heat water to be stored in a tank for overnight use. Although more difficult to ignite, coal burned in a stove will provide heat for 12 hours or longer.

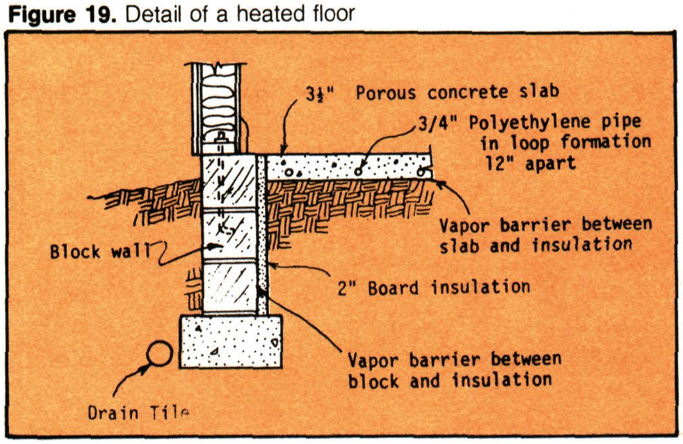
Recent research has shown that many plants respond according to the average temperature held during the night. Thus a wood or coal stove might be fired to start the evening so the greenhouse temperature is 70°. Then as the fuel burns down, the temperature may slowly drop to 50° by morning. But the plants in the greenhouse grow as if they are kept at 60° all night.

The **extension of a home heating system** to a small greenhouse is possible if the home furnace capacity is adequate. However, the rate of heat loss will differ for the home and the greenhouse, and separate control systems are needed. A heating contractor should be hired to make the modifications needed.

Natural convection created by **hot water and steam pipes** provide steady and more efficient heating than hot air. A typical hot water or steam heating system consists of a boiler piped to smooth or finned pipes mounted along the walls or under the soil or pots. A domestic water heater may have sufficient capacity for a small greenhouse. Soil can be heated with hot water, circulated through tubing such as plastic or EPDM, or with electric cable as in a hotbed.

In some greenhouses, a porous concrete floor serves as a heat storage and heat exchanger. The water can be heated by solar collector, wood stove or conventional boiler. The porous concrete floor provides a solid surface which controls weeds, yet allows excess irrigation water to drain through. The warm water can be circulated through loops of pipe in the floor or through water in gravel under the concrete slab. An important advantage of a warm floor situation is that most plants benefit from having their root zone warmed and the air temperature can be reduced significantly with no adverse effect on the plants. It is also possible to eliminate benches with some crops which require no hand labor through the growing season.

Figure 19. Detail of a heated floor



Hot water provides even heat, but is slower than steam to respond to sudden changes in outside temperatures. Steam heating systems are usually too complex and expensive for the small greenhouse. Hot water seems to give the best overall results. Many boilers for hot water systems are built to generate small quantities of steam to pasteurize soil.

HEATER SIZE

The amount of heat required depends on the temperature difference between the inside and the outside, the amount of surface area and glazing of the greenhouse, the quality or tightness of construction, the wind factor and the amount of insulation. For most greenhouses the heater size can be estimated by calculating heat loss through the uninsulated perimeter and through the transparent glazing. The heat loss through the insulated area is ignored because it is usually small compared to the loss through the glazing.

The eight steps of the calculation procedure are:

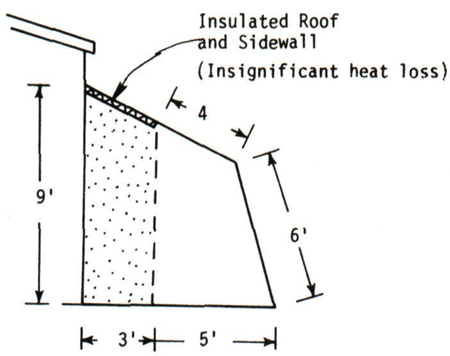
1. Decide the minimum **inside** temperature desired.
2. Estimate the minimum **outside** temperature.
3. Subtract the outside from the inside temperature to calculate the temperature difference to be maintained by the heater.
4. Estimate the glazing surface area.
5. Multiply glazing surface area by temperature difference and a U factor listed in Table 5 to find heat loss through the glazing.
6. Measure the length of the exposed perimeter.
7. Multiply perimeter length by the temperature difference and a heat loss factor of 0.6 BTU/hr °F ft.
8. Add the heat loss through the perimeter and glazing to calculate the heater size.

Table 5. Heat loss factor, U, for greenhouse glazing, Btu/hr/°F/sq. ft.

Materials	U factor, Btu/hr °F sq ft
Glazing	
Single layer glass	1.1
Single layer plastic	1.2
Double layer glass (sealed)	0.6
Double wall acrylic	0.8
Double layer polyethylene	0.8
Single layer glass + thin thermal blanket	0.5
Double layer glazing + thin thermal blanket	0.4
Wall and Roof Construction	
Softwood, 1" nominal	0.6
Non-insulated concrete block wall	0.5
Insulated wall or roof	0.1
	Btu/hr °F linear ft
Uninsulated perimeter	0.6

Sample Heater Size Calculation

An 8′ x 12′ attached greenhouse as shown has double wall acrylic glazing and a thermal blanket that can be drawn at night. Calculate the heater size needed to keep the greenhouse at 50°F when the outside temperature is 0°F. The area of the end wall glazing is 26 square feet.



Step 1. Minimum **inside** temperature 50°F.

Step 2. Minimum **outside** temperature 0°F.

Step 3. Temperature difference = 50 - 0 = 50°F.

Steps 4 & 5. Estimate glazing area and U factor from Table 5.

SECTION	SURFACE AREA, sq.ft.	U FACTOR	UA
Endwalls	2 x 26 = 52	0.7	36
Roof	4 x 12 = 48	0.7	34
Front Wall	6 x 12 = 72	0.7	50
Total	172		120

Glazing heat loss = UA (Temp diff) = 120 x 50 = 6000 BTU/hr

Step 6. Exposed perimeter length

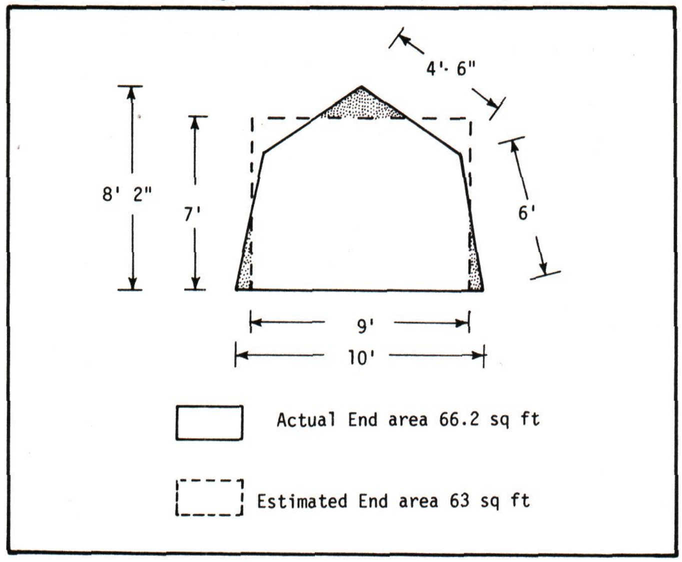
SECTION	LENGTH
Endwalls	5 x 2 = 10
Front Wall	12
Total	22 ft.

Step 7. Perimeter heat loss = 0.6 x Length(Temp diff)
= 0.6 x 22 x 50 = 660 Btu/hr.

Step 8. Heater **output** = glazing heat loss + perimeter heat loss
= 6000 + 660 = 6660 Btu/hr.

Calculating the exact surface area of greenhouses with unusual shapes is difficult, so approximations can be used instead. Often the roof and sidewalls are rectangular areas where the area is calculated by multiplying width and length. The area of the end wall may be estimated by assuming the end wall is a simple geometric shape, such as a rectangle that is slightly shorter than the greenhouse. Figure 20 shows an example of how the end area may be estimated.

Figure 20. Estimating the area of a complex shape



COMPARING FUELS

The fuel you select will depend on convenience, availability and price. Table 6 can be used to compare the cost per 100,000 Btu's for several fuels. To compare price per 100,000 Btu of heat output for typical heaters, multiply the fuel units in the last column by the fuel cost per unit. If you know the efficiency of your heater, use that value when calculating fuel cost.

Table 6. Comparison of heat output from various fuels.[1]

Fuel	Selling Unit	Heat Content Btu/Unit	Typical Heater Efficiency	Fuel Units per 100,000 Btu Heat Output
#2 Oil	Gallon	140,000	70%	1.0 gal.
Coal	Pound	12,500	60%	13 lbs.
Natural Gas	Cu. Ft.	1,000	70%	140 cu. ft.
LP Gas	Gallon	92,000	70%	1.6 gals.
Electricity	KWH	3,413	100%	29.3 KWH
Wood (dry, hardwood)	Cord	24,000,000	50%	1.2 cu. ft. or 23 lbs.

[1]To compare price per 100,000 Btu's of heat output for typical heaters multiply the fuel units in the last column by the fuel cost per unit. If you know the efficiency of your heater use that value when calculating fuel cost.

DISTRIBUTING the HEAT

Heat can be distributed from the heating unit with fans, ducts, or radiating pipes. A good distribution system will give more uniform temperatures and reduce moisture condensation and associated disease problems.

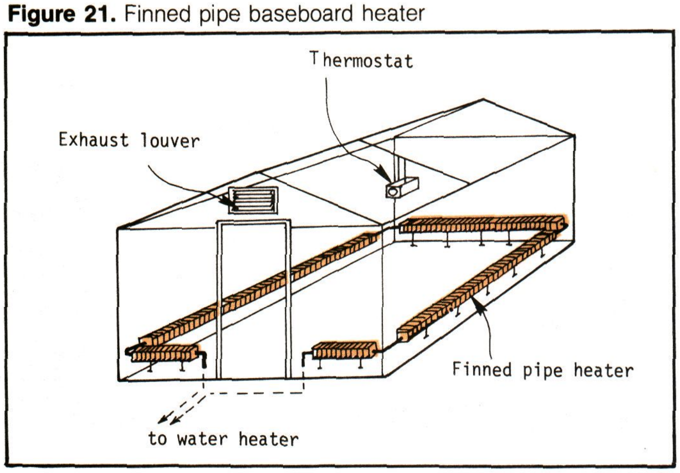
Fans can be used to move the warm air throughout the greenhouse. One or two small circulating fans capable of moving one-fourth the air volume of the house per minute can be used. The volume of a small greenhouse is an average height of 7' times the floor area. An 8' x 10' greenhouse has a volume of 8' x 10' x 7' or 560 cu ft. Fans should move 560 x 1/4 = 140 cu ft/min (cfm) for good heat distribution. Many space heaters and electric heaters include a fan as a part of the unit.

Ducts are sometimes used to obtain more even distribution of the warm air and conserve heat. Houses less than 100 to 150 square feet in area usually do not require ducts. Permanent galvanized steel ducting installed along the sidewalls works well. Most sheet metal shops have standard size ducts available. The ducts should have openings spaced every 1 to 2 feet with manually set dampers to adjust openings for best air distribution. Perforated polyethylene tubing makes excellent inexpensive ducts.

If there is headroom the heater and tubing can be mounted overhead. Alternately, they can be placed along a sidewall. Greenhouse suppliers are the best source for this tubing or you can make your own by taping a polyethylene sheet to form a tube. Use scissors or a propane torch to make a hole every foot or two along the tube.

Finned pipe baseboard units distribute heat from a hot water system. A single line around the perimeter (one line for each 4 or 5 feet of greenhouse width) will generally supply the required amount of heat. These systems use the least greenhouse space and provide good temperature control. Black iron pipe can also be used to distribute hot water heat. Four to six lines (equivalent to one finned pipe) around the perimeter and one or two overhead lines may be needed to provide enough hot surface.

Figure 21. Finned pipe baseboard heater



ENERGY CONSERVATION

The largest heat loss from a greenhouse occurs from the glazed area. Double glazing will reduce heat loss by at least 30 percent because the space between layers reduces heat flow. On the other hand each additional layer of glazing reduces the amount of solar energy entering the greenhouse by 5 to 15 percent.

For many greenhouses a single glazing and a movable insulating blanket work best to allow maximum light during the day and good insulation at night. For some, especially in milder climates, a double glazing is adequate.

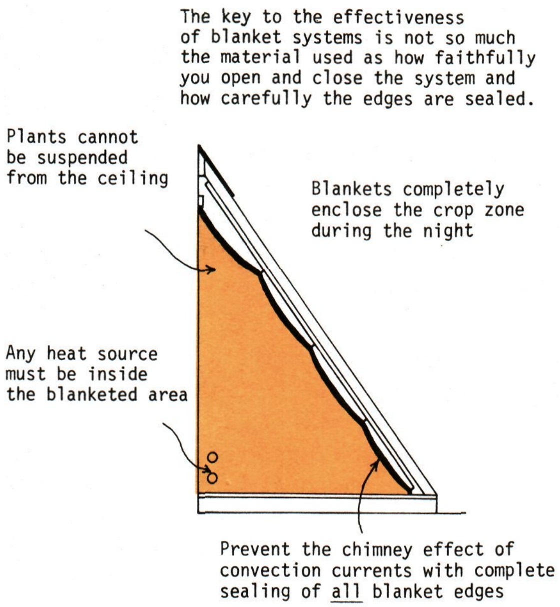
Moveable Blankets or Shutters. These nighttime insulation barriers can be very effective. The key to their effectiveness is not so much the material that is used; instead, it depends on how faithfully you open and close it. Often the insulation is not closed as soon as the sun starts to set. A properly installed and operated blanket or shutter can reduce heat loss 25-40% over an uninsulated system.

Table 7 reviews the more common blanket materials used. Most materials are supplied in rolls and must be fabricated to the proper size. Some manufacturers and suppliers have facilities to do the fabrication. The material should be flame-resistant, tear-resistant and easy to work with. It is also important that a tight seal be formed around the edges to reduce heat loss.

Table 7. Greenhouse blanket materials.[1]

Material	Cost/ sq.ft.	Avg. Life	Heat Trans-mission[2]	Heat Loss Reduction[3]
Black polyethylene film (6 mil thickness)	<$.10	5-10 yrs.	Medium	44%
Clear polyethylene film (6 mil thickness)	<$.10	< 5 yrs.	Medium	47%
Aluminized fabric (Foylon)	$.10-.20	5-10 yrs.	Medium	54%
PVC laminate (Ultrafilm) Al/Temp, Al/Black	$.10-.20	> 10 yrs.	High	26%
Spun bonded polyester (K shade, Tobacco netting, Remay)	$.10-.20	5-10 yrs.	High	38%
Foam backed, fiberglass drapery material	>$.20	> 10 yrs.	Low	na
Woven and lofted polyester (Thermoshade, Thermo-skreen)	$.10-.20	> 10 yrs.	Medium	50%

[1]Based on research at Pennsylvania State University and Rutgers University.
[2]Based on tests in a glass greenhouse.
[3]Approximate nighttime heat reduction in a glass greenhouse.



Before selecting an interior insulating system consider the following:

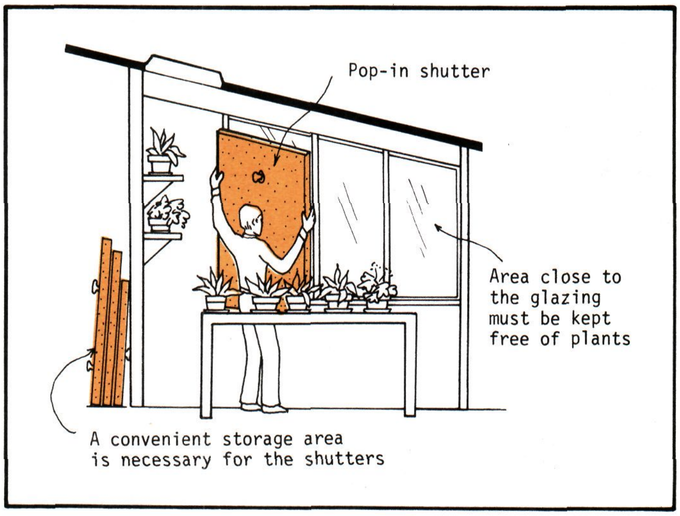
1. It should block very little, or no light when it is in the stored position. It is best stored against one of the insulated walls.
2. It should not interfere with the plants as it is being extended or withdrawn. The benches or beds should be kept 6 to 9 inches from the wall.
3. A one piece thermal blanket is better than several smaller ones as it will have fewer cracks. The effectiveness of the blanket will depend on how tight the edges seal in the heat.
4. The insulation should be withdrawn everyday. It should be left open on nights when heavy snow is expected, so snow will melt and not overload the greenhouse. Supplemental heat should also be used to help melt the snow.
5. The insulation should be flame-, tear-, and mildew-resistant, as well as easy to repair.
6. The heat source should be inside the blanketed area.

Pop-in shutters. Foam insulation board can be cut to fit between the wall studs and ceiling rafters. This insulation system is relatively inexpensive to build and, if installed properly, is more effective than thin blanket materials. Polyurethane, extruded polystyrene or isocyanurate are the best materials for this application. They can be easily fitted to irregular shapes and they do not absorb moisture. These insulators are also available with an aluminum foil facing that increases the insulation effect and provides some mechanical protection.

When building these units cut the pieces to fit snugly between the frame members. Edges can be covered with duct tape to keep them from breaking. Nail 1/2 inch wide spacers to the framing to keep a space between the insulation and the glazing. Wood turn knobs or magnetic clips will hold the panels in place. Roof and wall panels may be made to slide into place.

Shutters take longer to close than blankets as each piece must be handled individually. They also require storage space during the day such as a rack in one corner, under the benches or against fixed endwall panels.

Figure 22. Pop-in shutters



Track supported blanket. This insulating method uses a flexible, thin material supported by tracks and rollers or slides. During the day the material is stored folded against a back or endwall. At night it is extended to cover the glazed area. Many commercial greenhouses use this system as it is easy to install and operate. The materials are available from most greenhouse equipment suppliers.

Figure 23. Track supported blanket system

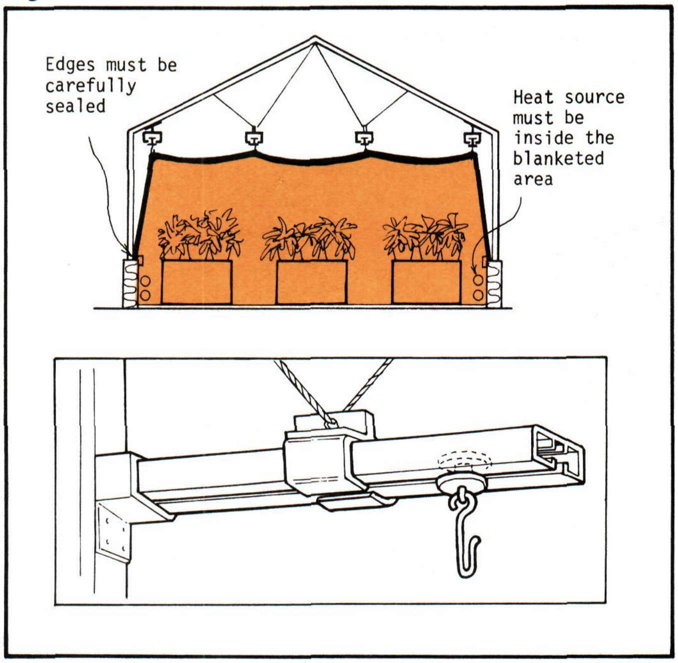
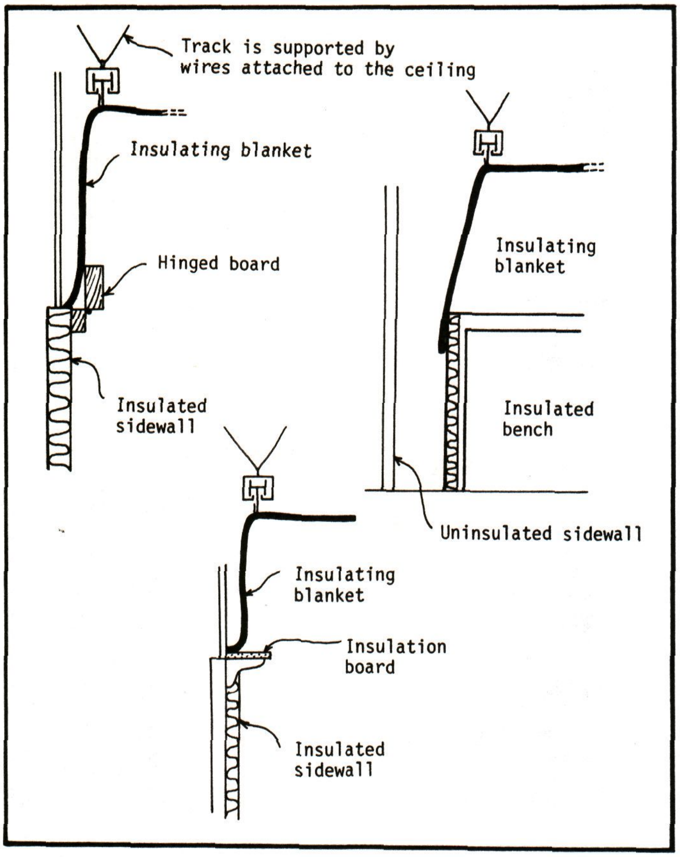


Figure 24. Edge seals for track supported blankets



Blanket Installation

1. Layout the system so that it will store in a convenient location. Track sections should be spaced no further than 8 feet apart. Provide space for the curtain to clear plants and benches.

2. Attach track to the framework or support with wires. The track can be bent slightly to follow roof contour. Track sections should remain parallel and level with each other. Insert the rollers before closing ends of the track.

3. Fabricate the blanket if this has not been done by the manufacturer. Allow extra material for seams, slight sag and extra material at sides for seal. The leading edge should have a stiffener (conduit or pipe) sewn in or attached to allow uniform movement.

Locate grommets, tabs or hooks carefully so that the blanket will hang and close evenly. Remember that the spacing of the supports should be twice the distance that you want the fold to hang (3 foot spacing of support = 18 inch fold).

4. Make provisions for sealing the sides. This can be 1 x 4 inch hinged boards or V shaped heat trap.

5. For ease of operation, install a cable-pulley system to open and close the blanket. A blanket in a small greenhouse with a horizontal track can be manually opened and closed. Where the track runs on an angle a system of pulleys and clothes line can be used to retract the blanket to its storage position.

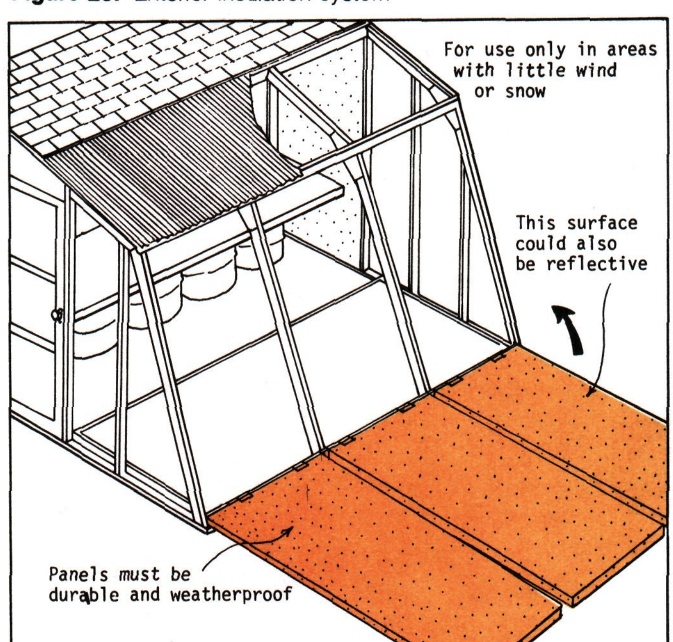
Roll-up blankets. An alternate method of installing a blanket, especially with sloping or vertical glazing is to roll the blanket similiar to a roll-up window shade. Both thin films and thicker insulating blankets can be handled with this method. Of course, the thicker the material, the larger the diameter of the roll and the more space is needed for storage.

The blanket is fabricated to fit the size of the glazed area. One end is permanently attached to the frame at the top of the glazing. The other end is fitted with a weight similiar to that used in the track supported method. On vertical glazed areas the blanket hangs free. On sloped areas it must be supported by wires or cables attached at both the ridge and eave and located several inches below the glazing.

The gaps at the edge of the blanket can be closed with hinged boards or magnetic tape. One such tape (Plastiform), manufactured by 3M Company, has an adhesive backing. One piece has to be placed on the blanket and a second piece placed on the greenhouse frame located where it will match the first.

Exterior insulation. Lack of space, the appearance or bench layout may preclude the use of an internal system. Exterior insulation systems may be used as an alternative . They work well when designed and fabricated so they are easy to operate and fit tightly when closed. Generally exterior units are more expensive to build because they have to be weather resistant. Sleet and snow are especially troublesome.

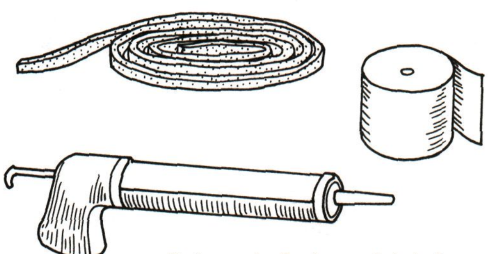
Figure 25. Exterior insulation system



Vapor Barriers. The warm, humid greenhouse can rapidly wet fiberglass and cellulose insulation so they lose their insulation value. Prevent this moisture movement by placing 4 mil (.004 inch) or thicker polyethylene film between the greenhouse and the insulation to create a vapor barrier.

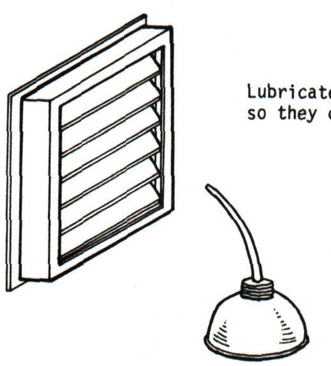
OTHER ENERGY CONSERVING MEASURES

1. **Reduce Air Leaks**
   - Keep doors closed - use a door closer or spring.
   - Weatherstrip doors, vents and fan openings.
   - Lubricate louvers frequently so that they close tightly. A partially open louver drastically increases heat losses.
   - Repair broken glass or holes in the plastic covering.
   - Close holes under the foundation of plastic covered houses.



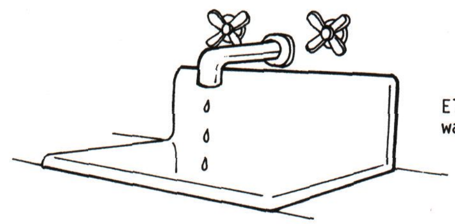
Reduce air leaks, patch holes, and weatherstrip doors.

2. **Efficient Heating Equipment**
   - Check the accuracy of thermostats with an accurate thermometer. They should be accurate to within a degree. Use a small fan to blow air across the thermostat for more uniform control.
   - Have the heating system checked to make sure it operates at peak efficiency.
   - Clean heating surfaces often.
   - Insulate distribution pipes or ducts in areas where heat is not required.



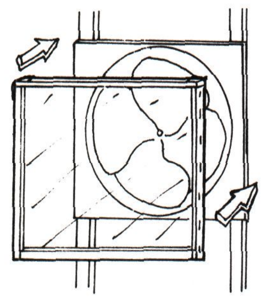
Lubricate louvers frequently so they close tightly.

3. **Water**
   - Insulate hot water pipes to reduce heat loss.
   - Eliminate all water leaks. A faucet dripping 60 drops per minute will waste 45 gallons per month. If this is hot water, it will cost 70 cents per month to heat it.



Eliminate all water leaks

4. **Winter Shut Down**
   - Cover unused fans, vents, etc. in winter.



VENTILATION and COOLING

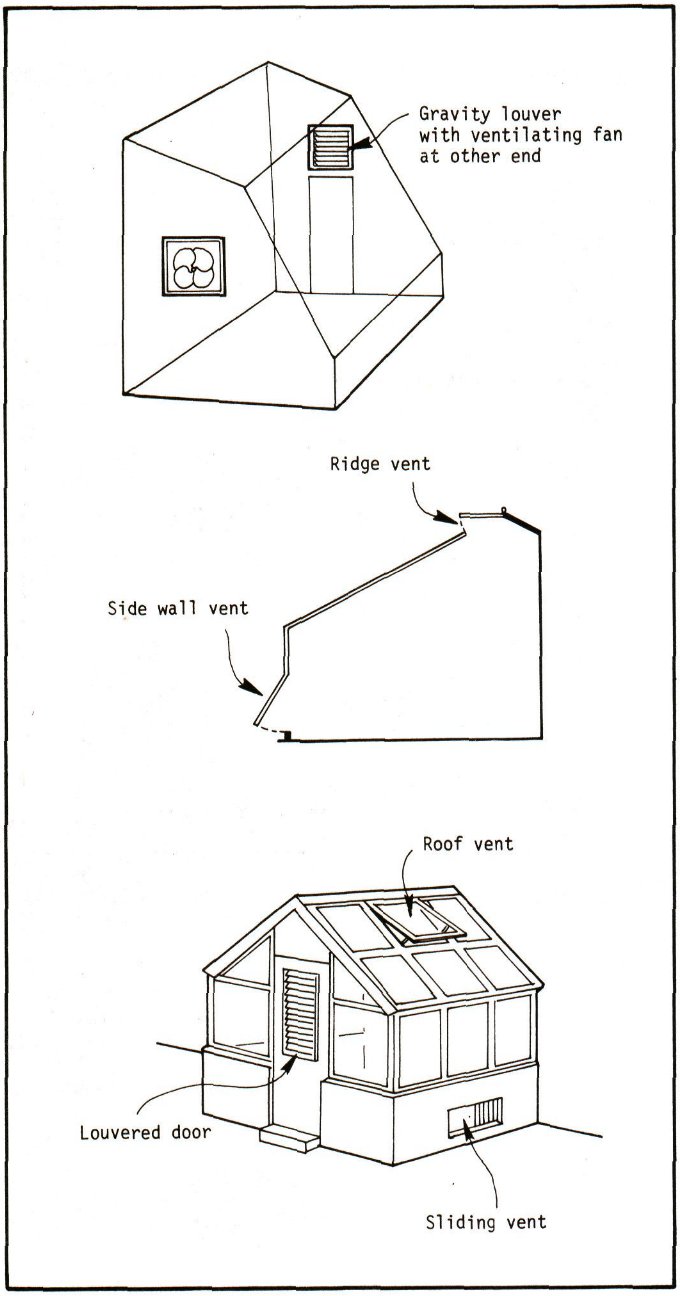
Greenhouses need ventilation for cooling, to reduce high humidity and to replenish carbon dioxide. In solar greenhouses, excess heat may be stored in the fall, winter and spring. Daytime heat is absorbed by water barrels, the floor or other storage media for later use at night rather than vented outside. During the summer, shading louvers or fans are used to reduce the temperature.

Fans

Ventilation can be achieved by opening the vents and doors in the greenhouse or by using exhaust fans in combinaton with inlet louvers or an open door. Fans are convenient because they can be automated by wiring them to a thermostat. In addition, they give positive air exchange that is sized to seasonal requirements. The inside temperature can be kept within 3 to 10°F greater than the outside air temperature.

A two-speed fan is desirable so that ventilation can begin at about half-rate, when outside air is very cold. The exhaust fan should be placed on the end away from prevailing summer winds. A motorized inlet louver at the opposite end works well controlled by the same thermostat starting the fan.

Figure 27. Greenhouse ventilation

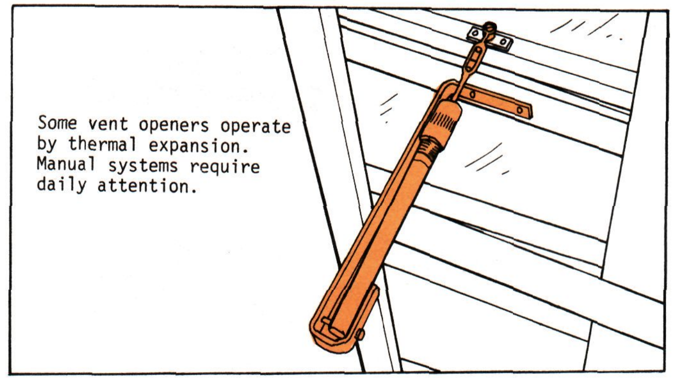


A small greenhouse having an air volume of 5,000 cubic feet or less should have an air exchange rate of at least 12 cubic feet per minute (cfm) per square foot of floor area to remove the summer heat load. Air inlets resist the flow of air, so the fan must work against a slight pressure. To compensate for this pressure loss, use a fan that delivers the required cfm at 0.1″ to 0.125″ of water pressure.

If the pressure rating of the fan is not known, reduce the listed cfm rating by 20%. For example, a 10′ x 12′ greenhouse needs a fan that delivers 1440 cfm [(10 x 12) 12] at 0.1″ static pressure or 1800 cfm when no pressure rating is shown. These fans are available through greenhouse manufacturers, greenhouse suppliers or heating and ventilation equipment suppliers.

Belt driven fans are quieter than direct driven fans, but may be difficult to find in smaller diameters.

Figure 28. Automatic ridge ventilation



Ridge Vents

A continuous vent along the ridge or top of the greenhouse provides the best natural ventilation. The ridge vent operates on the principle that warm air inside the greenhouse rises out the top of the house and cooler air enters to take its place. Ridge vents in small greenhouses are 1′ to 2′ wide. The wind should not blow cold air directly in onto the plants to chill them. Place the vent on the side away from the wind if the house is a lean-to or has the vent on only one side of the ridge.

Automatic vent controllers that open and close the ridge vent according to temperature are available and should be installed since it is difficult to constantly monitor and tend the greenhouse. (Figure 19).

Side Vents and Doors

Side vents and doors are often used in combination with ridge vents for good natural air flow. Cool air enters through the side vents and doors while the warm air rises and escapes through the ridge. Side vents are not often used in greenhouses less than 12′ long, since an open door or a few holes at each end allow enough air to enter on hot days. Small foundation vents, screened doors, and jalousie vents can be used for cross ventilation. The size of the vent openings should be adjustable to handle varying weather conditions.

Air Circulation

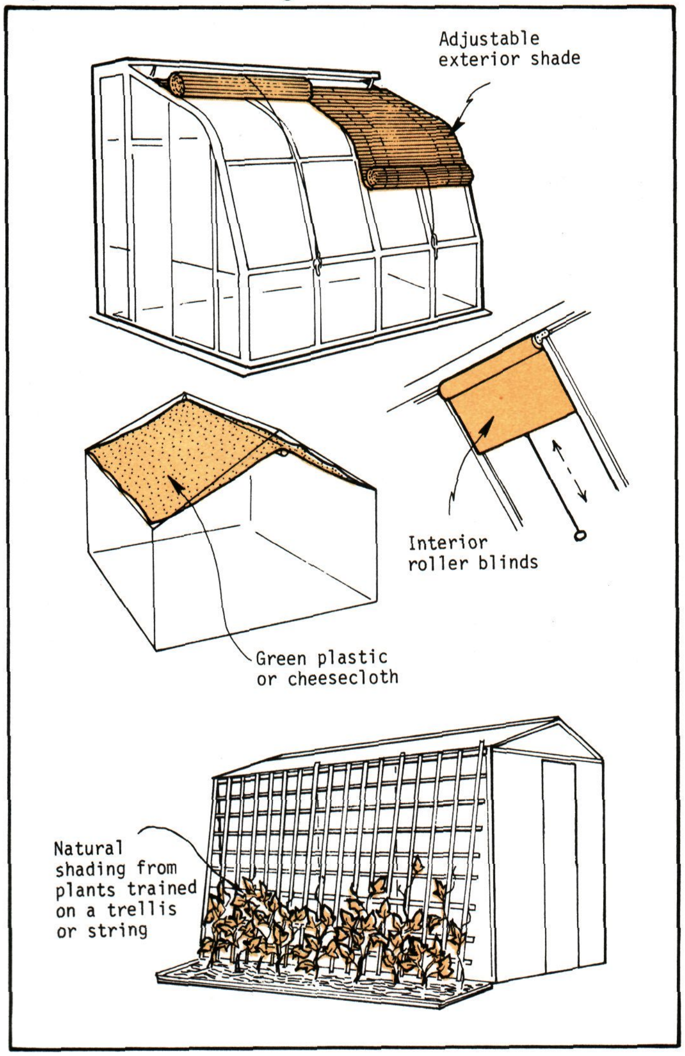
Small circulating fans can be used to circulate air for slightly more uniform temperatures in houses over 20′ long. This added air circulation is needed only when heating, or on cool days when little or no outside air enters the greenhouse.

Shading

Shades, besides reducing light, reduce the heat load in greenhouses. They are commonly used on the hobby greenhouse. Shading plus moisture evaporation from soil and plants can lower greenhouse temperatures 10° to 15°F.

Specially formulated compounds that can be washed off in the fall can be sprayed or painted onto the greenhouse cover and are available from greenhouse suppliers. Many companies sell roll-up shades made of plastic, wood, aluminum, or fiberglass that can be attached to the outside of the greenhouse roof.

Figure 29. Summer shading devices

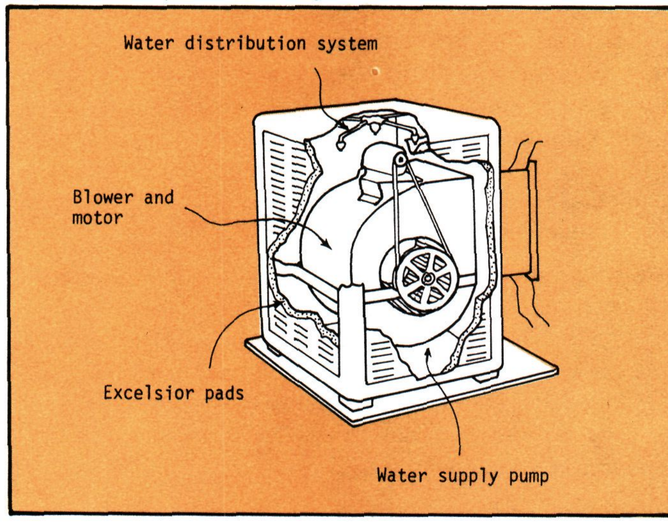


Evaporative Cooling

Air can be cooled by drawing it through wetted wood excelsior pads. Where temperatures exceed 90°F for more than 10 to 15 days a year, evaporative cooling can be worthwhile. Generally evaporative cooling is not needed in New England and northern New York. In the Northeast expect no more than 10°F or 15°F of cooling below outside air temperature by evaporation. A fine mist nozzle can be used to cool plants during the few really hot days. Frequent wetting of plants and walkways is not too effective for cooling.

Unit evaporative coolers are convenient for small greenhouses. Buy a unit that has a cfm (cubic feet per minute) air rating of at least 12 times the floor area of the greenhouse. An 8′ x 10′ greenhouse needs at least a 960 cfm (8′ x 10′ x 12) unit.

Figure 30. Evaporative cooling unit



Unlike refrigerated rooms, a door or vent must be open when using package evaporative coolers. Air must exchange freely for evaporative cooling to work. At least two square feet of opening for every 1000 cfm of cooler capacity is needed.

Perforated polyethylene tubing can be used to uniformly distribute the cooling air in greenhouses longer than 20 feet. This equipment can be purchased from greenhouse suppliers or you can make your own tube. Buy polyethylene film large enough to make a tube that will fit around the cooler outlet. Cut or burn holes every 1 to 2 feet along the tube.

Houses larger than 500 sq. ft. sometimes use a pad and fan evaporative cooling system. A wetted wood excelsior or treated paper (Celdek) pad is mounted along one wall, and exhaust fans along the opposite wall cool the air by drawing it through the pad. The air then passes through and cools the house. Greenhouse suppliers sell pad and fan equipment and can help size and install it.

Use a two stage thermostat to control the evaporative cooler. The first stage, set between 70° and 80°F, turns on the fan. The pump that circulates water to the pad is started by the second stage set between 80° and 90°F.

If an evaporative cooler is well maintained, it cools the greenhouse very effectively. It can be a maintenance headache. Pads must be replaced periodically. Hard water deposits and dirt must be cleaned from the system periodically. An algacide may have to be added to the water occasionally to keep algae growth under control.

HUMIDITY CONTROL

Diseases such as Botrytis are a problem, particularly in spring and fall months when moisture often condenses on plants. Moving the air with circulating fans will reduce disease. A better way to prevent this problem is to remove some of the moist air from the greenhouse and replace it with colder, drier outside air.

Cold air holds less water vapor than warm air, and accordingly, the cold outside air has less water vapor than that inside a greenhouse. When this drier outside air warms, it lowers the humidity and reduces the danger of moisture condensing on the slightly colder plants. Unfortunately, ventilation requires more heat, but this is the only practical way to reduce humidity.

Reducing humidity in the greenhouse is much more difficult than describing how to do it. Usually condensation occurs at sunset when plants and greenhouse cool rapidly. One suggestion is to start heating before sunset and gradually close the ridge vent until it is just barely open 1/4" or so. You should experiment to learn how to control humidity in your greenhouse.

Sometimes the humidity is so high on warm nights that condensation occurs. Because there is very little or no temperature difference between the inside and outside of the greenhouse, little can be done to help. Sometimes higher ventilation rates will reduce the severity of the problem.

During the winter and on hot summer days humidity may become too low for best plant growth. Water sprayed on the plants raises humidity only briefly and mineral deposits from the water can discolor them. Wetting the walks and other non-plant areas will help if done frequently.

Evaporative coolers or humidifiers will also humidify air. Humidistats that sense humidity can be used to operate humidifiers. Unfortunately humidistats lose their accuracy quickly and must be calibrated about every week. Hand or thermostat control is still the best way to control most of these systems.

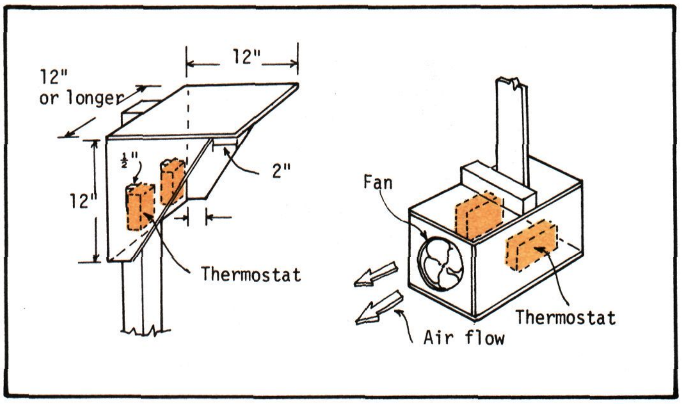
AUTOMATION

Watering, heating, cooling, fertilizing, and humidifying can all be done automatically. Only the budget limits how many chores are automated. Some people prefer to control all of these operations themselves, considering this part of the enjoyment of the greenhouse.

Some jobs, however, are better handled by automatic controls. Heaters and ventilation fans should be controlled by thermostats. Adjust thermostats to provide a smooth transition from heating to cooling. Mount all thermostat sensing elements at one location, shaded from the sun, and 3 to 5 feet high or in the plant canopy.

Thermostats should be located near the center of the greenhouse and away from doors, cold air drafts, and in the direct path of heated air. For most accurate control a small blower can be used to draw air over the sensors. Because thermostats are often poorly calibrated, place one or two thermometers in the greenhouse to check both the thermostat and the temperature distribution. A high-low thermometer provides a very good check of temperatures while you are away.

Figure 31. Shaded thermostats



The temperature sequence for a greenhouse with one fan and a heater might be:

- stage 1 (58°F), heater on, circulation fan on,
- stage 2 (64°F), heater off, circulation fan on,
- stage 3 (72°F), ventilation fan on, circulation fan off.

A control sequence for a greenhouse with a perimeter heating and an evaporative cooling system is shown in Table 8.

Table 8. Sample control sequence for a greenhouse with both a heater and evaporative cooler.

Stage	Temperature	Operation
1	60°	Heating, valve opens to supply hot water to the finned pipe
2	62°	No heating or cooling
3	72°	Cooling begins, exhaust louver opens until cooler blower starts on low speed
4	76°	Unit cooler blower switches to high speed
5	80°	Water starts circulating over the evaporator pads

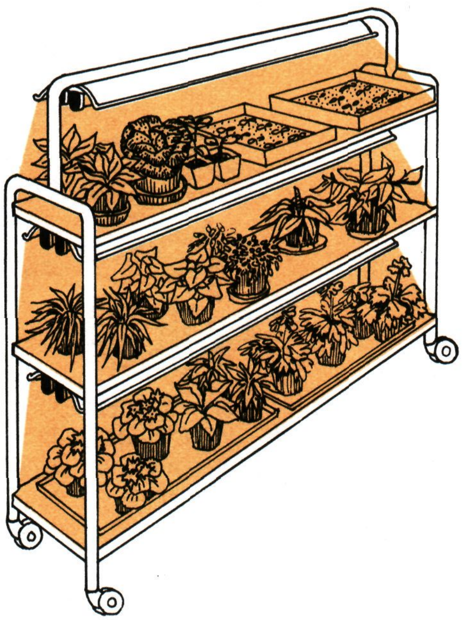
Note: A 10°F temperature difference between heating and cooling stages prevents the exhaust fan from running when the heater is on.

Temperature alarms are used to warn you when some part of the heating or cooling system is not working. Alarms can be purchased from greenhouse and some electronic equipment suppliers.

LIGHTING

Light has a major effect on plant growth. Water, carbon dioxide, nutrients and heat influence growth, but their first influence is related to how they affect photosynthesis.

Indoor electric gardening is a less expensive alternative to a greenhouse for starting seedlings, propagating cuttings, and lighting indoor plants.



It's possible when you use artificial light to change not only the total amount of light energy but also to change the color (quality or wave length) of light. Sunlight is a mixture of both visible and invisible wavelengths, of light. Research is continuing to find how the color of light affects plant growth. In general, intensity and duration, rather than color, of currently available light sources affect plant growth most. Orange and red light causes germination and growth as well as photosynthesis. Infrared (far red) can reverse actions started by red light. Ultraviolet light produced by sun lamps or germicidal lamps can be harmful to plants.

Two types of lighting are used to control plant growth, **supplemental lighting** for photosynthesis and **photoperiodic** lighting for day length. Supplemental lighting adds to the sunlight that is needed for growth of all green plants. A relatively high light intensity is needed. Duration of lighting is also important for photosynthesis. Most flowering plants and seedlings need 12 to 16 hours of light. Green plants can live, but grow slowly, with only 4 to 10 hours. Many people grow shade loving plants such as African violets or begonias inside under supplemental fluorescent lighting.

Photoperiodism refers to the effect of the length of periods of darkness and light on plants. Some plants, such as chrysanthemums, poinsettias, squash and onions, wait for days to grow shorter before they flower. These are called long night (short day) plants. Many annuals such as snapdragons, petunias and turnips respond to short nights (long days). Most plants are not affected by daylength.

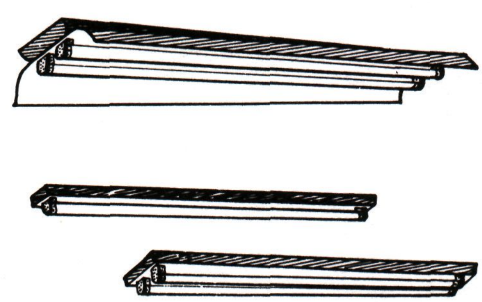
SUPPLEMENTAL LIGHTING SOURCES

Incandescent lamps (light bulbs) are the least costly light source to install, but the most costly to operate. They are very inefficient, converting around 8% of the energy input into light. The balance is converted to heat; plants placed close to incandescent lamps can be burned. Also, some lamps will break if water is accidently splashed on them.

Much of the energy of the incandescent lamp is in the red and infrared spectrum, so they are good for photoperiod lighting.

Fluorescent lamps are

- good supplemental light sources;
- poor for photoperiod control because they emit little or no infrared light;
- three times more efficient than incandescent lamps; (they cost less to run, but fixtures cost more than incandescents.)
- long lived with a typical service life of 7500 to 13000 hours. However, for good plant response they should be replaced once a year. Incandescents burn about 750 hours.
- cool operating. (Plants won't burn even if they touch the lamp. Water accidentally splashed on the lamp will not break it.)



Fluorescent lamp colors range from cool white to warm white. Special fluorescent lamps designed for plants are also available. Generally these lamps do not stimulate growth any more than the less expensive, standard cool white lamp. Plant growth lamps do enhance flower color for display.

Standard industrial or strip fixtures can be used to mount and power the fluorescent lamps. Four foot long shop fixtures with a white reflector that hold two 40-watt lamps are popular and often sale priced in many hardware stores. Special high light output lamps and fixtures are available, but they are expensive. They can be ordered from electrical supply firms, but you may have a buy a case of 12 lamps and wait several weeks for delivery.

What does it cost to run lights? A standard four foot, two lamp fluorescent fixture consumes about 100 watts. In many areas electricity costs eight cents or more per kilowatt hour, so if the light is burned 16 hours a day the cost is 13 cents a day. For the same illumination levels, incandescent lamps cost about three times more to operate than fluorescent lamps. Lighting systems can be controlled with a 24-hour clock for convenience and to keep them from burning more than necessary.

High Intensity Discharge (HID) lamps are normally used for street and parking lot lighting. These high wattage lamps (175 to 1000 watts) are seldom found in a small greenhouse. Fixtures are expensive and light is very intense. Several types are available, but mercury, metal halide and high-pressure sodium lamps are most often used for supplemental light for plant growth.

LIGHT INTENSITY

Light intensity is measured in footcandles or, in the metric system, in lux (1 lux = 10.76 footcandles). The natural light level on a bright, clear day can reach 10,000 to 12,000 footcandles while on a rainy day with heavy overcast, it may be as low as 200 footcandles.

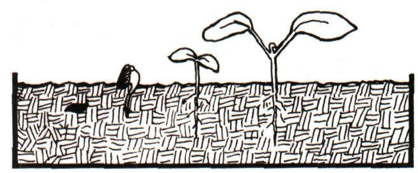
Most sun loving plants will grow very slowly with 1000 footcandles of illumination. Of course, they will grow faster with more light. Fifty footcandles is the minimal light level for plants that need heavy shade. Many indoor house plants grow well with 250-600 footcandles.

A two lamp fluorescent lighting fixture emits about 250 footcandles 18″ below the lamps, and 600 footcandles 6″ below the fixture.

INDOOR SEEDLING GERMINATION and PROPAGATION

Germinating seeds and cuttings being propagated need light levels of about 600 to 2000 footcandles to grow well. Four 40-watt cool white fluorescent lamps mounted 4″ away from plants in a white reflector on 2″ centers will provide about 1000 footcandles of illumination. Special high wattage fluorescent lamps must be used to achieve higher levels at greater distances. The soil is sometimes heated to speed germination.

Ingenuity and care are required to maintain optimum temperatures and humidity for propagation or germination under electric lights. Many plants do well when daytime temperatures are 80°F and night temperatures are 10° to 15° less. Night temperatures should not drop below 60°F.

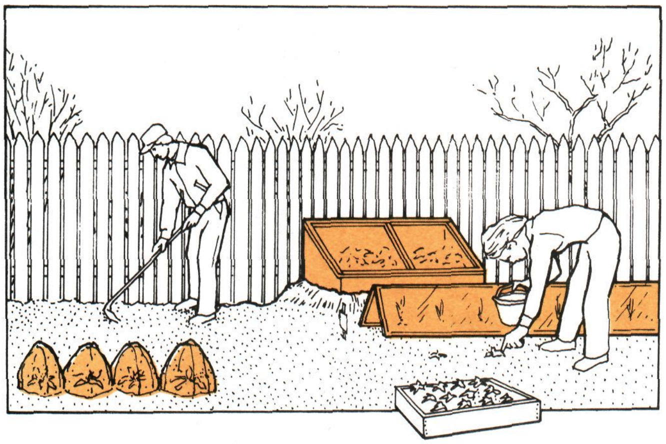


LIGHTING THE GREENHOUSE

Supplementing sunlight with electric light is expensive and seldom done in either the commercial or hobby greenhouse. Light can be added to extend the day length or interrupt the night to control bud initiation of some flowers. Sometimes fluorescent lighting is installed to grow plants under benches. The technical lighting books listed in the reference section have more information on greenhouse lighting.

Caution: The greenhouse is a damp, well-grounded area. Poor wiring can be deadly. Be sure any wiring meets national and local electrical codes. A ground fault circuit interrupter (GFCI) should be installed to prevent a shock and possible death. Hire a licensed electrician to wire the greenhouse if you are not familiar with electrical codes and wiring.

Cold Frames, Hotbeds and Window Greenhouses



COLD FRAMES and HOTBEDS

A cold frame or its heated version, the hotbed, is a miniature greenhouse used to start vegetable or flower seeds in the early spring. Heat for a cold frame comes from the sun. During the daytime the soil is heated. At night the cover slows the loss of heat. Ventilation is accomplished by raising or lowering the cover.

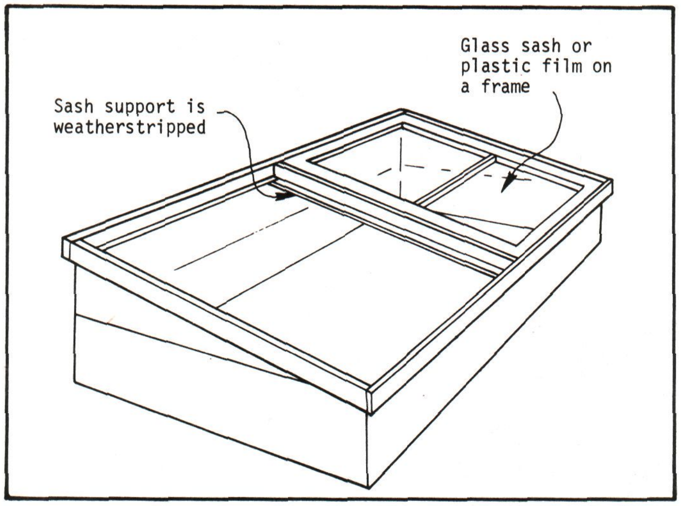
The versatile cold frame can also be used to extend greenhouse space, root cuttings, or grow an extra crop of vegetables. By converting it to a hotbed, lettuce, green onions, or parsley can be grown through the winter. In fact, a hotbed is a better choice for the gardener who is considering buying a greenhouse smaller than 5′ x 8′. It is much cheaper to build or buy, costs much less to heat, and can grow almost as much as a tiny greenhouse.

Construction

Figure 32 illustrates a typical cold frame. Old storm windows make an excellent cover. Paint wood parts with a primer and one or two coats of exterior white paint to preserve the wood and reflect light to the plants. Some people apply a wood preservative, such as copper naphthenate, before painting. Do not use creosote or pentachlorophenol preservatives because they release vapors that are toxic to plants.

Polyethylene film is an inexpensive covering that will last several seasons if stored away from the sun during the summer. Clear vinyl film or rigid fiberglass panels will last longer. Two layers of polyethylene or vinyl spaced 3/4″ apart hold heat better than a single layer.

Figure 32. Typical cold frame



Location

Locate hotbeds and cold frames on a sloping, well-drained soil to remove rainwater runoff. The bed area must be level. A south facing sunny site with wind protection on the north and west is ideal. Locating the frame near the house has several advantages. It is close to water and electricity, and it is easy to reach for the frequent attention needed by young plants. Frames that are built slightly below ground or that have soil banked up on the outside are warmer.

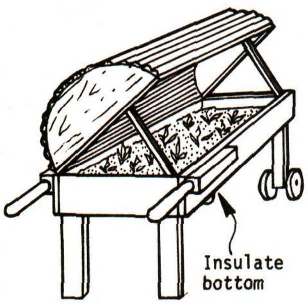
COLD FRAME OPERATION

An easily read thermometer is an essential part of a cold frame. Cool-season crops thrive in 50° to 60°F day temperatures, and warm season crops do well at 65° to 75°F. When temperatures in the cold frame become too warm for best growth the top should be opened. Then as outside temperatures fall, such as in late afternoon, close the top to trap heat for the night. Heat actuated vents are available to automate ventilation.

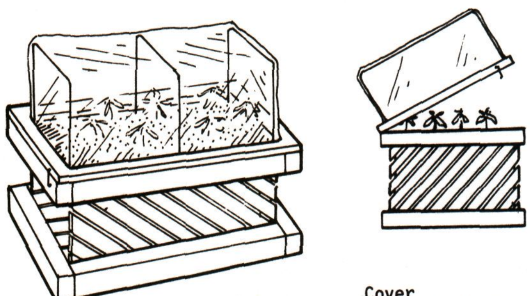
Often, good temperature control requires remembering to do it. A maximum-minimum thermometer can show whether you are opening the top the right width during the day.

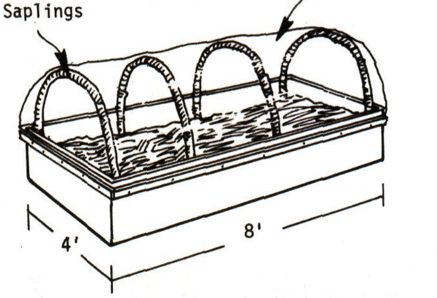
Joints should be tight and weatherstripped to retain heat. Also an inch of foam-board insulation can be attached to the sides. During extremely cold weather the top can be covered temporarily with straw or other insulating material.

Watering is particularly important. The nearly airtight cold frame slows evaporation so it is easy to overwater. Keep the bed moist, but not soaked, at all times. Apply water in the morning so plant foliage can dry before evening.



Moveable planters and raised beds can be fitted with cold frame covers and opened according to heat needs. Cover with a blanket or quilt in very cold weather.

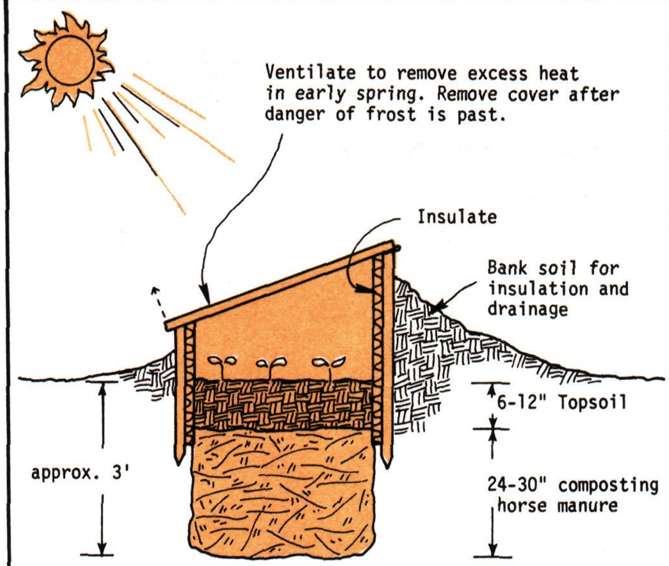




HEATING

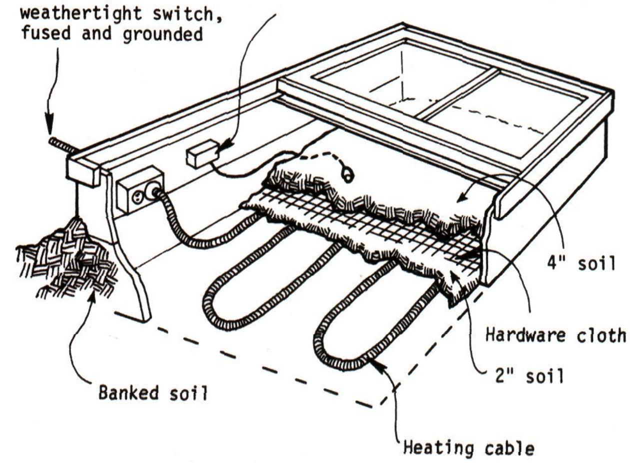
The earliest hotbeds were heated by placing them over 12" to 24" of horse bedding and manure. The composting manure then heated the frame. Where animal bedding and manure is abundant this method is still used, but an electric heating cable is more commonly used for supplemental heat today. Heating cable is available from some hardware stores and greenhouse or garden suppliers.

Figure 33. Hotbed with composting manure



1. Dig a trench approximately 3' deep in the fall and stockpile enough soil to replace the top 6 - 12" layer, as this soil would otherwise be frozen in winter. Build and install the cold frame. Bank soil on sides.
2. In January, place 2 - 2½' of fresh horse manure in the bottom. Cover with 6 - 12" of soil and plant your seedlings.
3. Ventilate, especially from March onward, as light levels and temperature increase can cause overheating.
4. Remove the cover as the danger of frost passes.
5. Transplant into the garden as danger of frost passes.
6. Dig the compost into the garden.

Figure 34. Hotbed with electric cable

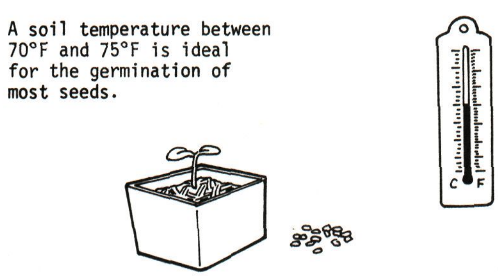


In northern areas of the United States, supply 12 to 16 watts of heating cable per square foot of bed area. For a 3′ x 6′ frame a cable rated at 250 watts can be used. Cables are available in several lengths and wattage ratings. Lay the cable on the soil at the bottom of the bed and uniformly spaced across the bed. The spacing between the edge of cold frame and the cable is one-third to one-half the spacing between the cables. Cover with 2″ of sand. Then place 1/2″ mesh hardware cloth on the sand to protect the cable from mechanical damage. Finally, add a 4″ layer of soil, or soil mix, for the growing bed. Sometimes 2″ of vermiculite insulation is placed below the cable to conserve heat.

Caution: Lay the cable with care. Kinks may break the cable. Do not cross the cable over itself or another cable. Do not shorten the cable or it may burn out. Use weatherproof wiring and service entrances. The newest electrical code requires that outdoor wiring have a ground fault circuit interrupter (GFCI). This safety device will trip off the circuit when even a small current runs to ground. A qualified electrician should install all wiring.

OPERATING the HOTBED

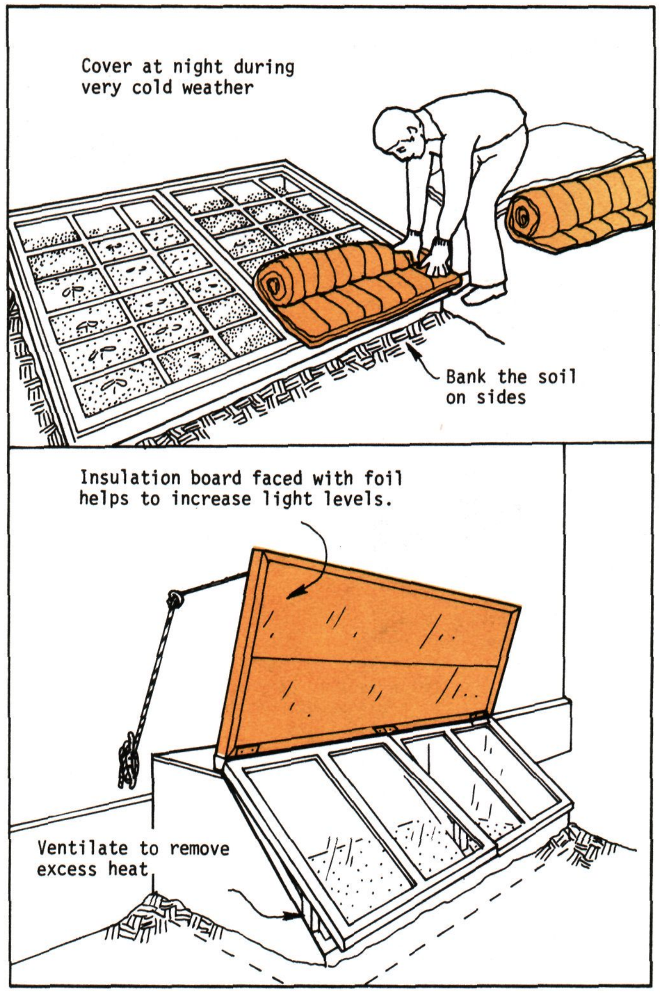
Use a thermostat to control soil temperature. A soil temperature of 70° to 75° is ideal for germination of most seeds. Check that the thermostat is working properly by placing a thermometer so the bulb senses the temperature at seed depth. The cost of operating an electrically heated bed depends on the time of year, weather conditions, location and construction. A 3′ x 6′ bed may use from 1 to 2 kilowatt-hours of electricity per day during March.



After the seeds germinate adjust the temperature to suit the particular plant. Cabbage, cauliflower, and lettuce grow well in an air temperature of 60° to 65°F during the day. Eggplant, peppers, tomatoes, and melons are warm season crops that grow best at 65° to 75°F or more.

Careful operation and good maintenance conserve heat to reduce operating costs. For example, insulate, weatherstrip and repair any holes in the cover.

Figure 35. Night insulation for cold frames and hotbeds



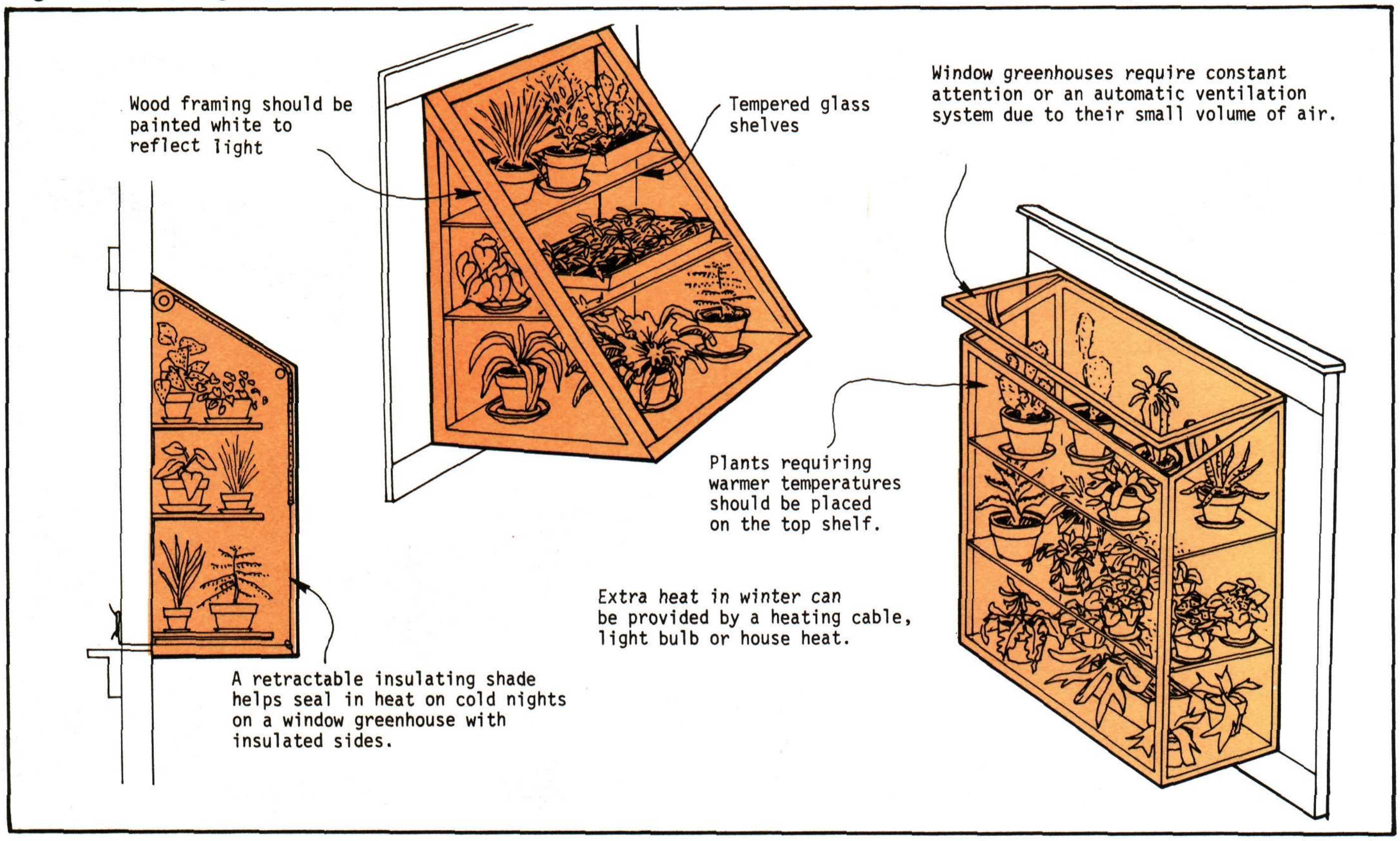
WINDOW GREENHOUSES

A window greenhouse is a good choice where you have limited time for gardening or space is not available for a greenhouse. Before you decide to install one consider the following factors.

A south facing window that is not shaded by trees or buildings is best. Windows facing east or west are also acceptable. Some plants will even grow on a north facing window that receives no direct sunlight. Here plant selection and watering are very important. Also select a window that is not shaded by trees or other buildings during the day.

The window to which your greenhouse is attached must be the double hung casement type (opening up and down) or one that slides sideways because the plants must be accessible from inside. The plants growing in the greenhouse can block out light coming into the room. The window can no longer be used for room ventilation. In areas where vandalism is a problem, an acrylic or polycarbonate glazing may be substituted for the more conventional glass glazing.

Figure 36. Window greenhouses



If the greenhouse is larger than the existing window, it can provide extra heat to the room during sunny days in the winter. It can also overheat the room during the summer unless it is shaded and can be opened. Extra heat will be needed to keep the plants warm during the winter. This can come from the room heater, a heating cable with thermostat or an enclosed light bulb.

Operation

A window greenhouse contains such a small volume of air that the interior can heat rapidly. You must be constantly alert to the ventilation needs or purchase an automatic system. The temperature in a closed window greenhouse can exceed 100°F on a sunny day which may kill the plants.

Many greenhouse manufacturers make window greenhouses both in standard and custom sizes to fit most windows. In selecting a size consider where it can be attached to the house conveniently. In some cases this will be the window frame, in others it may be the wall around the window. Remember that the attachment has to be strong enough to support the greenhouse, the plants and a heavy wind.

Before making a selection check whether snow or icicles from an overhead roof will fall onto the greenhouse. For this condition you may need to install a roof deflector or build a solid greenhouse roof.

Most window greenhouses come with wire or tempered glass shelves spaced 12 to 18 inches apart. A prefabricated metal pan or cookie sheets filled with sand or small stone should be placed on the bottom shelf to catch any water drips. You can install the greenhouse without the shelves if you want to grow tall plants such as tomatoes.

To reduce the heat loss during the winter make sure that all joints are caulked, especially where the frame contacts the house. Foam insulation board may be attached to the bottom and top on some models. Also removable insulation shutters help keep the greenhouse warmer on cold winter nights. With some models it may be possible to install insulating pull-down shades to keep the heat in.

During warm weather these greenhouses need some type of ventilation. Some models have top and bottom vents; others use a small exhaust fan.

Most commercial models use metal frames. You may find it easier to use wood if you decide to make your own. All lumber should be treated with copper naphthenate wood preservative before being painted white. Do not use pentachlorophenol as it will injure the plants. A used storm window, large pieces of one quarter inch plexiglass or double wall acrylic panels make good glazing materials.

In operating your window greenhouse keep it filled with plants to take advantage of all space. Also remember that plants requiring a warmer environment will do better near the top.

Growing Plants in Passive Solar Greenhouses

Selecting plants for solar greenhouse production requires an understanding of variations in light and temperature caused by geographic location, seasonal variation, exposure to sun, and the effects of structural design, shape, and air flow patterns. (Figure 28).

Table 9. Average temperature range of 20 passive solar greenhouses in the Northeast, November through May.[1]

Month	Degrees Farenheit Average High	Average Low	Highest High	Lowest Low
November	74	46	81	38
December	67	42	76	32
January	62	38	71	33
February	70	41	77	30
March	73	48	79	42
April	73	51	86	44
May	77	56	86	49

[1]Adapted from a study of passive solar greenhouses by the National Center for Appropriate Technology. The greenhouses vary considerably in design, cost, and efficiency. Some are attached to buildings, some are freestanding. Some have back-up heat systems, others are completely reliant on the sun.

FOOD PRODUCTION

In the Northeast, the solar greenhouse is best used as a season extender. Garden vegetables can be started inside earlier in the spring, so when they are transplanted outside, they will reach maturity sooner. This growing method allows more than one crop to be grown in the same space in one season. In the fall, some crops, like tomatoes and peppers, can be transplanted into large containers and moved in before frost; then harvesting can continue. It is best to prune the roots the diameter of the container a week or two before transplanting.

The short winter days, low sun angle and cold, cloudy weather make mid-winter vegetable crops marginal in the Northeast. However, if you are willing to accept slow growth, many leafy green vegetables will tolerate these conditions. Table 10 lists the vegetables that grow best under winter solar greenhouse conditions.

Figure 37. Internal greenhouse climate zones.

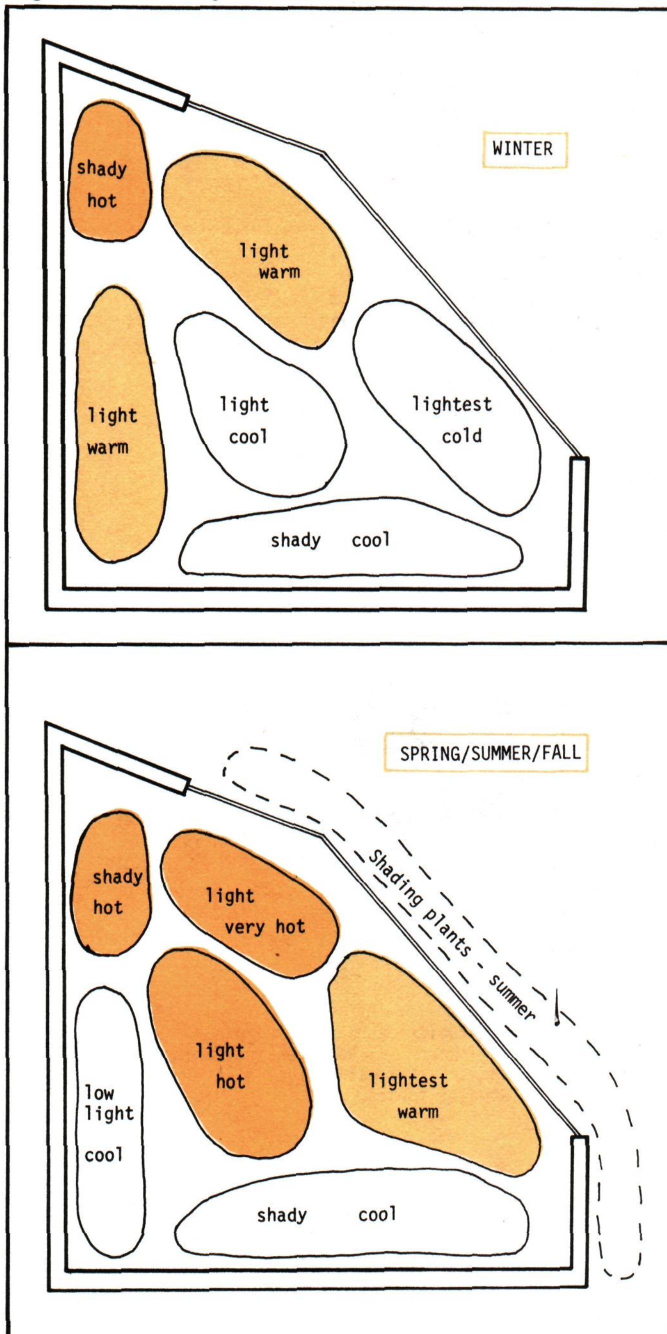
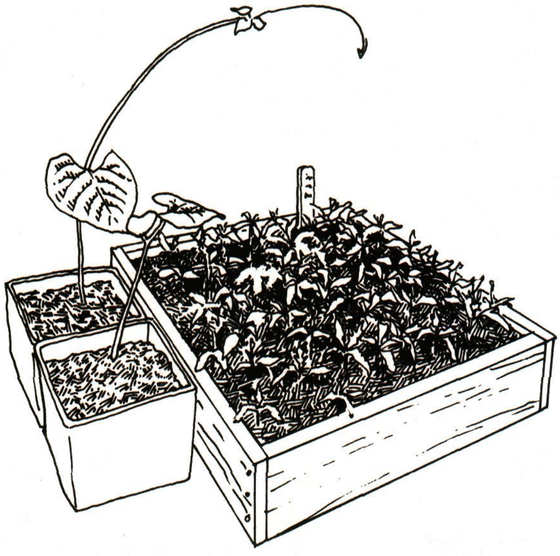


Table 10. Suitability of vegetables and herbs for production in the winter solar greenhouse.

Excellent	Good	Fair	Poor
Swiss Chard	Cherry Tomatoes[2]	Broccoli	Beans
Leaf Lettuce	Green Onions	Peppers[2]	Corn
Celery	Cucumbers[2] (European Type)	Large Tomatoes[2]	Carrots
Kale		Eggplant[2]	Radishes
Turnip		Edible Pod Peas	Turnips
Mustard Greens	Garlic		Melons[1]
Dill	Leek		Squash[1]
Spinach	Cabbage		
Oregano	Collards		
Parsley			
Marjoram			
Basil			
Fennel			

[1]Listed poor because they are pollinated naturally by bees. They could be hand pollinated and listed fair. European cucumbers are not noted since they require no pollination.

[2]Require warm temperatures.



Garden vegetables can be started early in the greenhouse so that when they are transplanted to the garden they will reach maturity sooner.

The inexperienced grower can easily overproduce some items. Scheduling crops to meet your needs will come with experience and careful record keeping. Table 11 suggests space requirements for vegetables for a family of four. Table 12 outlines temperature guidelines for best growth and quality of vegetable crops.

Table 11. Space requirements for vegetables for a family of four.

Vegetable or Herb	Total Spacing (Sq. Ft.)	Spacing (Inches)	Plants Needed (Number)
Swiss Chard	9	12	9
Leaf Lettuce	18	9	30
Celery	9	9	12
Greens	10	6	40
Spinach	10	6	40
Herbs (Dill and Fennel *require more space* than others)	15	6	4 each of 5 kinds
Cherry Tomatoes	6	12	6
Green Onions	6	3	72
Cucumbers	6	18	2
Garlic	2	3	12
Leek	2	3	12
Cabbage	12	12	12
Collards	10	12	10
Broccoli	10	12	10
Peppers, Hot	6	18	2
Peppers, Sweet	6	18	2
Large Tomatoes	6	24	3
Eggplant	2	24	1
Edible Pod Peas	10	3	40

Table 12. General temperature guidelines for best growth and quality of vegetable crops.[1]

Temperatures (°F)			
Optimum	Minimum	Maximum	Vegetable
55-75	45	85	Chicory, chives, garlic, leek, onion, salsify, shallot
60-65	40	75	Beet, broad bean, broccoli, Brussels sprouts, cabbage, chard, collard, horseradish, kale, kohlrabi, parsnip, radish, rutabaga, sorrel, spinach, turnip
60-65	45	75	Artichoke, cardoon, carrot, cauliflower, celeriac, celery, Chinese cabbage, endive, Florence fennel, lettuce, mustard, parsley, pea, potato
60-70	50	80	Lima bean, snap bean
60-75	50	95	Sweet corn, Southern pea, New Zealand spinach
65-75	50	90	Chayote, pumpkin, squash
65-75	60	90	Cucumber, muskmelon
65-75	58	80	Sweet pepper, tomato
70-85	65	95	Eggplant, hot pepper, martynia, okra, roselle, sweet potato, watermelon

Adapted from *Knotts Handbook for Vegetable Growers.* Second Edition. Oscar A. Lorenz and Donald Maynard. John Wiley and Sons, N.Y. 1980.

[1]Some crops can be planted as temperatures approach the proper range. Cool-season crops grown in the spring must have time to mature before warm weather. Fall crops can be started in hot weather to ensure a sufficient period of cool temperature to reach maturity. Within a crop, varieties may differ in temperature requirements; hence this listing provides general rather than specific guidelines.

ORNAMENTALS

Many ornamental crops tolerate low light and cold temperature. During the coldest months, grow plants which tolerate 45°F or less, such as pocket book plant (calceolaria), cineraria, tulips, daffodils, begonias, bromeliads, geraniums and some orchids. Foliage and succulent plants which tolerate low temperatures include araucaria, citrus, fatsia, hedera, philodendron, podocarpus, agave, many cacti and lithops.

CROP MANAGEMENT

Scheduled planting minimizes the amount of empty growing space at any given time. Ideally when one crop is removed, another is ready to replace it. This requires careful manipulation of crop choice and layout. A grower must be aware of germination time, the number of days to transplant size, maturation time, and the length of productivity for specific crops.

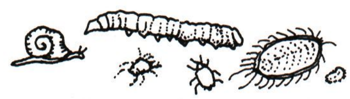
Keeping accurate planting records will provide data for planning future crops. Tables 13 and 14 show a hypothetical management plan for ornamental- and vegetable-producing greenhouses. Seed packages, catalogs, and gardening books also provide useful information.

GREENHOUSE MANAGEMENT

No matter how carefully a greenhouse is managed, some problems arise. A few preventative measures can save money and time that would otherwise be lost to insect pests or disease. The importance of following the basic rules for greenhouse operation cannot be overemphasized. Venting and heating at the proper time helps maintain a healthy environment for plant growth. General cleanliness reduces the chances for pests and diseases to breed.

Cultural techniques may require modification from those used in the garden. Soil should be lighter and drain better than many garden soils. Whether cultivation is in ground beds, raised beds or containers, it is necessary to prepare a soil mix especially for indoor use and change it annually. Drainage holes in containers are as important as light soil. Watering and fertilizing is based on plant growth, which is directly related to light and temperature.

Fewer pests are usually found in a greenhouse garden; however, the pests must be controlled. Due to the enclosed nature of the greenhouse, interrelated ventilation, and the proximity of family and pets, extreme caution must be exercised when using pesticides. As far as possible use innocuous controls such as yellow sticky bands for white fly, soup solutions for spider mites and alcohol swabs for mealy bug control.



Good air circulation reduces fungus diseases. If an attached greenhouse does not have good natural airflow, a small fan may be added. In late spring, summer, and early fall, ventilation to the outside will be necessary to prevent excessive temperature buildup. In many areas, unless shade and ventilation are provided, the summer temperatures will be too high for optimum vegetable growth in the greenhouse.

Table 13. Hypothetical crop management plan for ornamentals.

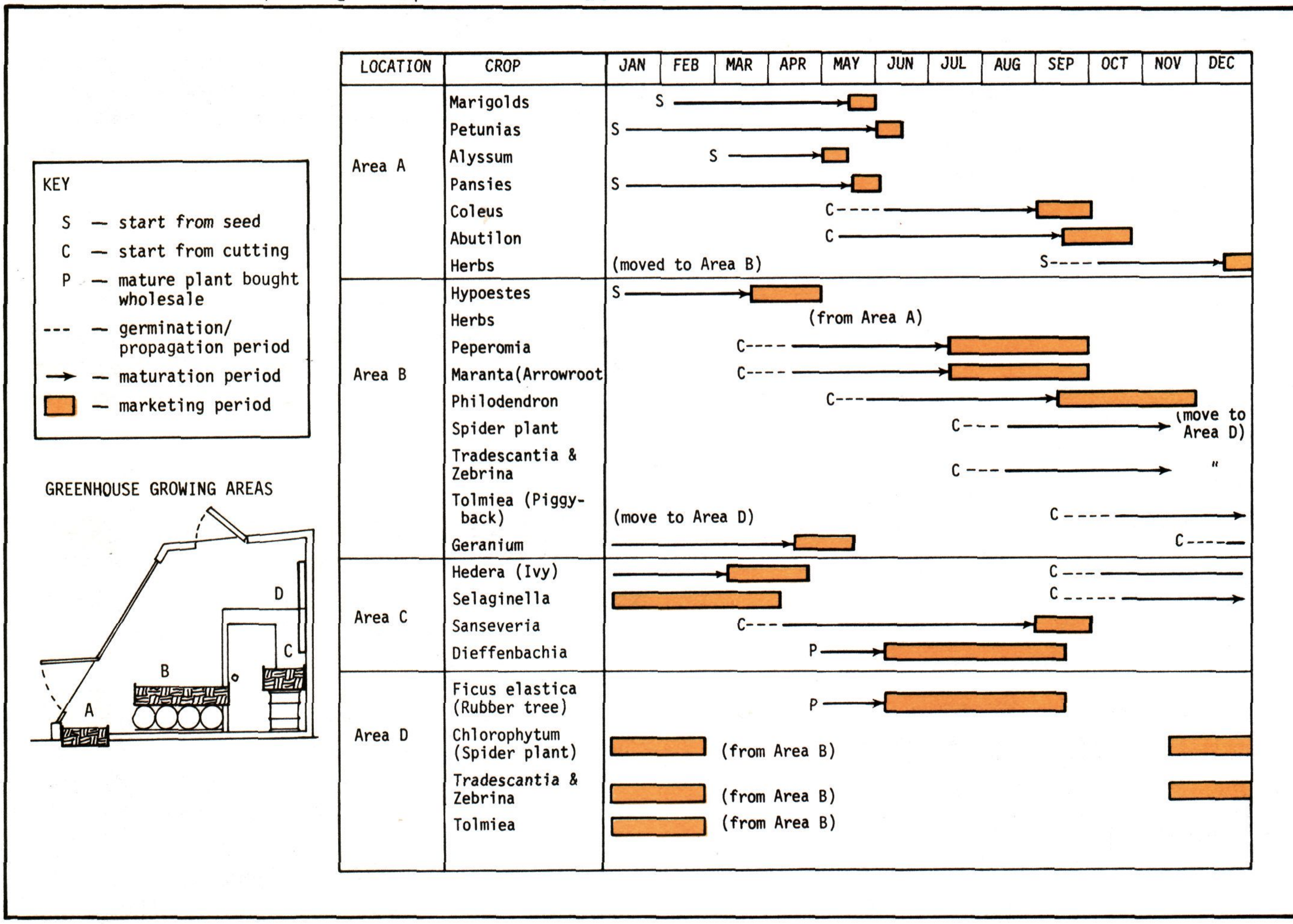
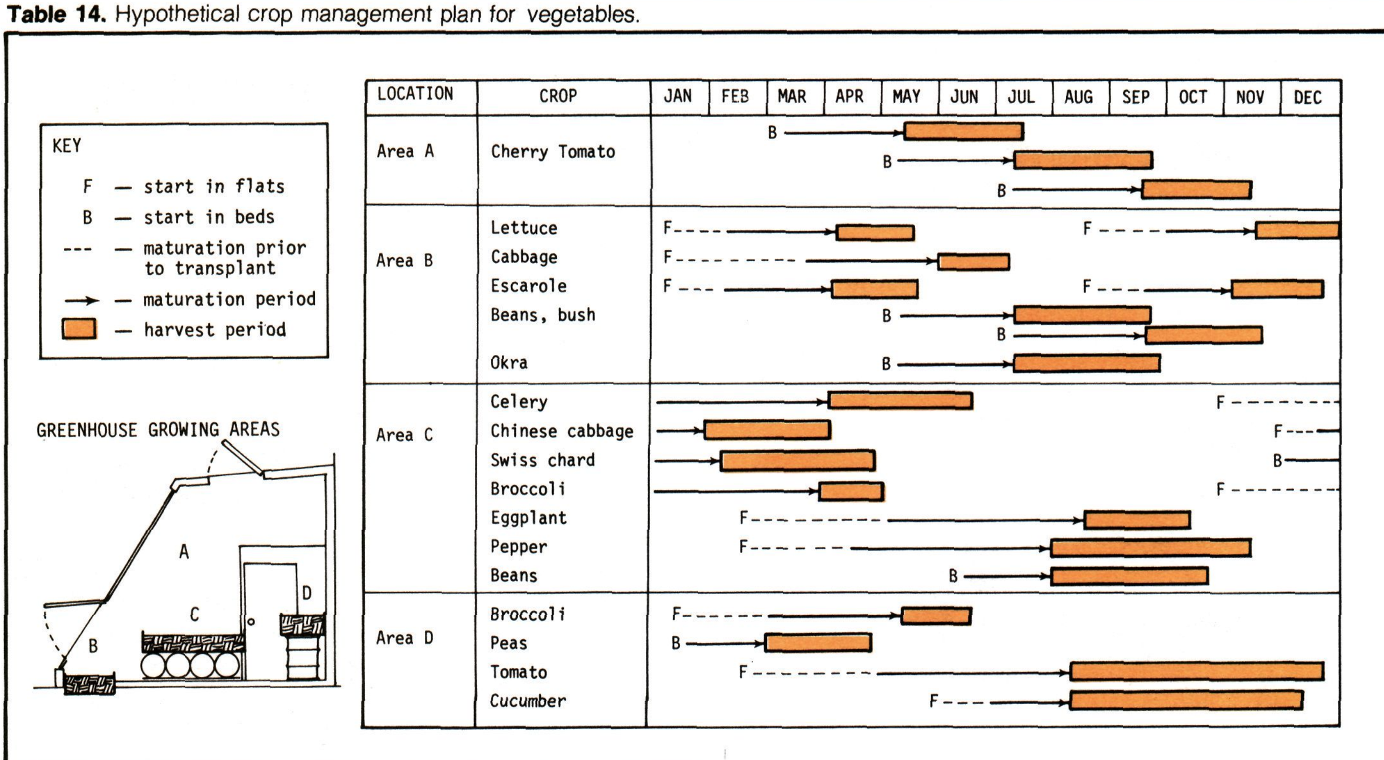


Table 14. Hypothetical crop management plan for vegetables.



General Greenhouse Operation Guide

1. No smoking in the greenhouse.

2. Keep floors clean.

3. Keep all utensils and tools clean; wash them after use.

4. Keep hose out of the way when not in use and the end off the floor.

5. Wash pots and flats with chlorine and water (1:9 ratio) after use.

6. Keep a log of crop production.

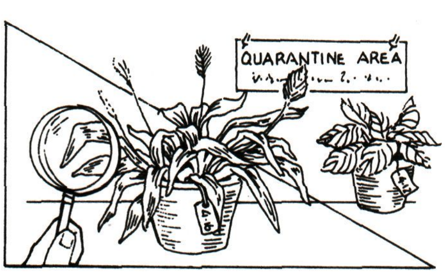
7. Organize greenhouse materials (tools, records) in a designated storage area.

8. Wash hands before handling plants and after applying fertilizer or insecticides.

9. Don't allow weeds to grow next to the greenhouse.

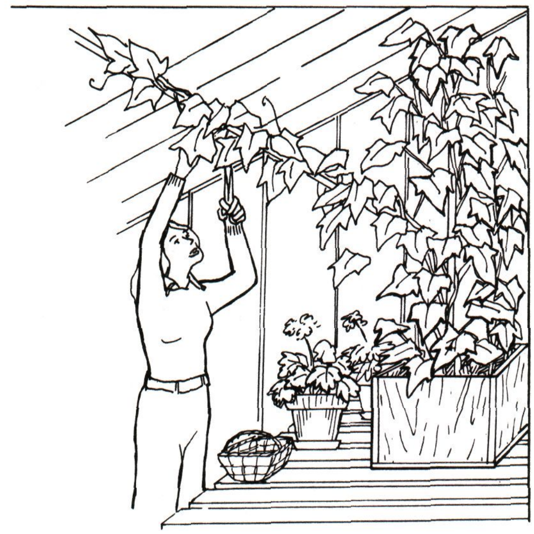
10. Keep screen door to greenhouse closed; don't invite insects in.

11. Check any new plants coming in for evidence of pests or disease.



12. Use soilless materials, such as perlite, vermiculite, peat moss, and sand in various combinations.

13. Remove dead foliage from plants and soil.

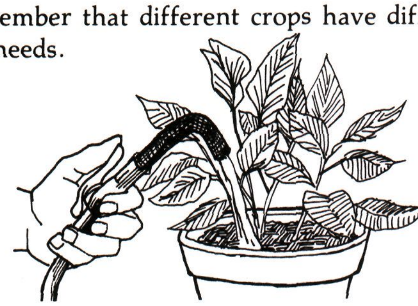


14. Destroy diseased plants; do not leave them near the greenhouse.

15. Ventilate when the temperature exceeds 80°F, or the relative humidity is above 80%.

16. Watering tips:

- Water thoroughly, but not too frequently (anywhere from 1 to 10 days, depending on temperature and humidity).
- Generally, water is needed if the top 2 inches of soil are dry.
- Water at the base of the plant, not on the foliage.
- Usually, the larger the plant, the less water it needs.
- Be careful when watering seedlings; use a mister or water from the bottom.
- Remember that different crops have different water needs.



PLANT DISORDERS

Every experienced gardener has encountered some problems with nutrient deficiency, pests or disease. Many good texts on gardening or horticulture discuss diagnosis and treatment of plant disorders. In addition, state cooperative extension service offices can help. In urban areas, these agencies often are affiliated with city-wide gardening programs. City botanic gardens and conservatories also can offer helpful advice.

A common mistake is to associate disorders with exotic rather than simple causes. However, a majority of plant problems stem from too much or too little light and/or water. After determining that these environmental factors are not the cause, carefully examine the sick plant for evidence of insect attack. A meticulous inspection of the roots, stems, and leaves will usually find the problem. Only after eliminating these possibilities should nutrient deficiency or disease be considered as a cause.

Sometimes the trouble may have more than one source. Symptoms rarely fit the precise descriptions given in textbooks. If a plant appears to be diseased, remove it from the greenhouse. Do not jeopardize the well-being of an entire crop in order to save one plant.

Become acquainted with the various methods of treatment available for plant disorders. Disease, once it becomes established, is often difficult to control. Nutrient deficiencies and insect pests can be effectively managed by either chemicals or organic techniques. Numerous gardeners advocate both methods and arguments abound as to which is better.

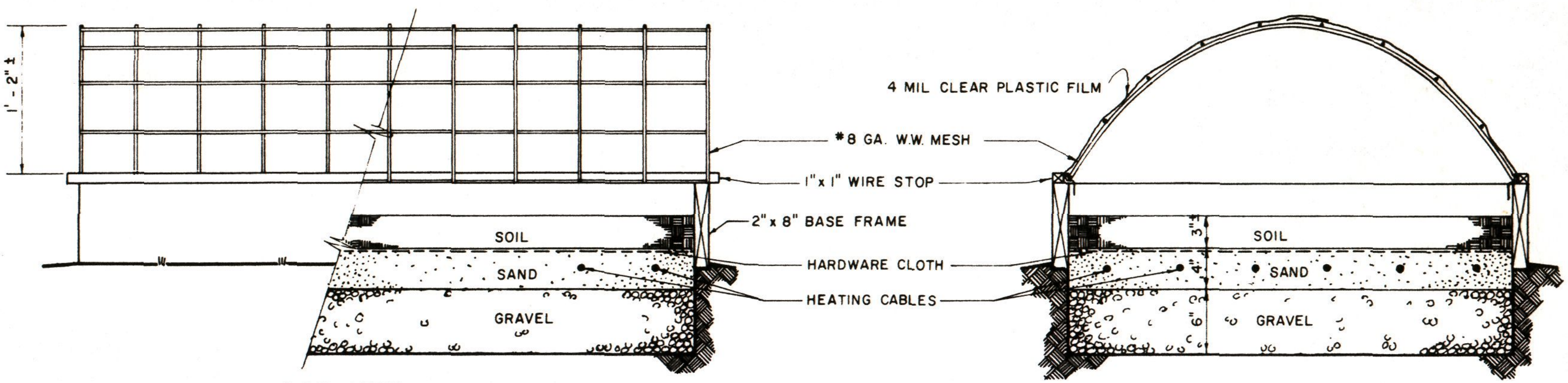
In general, chemical fertilizers and pesticides are quick-acting, effective, dependable and inexpensive initially. However, extended improper use of chemical fertilizers without adequate leaching can cause the build-up of salts in the soil and damage plant roots. Chemical pesticides are toxic to beneficial insects as well as to pests. They may require repeated applications since many insect populations have resistance stages to the pesticide.

Organic approaches also have advantages and disadvantages. Organic fertilizers improve soil texture, but are slow-acting and do not always provide the best nutritional mix for plants. Biological control is a safe method of pest management but is never 100% effective. This approach takes effect more slowly and is not always reliable. Generally, chemicals are more hazardous, while successful organic growing requires more skill and time.

TEMPERATURE FLUCTUATION

The wide temperature swings found in the passively heated solar greenhouse with little heat storage mass and no back-up heat make it difficult to grow plants. Most greenhouse crops are selected to grow where temperatures are controlled within a few degrees of an optimum. Large temperature variations may be tolerated, but crops and varieties must be selected which will grow, flower and fruit with greater temperature swings. The extent of temperature tolerance necesssary will depend on whether the crop is being grown as a hobby, for supplemental food or for commercial sales. If the crop is grown primarily for personal satisfaction you may accept slower growth, occasional abortion of flowers or misshapen fruit. However, if the crop is grown for sale, and you are trying to pay for the investment, crop and variety selection will be much more critical. But a producer may be able to live wth slower growth if production costs are lower.

Plans



SIDE VIEW
CUT AWAY

END VIEW
SECTION

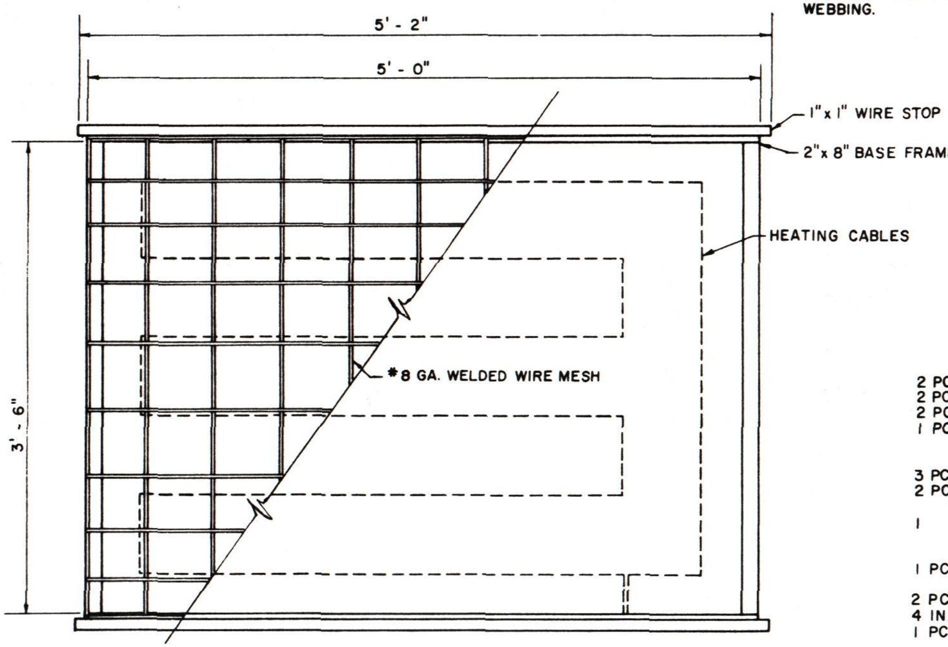
NOTE: SEPARATION OF HEATING CABLES IS VARIABLE TO AMOUNT OF HEAT NEEDED PER SQ. FT. ACCORDING TO GEOGRAPHIC LOCATION. REFER TO LEAFLET NO. 445 U.S.D.A.

ALL WOOD SHOULD BE TREATED WITH PRESERVATIVE AFTER CUTTING AND BEFORE ASSEMBLY.

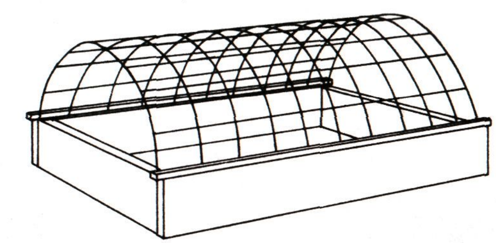
METAL PARTS AND FASTENINGS TO BE GALVANIZED OR OTHERWISE RESISTANT TO CORROSION.

WOOD PARTS MAY BE FASTENED WITH SCREWS OR WITH NAILS.

PLASTIC MAY BE FASTENED BY CLOTHES PINS OR BY PLASTIC WEBBING.



TOP VIEW
CUT AWAY



PERSPECTIVE VIEW
NOT TO SCALE

MATERIAL LIST

2 PCS.	2"x 8"- 5' LONG FOR SIDES
2 PCS.	2"x 8"- 3'- 6" LONG FOR ENDS
2 PCS.	1"x 1" WIRE STOP - 5'-2" LONG FOR SIDES
1 PC.	NO.8 GAUGE 6"x6" WELDED WIRE, 5' LONG 4'- 6" WIDE FOR TOP OF WOOD FRAME TO SUPPORT PLASTIC FILM.
3 PCS.	PLASTIC WEBBING 2" WIDE - 5' LONG
2 PCS.	PLASTIC FILM, 4 MIL, CLEAR 3' WIDE 7' LONG.
1	360-WATT SOIL HEATING CABLE, THERMOSTATICALLY CONTROLLED TO SHUT OFF AT 70°F.
1 PC.	WHITE PLASTIC FILM, 4 MIL, 5'x8' FOR COVERING FRAME DURING WINTER.
2 PCS.	CHEESECLOTH, 3'x7'
4 IN.	SAND - 2" ABOVE, 2" BELOW HEATING CABLE
1 PC.	1/2" HARDWARE CLOTH, 5'x 3 1/2'

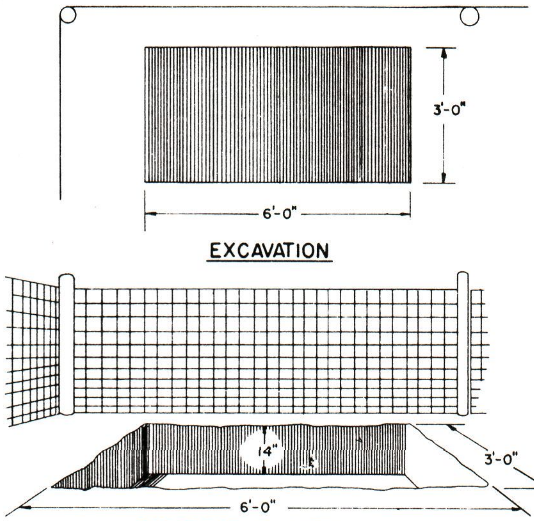
DESIGNED IN COOPERATION WITH:
CROPS RESEARCH DIVISION

COOPERATIVE EXTENSION WORK IN
AGRICULTURE AND HOME ECONOMICS
AND
UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

MINI-HOTBED AND PROPAGATING FRAME

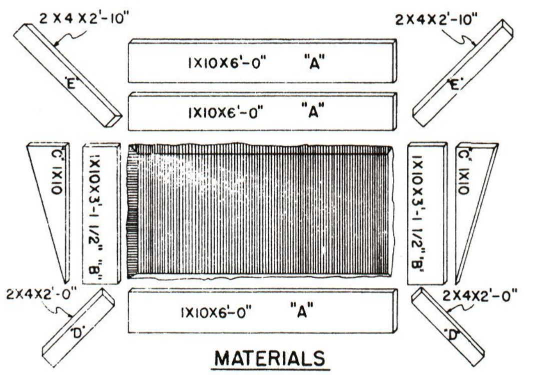
U.S.D.A. '69	6080	SHEET 1 OF 1

FOR AVERAGE HOME GARDEN

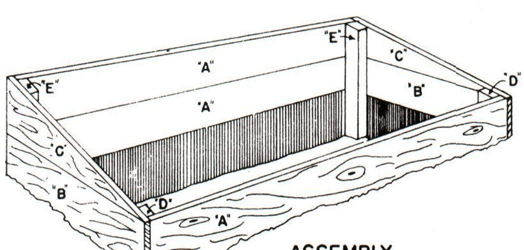


EXCAVATION

PERSPECTIVE VIEW



MATERIALS

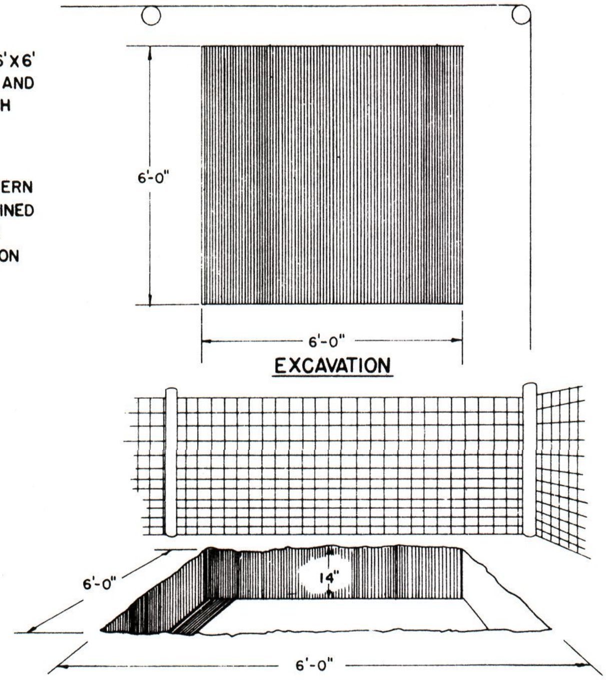


ASSEMBLY

HOT BEDS LARGER THAN 6'X6' SHOULD BE BUILT 6' WIDE AND MULTIPLES OF 3' IN LENGTH

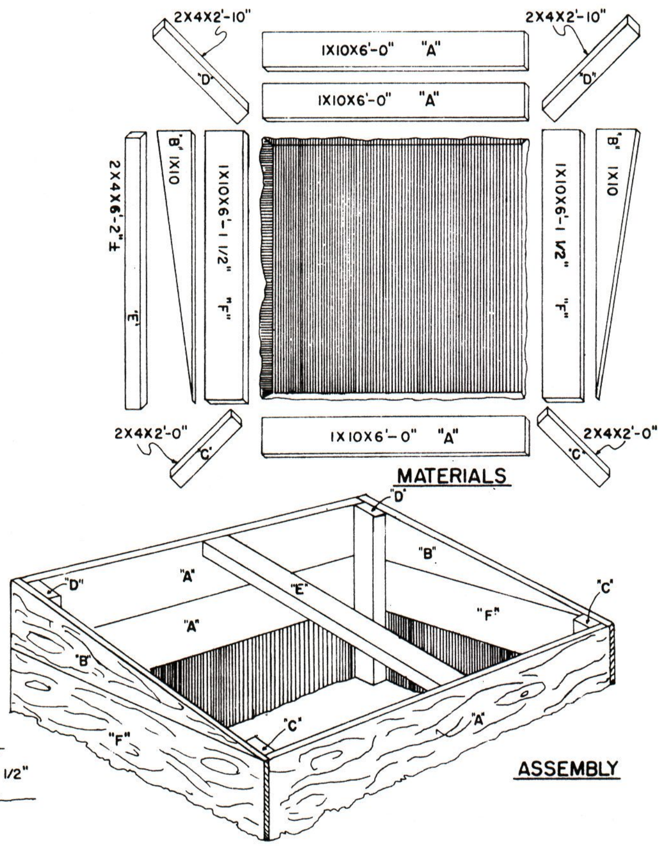
LOCATION-A SUNNY SOUTHERN EXPOSURE IN A WELL DRAINED LOCATION IS NEEDED. SOME WINDBREAK PROTECTION ON NORTH IS DESIRABLE.

FOR AVERAGE GARDEN & SURPLUS FOR SALE



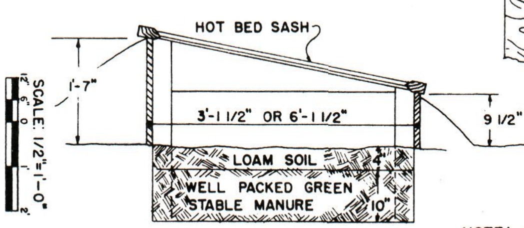
EXCAVATION

PERSPECTIVE VIEW



MATERIALS

ASSEMBLY



TYPICAL CROSS SECTION

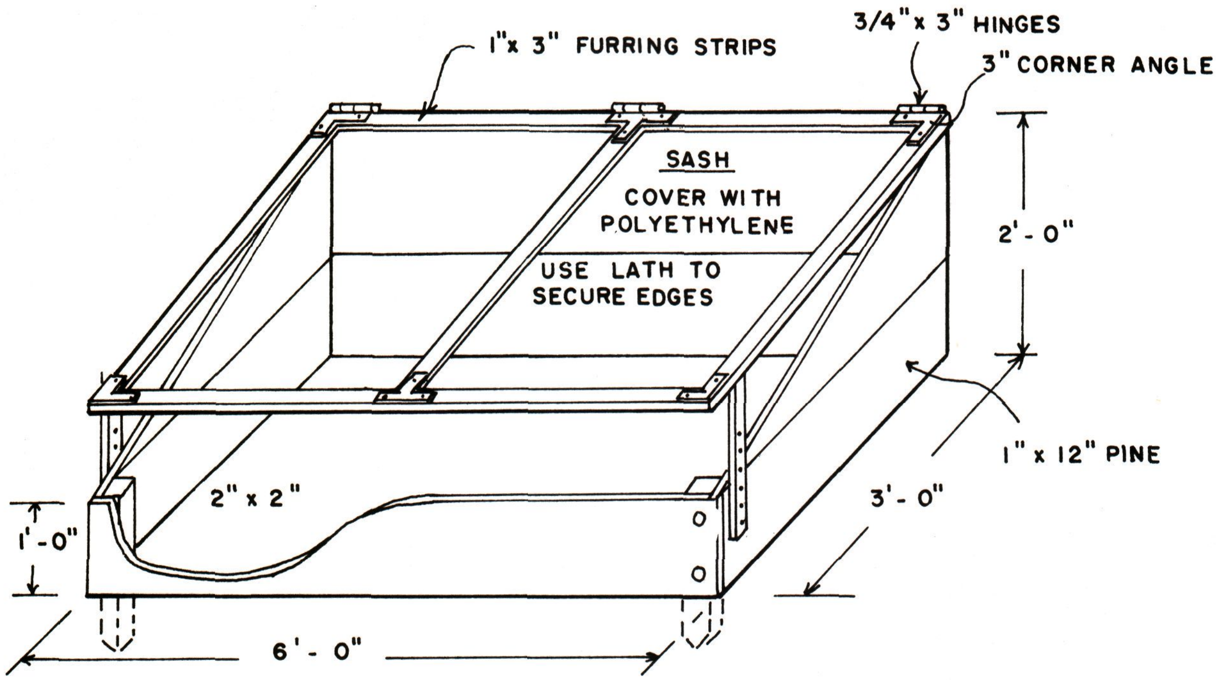
NOTE: THE SASH COVER CAN BE MADE OF ONE OF SEVERAL MATERIALS. THE STANDARD GLASS HOT BED SASH IS 3'X6' IN SIZE. IT REPRESENTS THE IDEAL COVER-LASTING MANY YEARS. IT IS SOMEWHAT EXPENSIVE, IF OLD DISCARDED WINDOW SASH ARE AVAILABLE, USE THEM. BUILD FRAME TO FIT SASH. INEXPENSIVE COVERS CAN BE MADE WITH 4 OR 6 MIL. PLASTIC TACKED ON A LIGHT HOMEMADE FRAME, IT CAN BE MADE IN MANY DIFFERENT SIZES. THIS IS SATISFACTORY FROM STANDPOINT OF LIGHT, BUT IS SHORT LIVED, USUALLY TWO SEASONS.

BASED ON: MISS. STATE UNIV. PLAN 6080-A

COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS
UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING AND

HOT-BED

MISS.	'74	6206	SHEET 1 OF 1



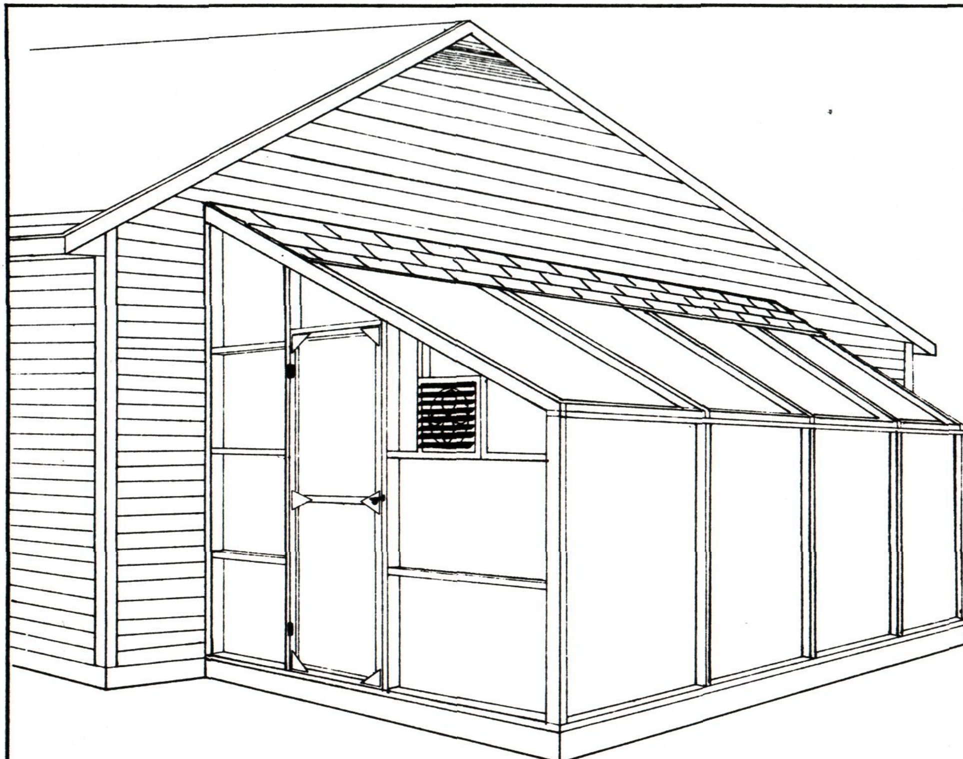
BILL OF MATERIALS

27 LINEAR FEET	1" X 12" NO. 3 PINE OR SPRUCE
8 " "	2" X 2" SPRUCE OR FIR
24 " "	1" X 3" FURRING STRIPS
21 " "	1/4" X 1 1/2" LATH
6	3" X 3" CORNER ANGLES
3	3/4" X 3" STEEL HINGES
4' X 6' PIECE	6 MIL. POLYETHYLENE PLASTIC
30	1 1/2" X NO. 10 FLAT HEAD WOOD SCREWS
3 OZ.	3/4" WIRE NAILS
1/2 GAL.	COPPER NAPTHANATE WOOD PRESERVATIVE
1 QT.	WHITE PAINT

CONSTRUCTION NOTES

1. TREAT ALL LUMBER WITH 3 COATS OF COPPER NAPTHANATE (2 0%)
2. IF DESIRED, PAINT WOOD AFTER TREATING
3. DISASSEMBLE AND STORE AFTER GROWING SEASON
4. LINE INSIDE WITH 1" BOARD INSULATION
5. BIRM OUTSIDE WITH SOIL
6. FOR WINTER USE, COVER AT NIGHT WITH BLANKET OR INSULATION

COLD FRAME
CT - SP 59 8
page one of one



CONSTRUCTION NOTES

GENERAL

SELECT A LEVEL, WELL DRAINED SITE.
PREFERRED LOCATION: SOUTH OR SOUTHEAST, EAST, WEST.
PAINT POSTS, BENCHES AND LUMBER THAT IS NEAR THE GROUND WITH THREE COATS OF COPPER NAPTHENATE WOOD PRESERVATIVE.

FRAME

USE CONSTRUCTION GRADE FIR LUMBER.
PAINT FRAME WITH AN EXTERIOR WHITE PAINT.
DOOR CAN BE PLACED AT EITHER END.
USE FLASHING BETWEEN HOUSE WALL AND GREENHOUSE ROOF.
CAULK ALL CRACKS.

COVERING

ROUND AND SMOOTH ALL EDGES
FOR SPRING AND FALL USE, USE SINGLE LAYER OF 6 MIL POLYETHYLENE PLASTIC HELD IN PLACE BY 1"x2" FIRRING STRIPS.
FOR YEAR AROUND USE 2 LAYERS OF POLYETHYLENE WITH UV INHIBITOR SEPARATED BY A 2"x2" SPACER.
PLASTIC SHOULD BE APPLIED IN SEPTEMBER OR OCTOBER.
5 OZ. CLEAR FIBERGLASS CAN BE USED AS A COVERING TO REDUCE MAINTENANCE.

WALKS

A CENTER WALK OF PEA STONE OR BRICKS LAID IN SAND CAN BE ADDED AFTER THE GREENHOUSE IS BUILT.

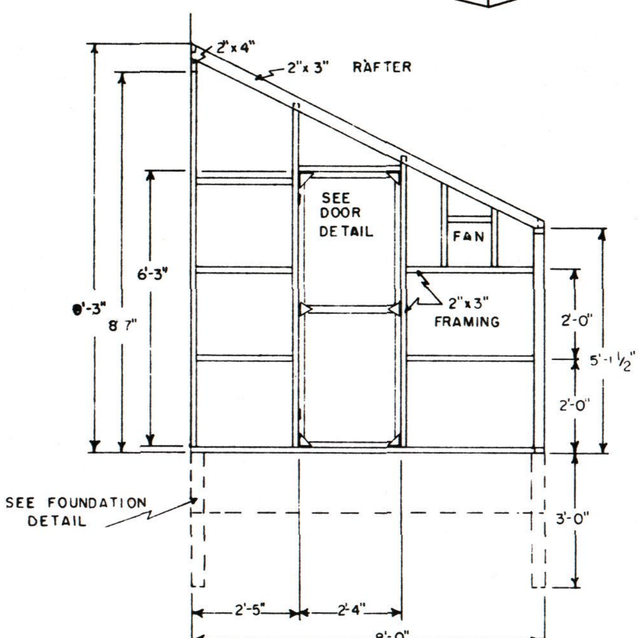
VENTILATION

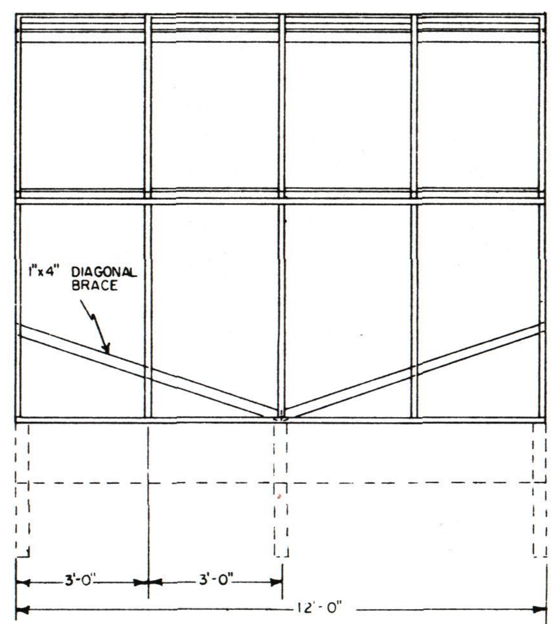
A 10 INCH DIAMETER FAN WITH AUTOMATIC BLOWER AND THERMOSTAT SHOULD BE USED.
LOCATE A 10 OR 12 INCH INTAKE LOUVER ON OPPOSITE END WALL.
PLACE THERMOSTAT ALONG SIDE WALL NEAR PLANT LEVEL.

HEAT

HEAT MAY BE SUPPLIED FROM THE HOME HEATING SYSTEM OR FROM A SEPARATE HEATER. OUTPUT REQUIRED CAN BE OBTAINED FROM THE FOLLOWING TABLE.

MINIMUM OUTSIDE TEMPERATURE °F	SINGLE LAYER PLASTIC OR FIBERGLASS BTU/HR			DOUBLE LAYER PLASTIC BTU/HR		
30°	8960	13780	17820	5940	9160	11900
20°	13780	17820	22360	9160	11900	15340
10°	17820	22360	26780	11900	15340	17800
0°	22360	26780	31200	15340	17800	20800
-10°	26780	31200	35750	17800	20800	23720
MINIMUM NIGHT TEMPERATURE	50°	60°	70°	50°	60°	70°

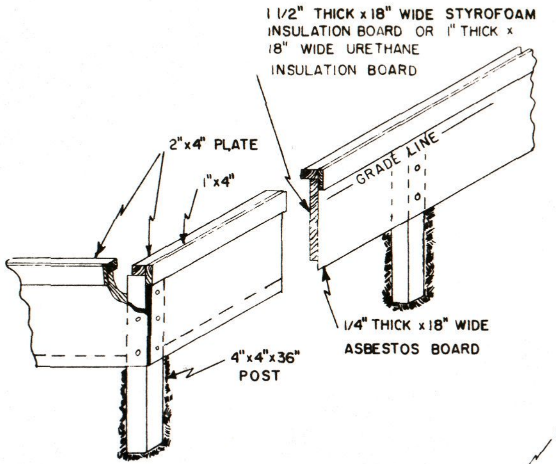




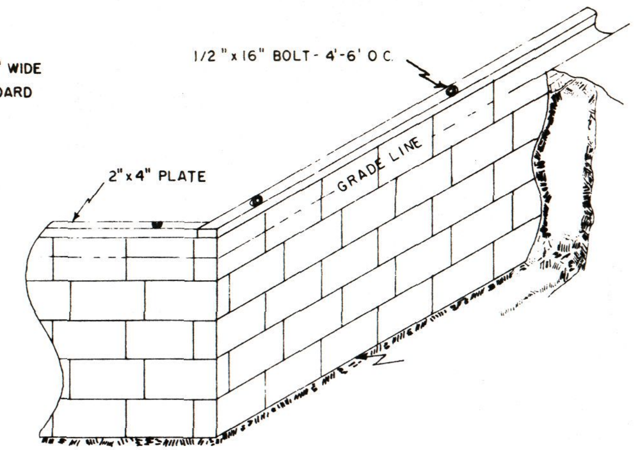
COOPERATIVE EXTENSION WORK IN
AGRICULTURE AND HOME ECONOMICS
AGRICULTURAL ENGINEERING DEPARTMENT
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT
AND
U. S. DEPARTMENT OF AGRICULTURE COOPERATING

8'x12' LEAN-TO GREENHOUSE

DR. BY JWB	CK. BY	SHEET 1 OF 2
SCALE 1/2"=1'-0	DATE 11-28-72	PLAN # 248



POST FOUNDATION DETAIL

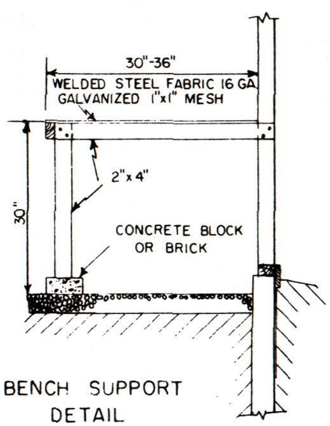


CEMENT BLOCK FOUNDATION
(ALTERNATE METHOD)

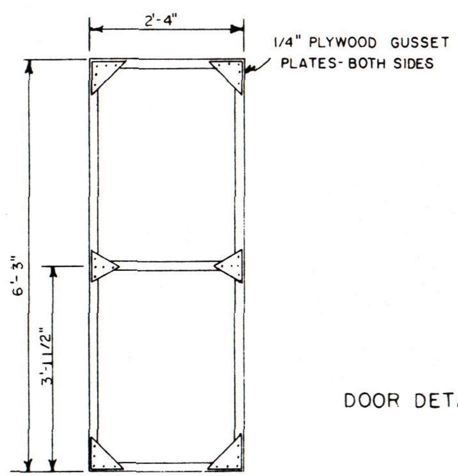
BILL OF MATERIALS

QUANTITY	ITEM	LOCATION
5 PCS	4"x 4" x 3'	POSTS
5 PCS	2"x3"x14'	RAFTER AND SIDEWALL
1 PC	2"x4"x 12'	HOUSE WALL PLATE
3 PCS	2"x3"x 12'	BASE
2 PCS	2"x 3"x 8'	BASE
10 PCS	2"x 3"x 10'	END WALLS
2 PCS	2"x2"x 12'	DOOR
	1/4" EXTERIOR PLYWOOD SCRAPS	DOOR
1 PC	1"x 4"x 14'	DIAGONAL BRACE
200 LIN. FT.	1"x 2" FIRRING STRIPS	BATTENS
1/2 GALLON	COPPER NAPTHENATE WOOD PRESERVATIVE	BASE
1 GALLON	WHITE EXTERIOR PAINT	ALL FRAMEWORK
1 PR	3" STEEL BUTT HINGES	DOOR
1	DOOR LATCH	DOOR
1 ROLL	10'x50' 6 MIL POLYETHYLENE PLASTIC	COVERING - SINGLE LAYER
3 LBS	10 D GALVANIZED COMMON NAILS	FRAME
2 LBS	6 D DUPLEX HEAD NAILS	BATTENS

50



BENCH SUPPORT DETAIL

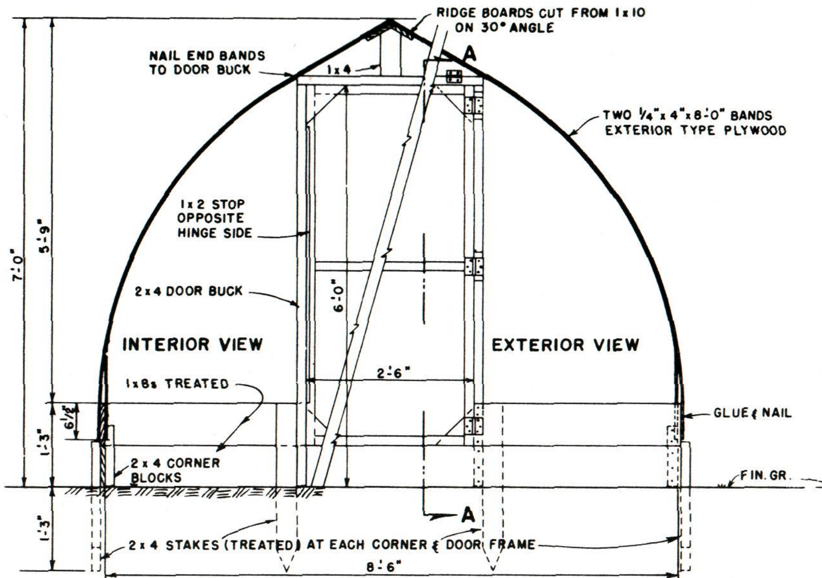


DOOR DETAIL

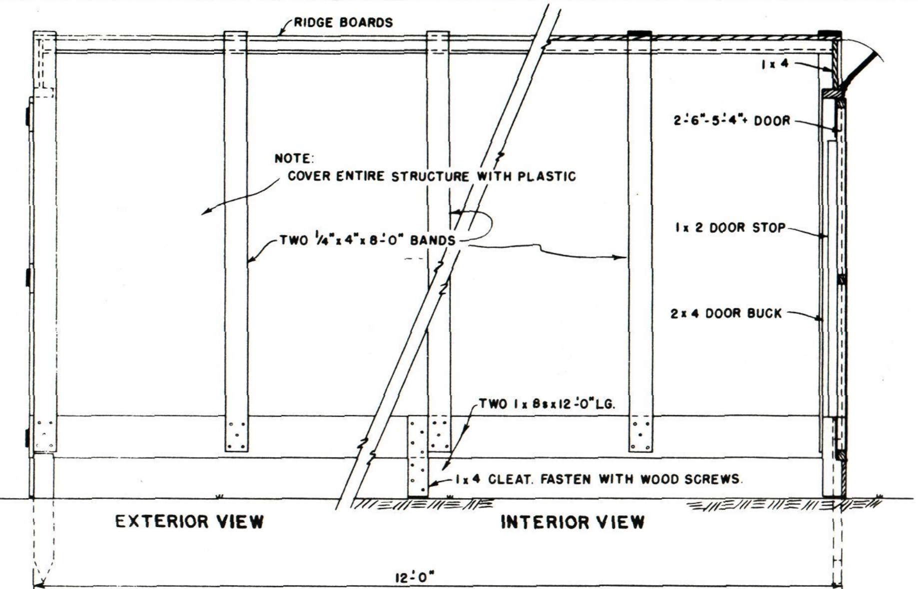
COOPERATIVE EXTENSION WORK IN
AGRICULTURE AND HOME ECONOMICS
AGRICULTURAL ENGINEERING DEPARTMENT
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT
AND
U. S. DEPARTMENT OF AGRICULTURE COOPERATING

8'x12' LEAN-TO GREENHOUSE

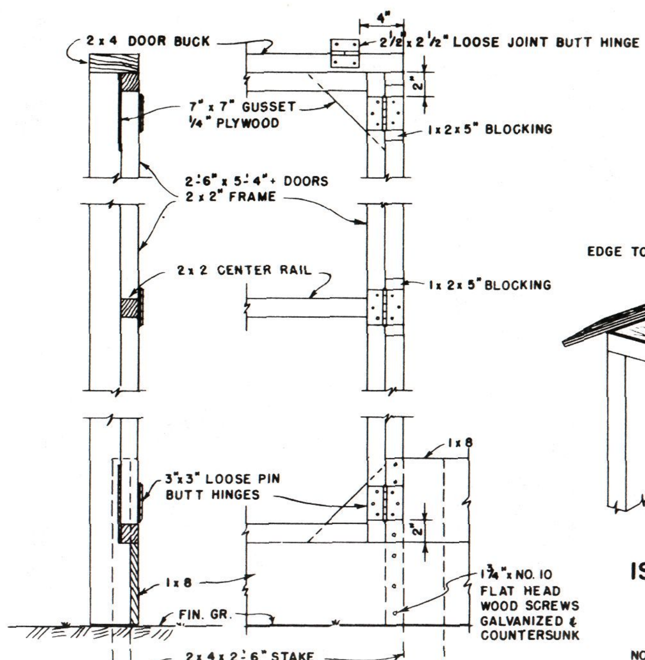
DR. BY JWS	CK. BY	SHEET 2 OF 2
SCALE 1/2"=1'0"	DATE 11-28-72	PLAN # 248



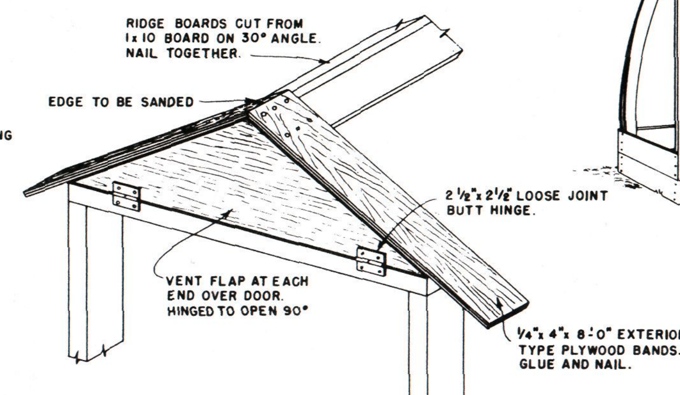
END ELEVATION



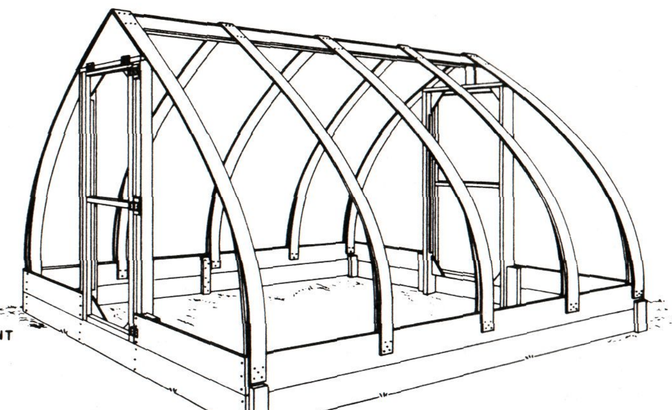
SIDE ELEVATION



SECTION A-A



ISOMETRIC OF GABLE



PERSPECTIVE

NOTE: COVER DOOR WITH PLASTIC.
FASTEN ENTIRE STRUCTURE TOGETHER WITH WOOD SCREWS UNLESS OTHERWISE NOTED.
ALL SCREWS TO BE GALVANIZED

BASED ON ORE. PLAN 73

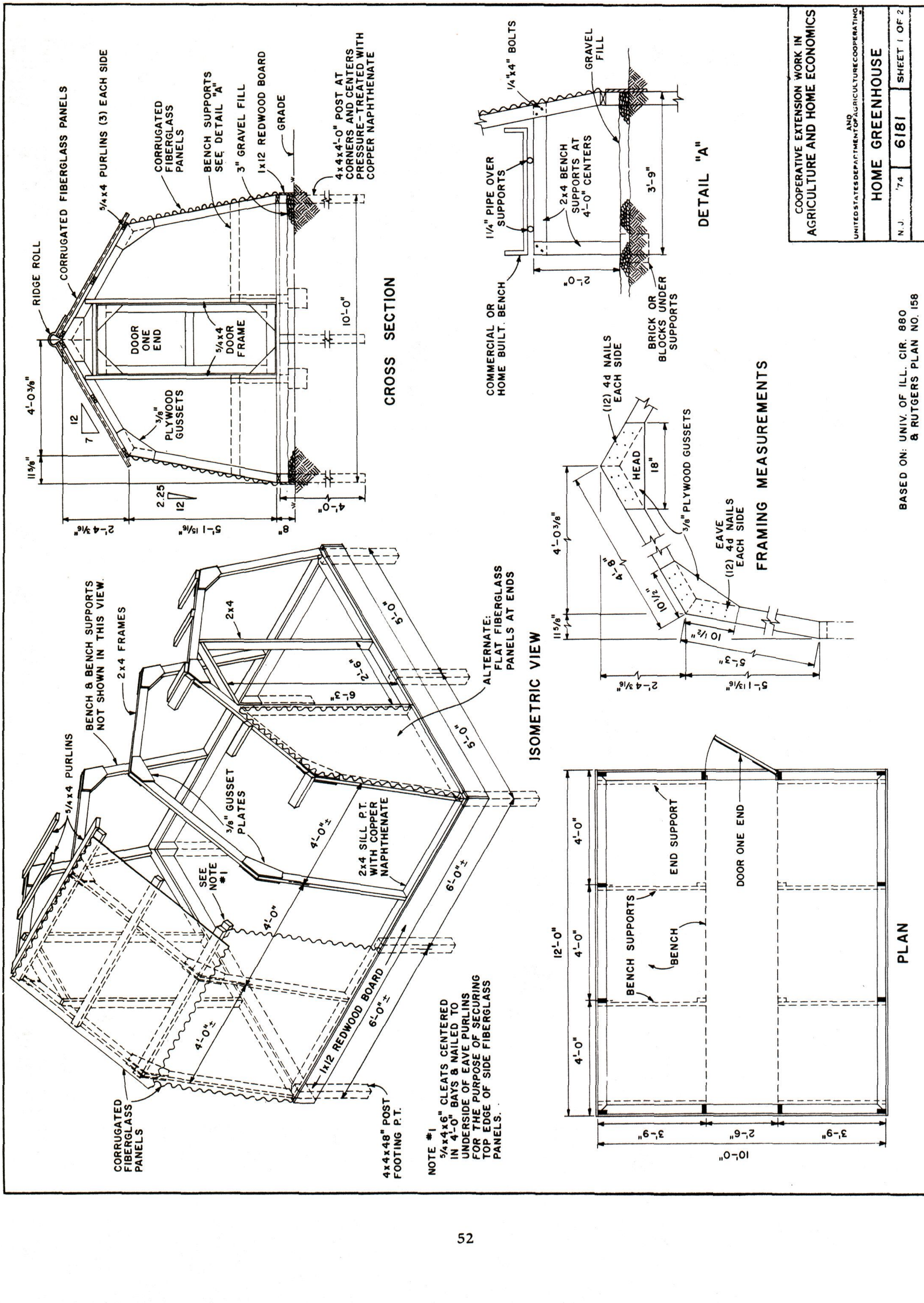
COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS

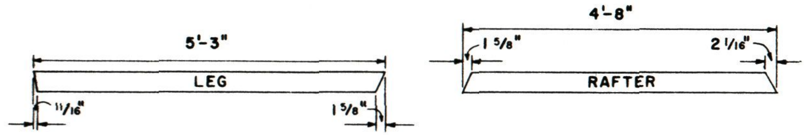
AND

UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

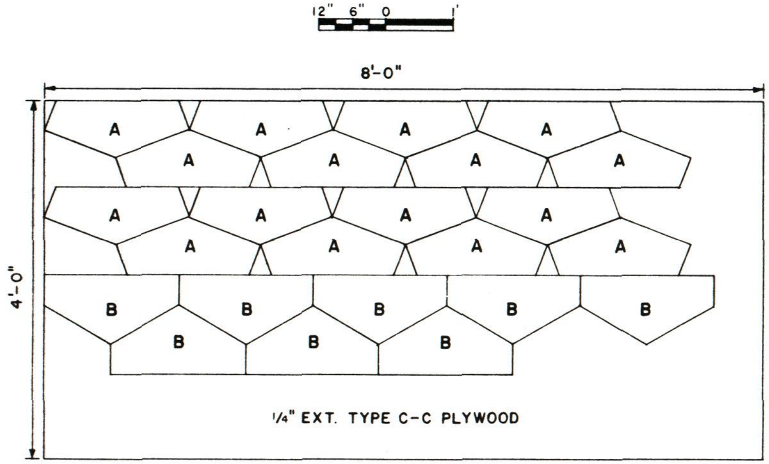
PORTABLE PLASTIC GREENHOUSE

USDA '63	EX. 5946	SHEET 1 OF 1

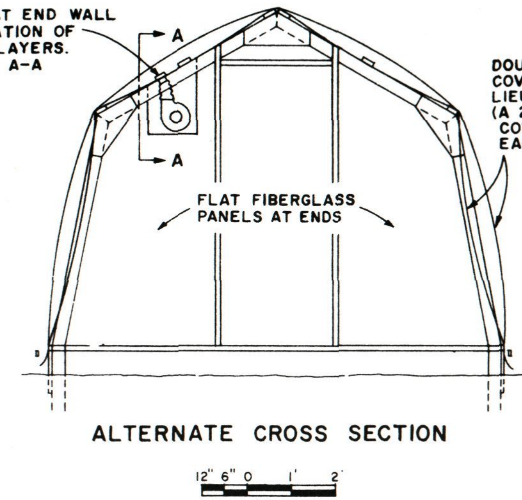

COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS
UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING AND
HOME GREENHOUSE
N.J. '74
6181
SHEET 1 OF 2
CROSS SECTION
RIDGE ROLL
CORRUGATED FIBERGLASS PANELS
5/4x4 PURLINS (3) EACH SIDE
CORRUGATED FIBERGLASS PANELS
BENCH SUPPORTS SEE DETAIL "A"
3" GRAVEL FILL
1x12 REDWOOD BOARD
GRADE
4x4x4'-0" POST AT CORNERS AND CENTERS PRESSURE-TREATED WITH COPPER NAPHTHENATE
DOOR ONE END
5/4x4 DOOR FRAME
3/8" PLYWOOD GUSSETS
4'-0 3/8"
11 5/8"
2.25
12
7
10'-0"
4'-0"
2'-4 3/16"
5'-1 15/16"
8"
DETAIL "A"
1/4"x4" BOLTS
GRAVEL FILL
1 1/4" PIPE OVER SUPPORTS
2x4 BENCH SUPPORTS AT 4'-0" CENTERS
COMMERCIAL OR HOME BUILT BENCH
BRICK OR BLOCKS UNDER SUPPORTS
2'-0"
3'-9"
FRAMING MEASUREMENTS
(12) 4d NAILS EACH SIDE
HEAD
18"
3/8" PLYWOOD GUSSETS
EAVE
(12) 4d NAILS EACH SIDE
4'-0 3/8"
4'-8"
10 1/2"
11 5/8"
10 1/2"
5'-3"
2'-4 3/16"
5'-1 13/16"
ISOMETRIC VIEW
5/4x4 PURLINS
BENCH & BENCH SUPPORTS NOT SHOWN IN THIS VIEW.
2x4 FRAMES
2x4
3/8" GUSSET PLATES
SEE NOTE #1
2x4 SILL P.T. WITH COPPER NAPHTHENATE
ALTERNATE: FLAT FIBERGLASS PANELS AT ENDS
2'-9"
6'-3"
5'-0"
5'-0"
4'-0"±
4'-0"
4'-0"±
6'-0"±
6'-0"±
1x12 REDWOOD BOARD
CORRUGATED FIBERGLASS PANELS
4x4x48" POST FOOTING P.T.
NOTE #1
5/4x4x6" CLEATS CENTERED IN 4'-0" BAYS & NAILED TO UNDERSIDE OF EAVE PURLINS FOR THE PURPOSE OF SECURING TOP EDGE OF SIDE FIBERGLASS PANELS.
PLAN
END SUPPORT
DOOR ONE END
BENCH SUPPORTS
BENCH
12'-0"
4'-0"
4'-0"
4'-0"
3'-9"
2'-6"
3'-9"
10'-0"
BASED ON: UNIV. OF ILL. CIR. 880 & RUTGERS PLAN NO. 158



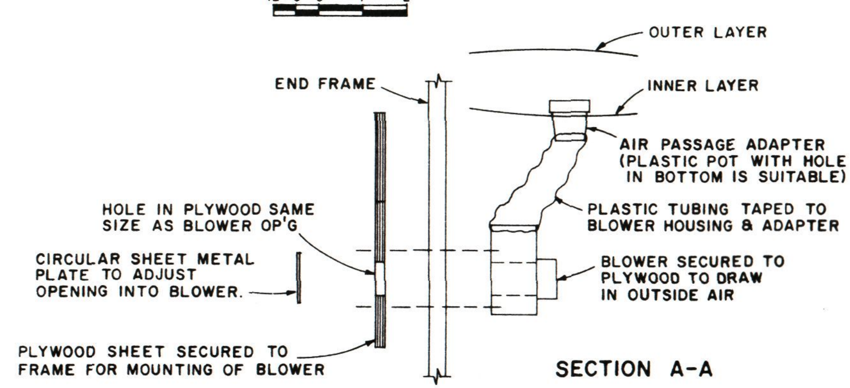
FRAME CUTTING LAYOUT (CUT FROM (8) 2x4x10')



PLYWOOD SHEET CUTTING DIAGRAM



ALTERNATE CROSS SECTION



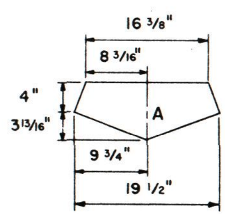
SECTION A-A

BILL OF MATERIALS

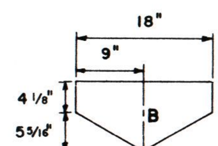
CORRUGATED FIBERGLASS REINFORCED PANELS (F.R.P.) *
5 OZ. COATING:

ROOF PANELS (6) 2'x10' CUT IN HALF
SIDE PANELS (5) 2'x12', 2 SHEETS EACH SIDE
5 TH SHEET CUT LENGTHWISE
END PANELS (9) 2'x8' OF WHICH 5 ARE LOCATED
AT END WITH NO DOOR
RIDGE ROLL (1) 12' LENGTH

LUMBER:
(8) 2x4x10' TO MAKE FRAMES
(2) 2x4x10' SILL AT ENDS (P.T. COPPER NAPHTHENATE)
(2) 2x4x12' SILL AT SIDES (P.T. COPPER NAPHTHENATE)
(2) 2x4x16' END FRAMING
BENCH SUPPORTS NOT INCLUDED
(8) 5/4x4x12' FOR PURLINS & DOOR
(2) 4x4x16' P.T. POST FOR FOOTINGS
(2) 1x12x12' & (2) 1x12x10' REDWOOD BOARDS
(1) 4'x8'x1/4" EXTERIOR TYPE CC PLYWOOD SHEET FOR PLYWOOD GUSSETS. SEE CUTTING DIAGRAM.
* CHECK WITH FIBERGLASS SUPPLIER FOR NECESSARY RELATED HARDWARE & COVERING INSTRUCTIONS.
NAILS, HINGES & LATCH.



SIDE GUSSETS
16 REQ'D



HEAD GUSSETS
8 REQ'D

ENVIRONMENTAL CONTROL

HEATING:
TO MAINTAIN A TEMPERATURE DIFFERENCE OF 60° BETWEEN INSIDE & OUTSIDE
30,000 BTU/HR. SINGLE COVERING
20,000 BTU/HR. DOUBLE COVERING
CONNECTION TO HOME HEATING SYSTEM IS MOST DESIRABLE. IF NOT POSSIBLE, USE GAS OR OIL HEATER VENTED TO THE OUTSIDE. ELECTRIC HEATERS ARE EASY TO INSTALL, CLEAN, BUT EXPENSIVE TO OPERATE. WHEN USING OIL OR GAS, BE SURE TO PROVIDE A FRESH AIR SUPPLY DIRECTLY TO THE HEATER TO SUPPLY OXYGEN FOR COMBUSTION.

VENTILATING:
REQUIRE A TWO SPEED FAN RATED AT 1000 CFM. AN AUTOMATIC AIR INLET OF 2 SQ. FT. IS REQUIRED. THE FAN CAN BE MOUNTED IN ONE GABLE END AND AIR INLET IN THE OTHER. BOTH SHOULD BE CONTROLLED BY A THERMOSTAT.

FOR MORE INFORMATION SEE USDA BULLETIN NUMBER 357 "BUILDING HOBBY GREENHOUSES."

COOPERATIVE EXTENSION WORK IN
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AND
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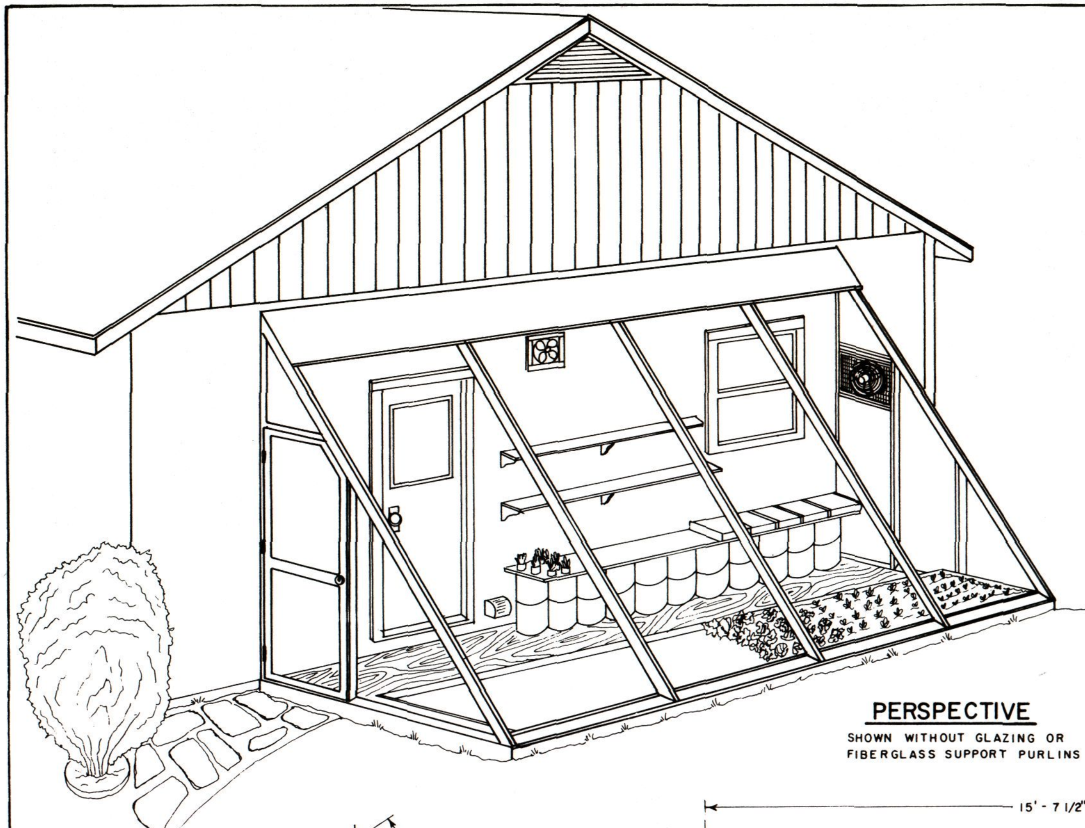
HOME GREENHOUSE

N.J.	'74	6181	SHEET 2 OF 2



PERSPECTIVE

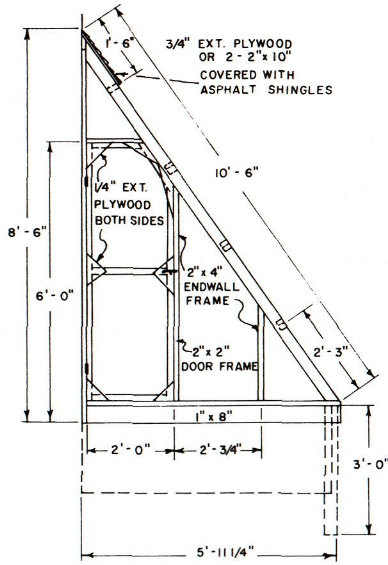
SHOWN WITHOUT GLAZING OR FIBERGLASS SUPPORT PURLINS

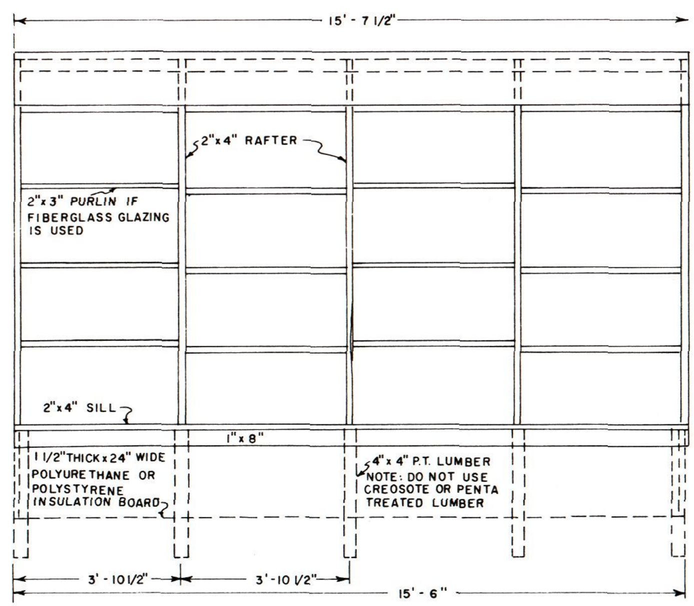
MATERIALS LIST

14	2" x 4" x 10'	RAFTERS - DOOR - ENDWALL - SILL
1	2" x 4" x 12'	SILL
1	4" x 4" x 16'	POSTS
8	2" x 3" x 8'	PURLINS (IF FIBERGLASS GLAZING IS USED)
2	1" x 8" x 8'	FOUNDATION
3	1" x 8" x 12'	FOUNDATION - GROUND BED
4	1" x 10" x 8'	ROOF
2 SHTS	4' x 8' x 1 1/2"	POLYSTYRENE INSULATION
1 PR	4"	BUTT HINGES
1		DOOR LATCH
		ASSORTED COMMON NAILS - 6D, 8D, 16D

GLAZING

4 SHTS	4' x 8' - 5 oz	CLEAR CORRUGATED FIBERGLASS REINFORCED PLASTIC
1 ROLL	4' x 25' - 4 oz	CLEAR FLAT FIBERGLASS REINFORCED PLASTIC
300	1 1/4"	ALUMINUM NAILS WITH NEOPRENE WASHERS
30'		CORRUGATED RUBBER SEALING STRIPS
		OR
1 ROLL	10' x 100' 6 MIL	GREENHOUSE GRADE POLYETHLENE FILM
200'	1" x 3"	FURRING STRIPS TO ATTACH POLY OUTSIDE & INSIDE





COOPERATIVE EXTENSION WORK IN
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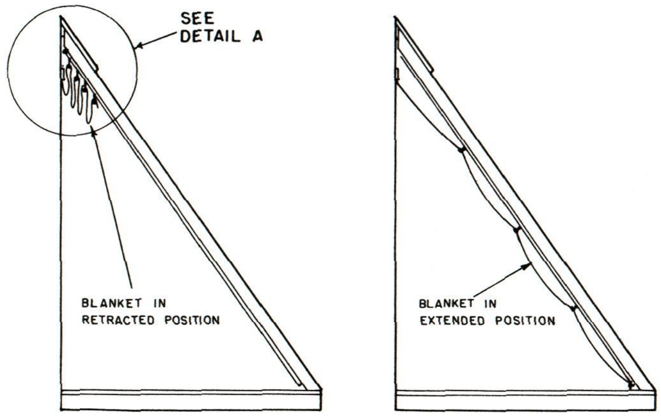
AGRICULTURAL ENGINEERING DEPARTMENT
UNIVERSITY OF CONNECTICUT
STORRS, CONNECTICUT
AND
U.S. DEPARTMENT OF AGRICULTURE COOPERATING

ATTACHED GREENHOUSE & SOLAR COLLECTOR

DR. BY J. BARTOK	CK. BY R. ALDRICH	SHEET 1 OF 2
SCALE AS SHOWN	DATE 4 - 82	PLAN 252



CONSTRUCTION NOTES

GENERAL

OBTAIN BUILDING PERMIT IF REQUIRED.
SELECT A SITE WITH SOUTH, SOUTHEAST OR SOUTHWEST EXPOSURE.
PROVIDE ADEQUATE DRAINAGE.
USE PRESSURE TREATED LUMBER OR TREAT WOOD IN CONTACT WITH THE GROUND WITH COPPER NAPTHENATE WOOD PRESERVATIVE.
PAINT FRAME WITH AN EXTERIOR WHITE PAINT.
DOOR CAN BE LOCATED AT EITHER END.
USE FLASHING BETWEEN HOUSE AND GREENHOUSE ROOF.

COVERING

ROUND AND SMOOTH ALL EDGES.
USE A DOUBLE LAYER OF 6 MIL GREENHOUSE GRADE POLYETHYLENE PLASTIC - AVAILABLE FROM GREENHOUSE SUPPLIERS - ONE LAYER INSIDE, ONE LAYER OUTSIDE. FASTEN WITH FURRING STRIPS.
ALTERNATE COVERINGS - CLEAR FIBERGLASS REINFORCED PLASTIC (FRP), DOUBLE WALL ACRYLIC OR POLYCARBONATE.

WALKS

AREAS OTHER THAN BEDS CAN BE COVERED WITH BRICKS, FLAGSTONE OR PEA STONE OVER SAND BASE.

VENTILATION

A 10" - 1/20 HP SHUTTER MOUNTED FAN WITH INTAKE LOUVER AND THERMOSTAT SHOULD BE USED FOR SUMMER VENTILATION. SHADE THERMOSTAT FROM DIRECT SUNLIGHT.
TOBACCO NETTING OR POLYPROPLENE SARAN SHADE CAN BE USED TO REDUCE SUMMER HEAT.

ENERGY CONSERVATION

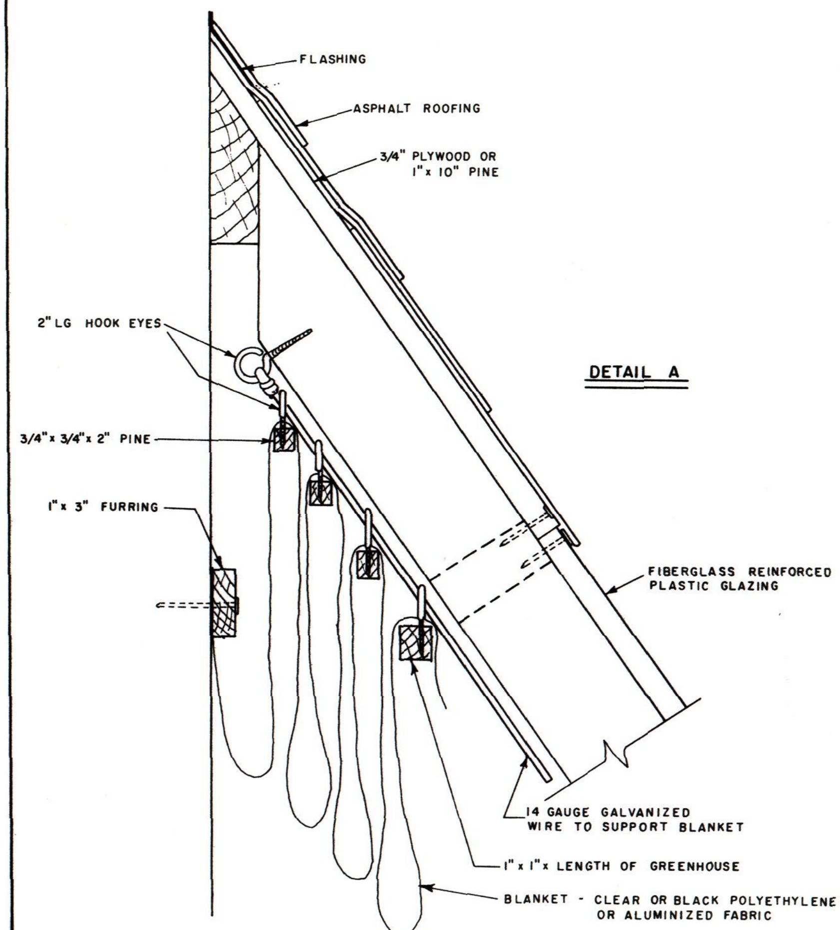
FIXED OR REMOVABLE POLYSTYRENE INSULATION PANELS CAN BE USED ON ALL OR PART OF ENDWALLS.
CAULK ALL CRACKS.

HEAT STORAGE

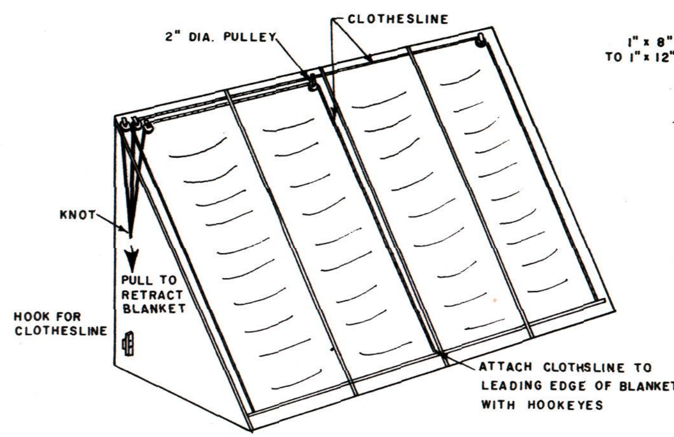
IF GREENHOUSE IS TO BE USED FOR GROWING PLANTS PROVIDE 150 TO 200 GALLONS OF WATER IN ONE OR FIVE GALLON CONTAINERS.
IF GREENHOUSE IS TO BE USED FOR HEATING THE HOME NO STORAGE IS NECESSARY AND HEAT TRANSFER CAN BE ACCOMPLISHED WITH AN 8 OR 10 INCH DIAMETER ROOM TO ROOM FAN LOCATED NEAR THE CEILING AND AN 8 TO 10 INCH SQUARE WALL LOUVER NEAR THE FLOOR.

SUPPLEMENTAL HEAT

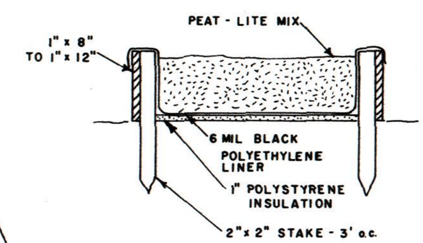
TO MAINTAIN GREENHOUSE TEMPERATURE AT 50°F AT 0°F OUTSIDE DURING EXTENDED PERIODS OF CLOUDY WEATHER, A HEATER WITH AN OUTPUT OF 6000 TO 8000 BTU/HR IS NEEDED.



DETAIL A



BLANKET RETRACTION SYSTEM



BED CONSTRUCTION

COOPERATIVE EXTENSION WORK IN
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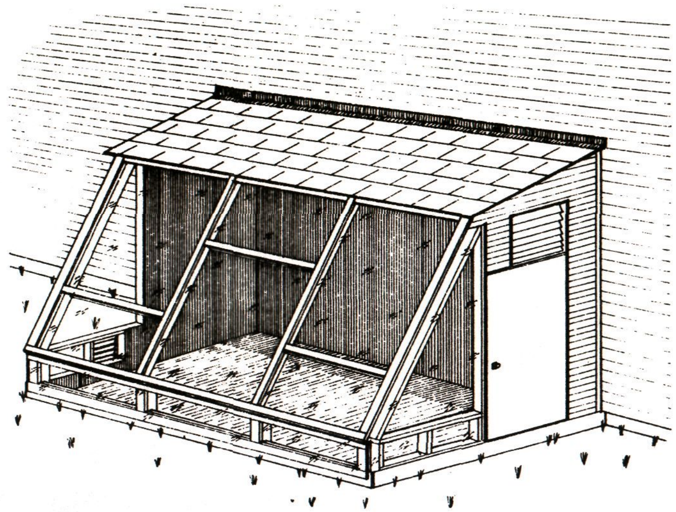
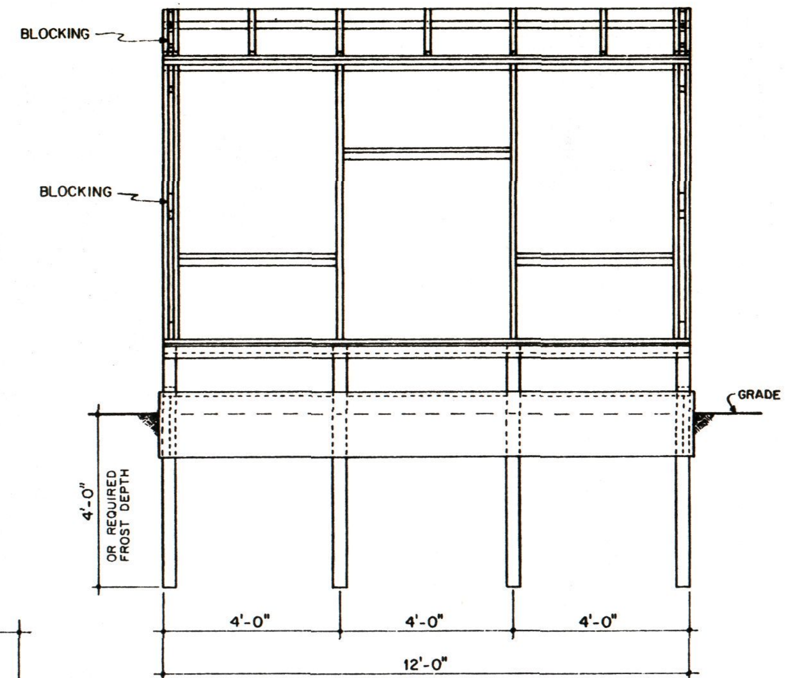
ATTACHED GREENHOUSE & SOLAR COLLECTOR

DR. BY J. BARTON	CK. BY R. ALDRICH	SHEET 2 OF 2
SCALE NONE	DATE 4 - 82	PLAN 252



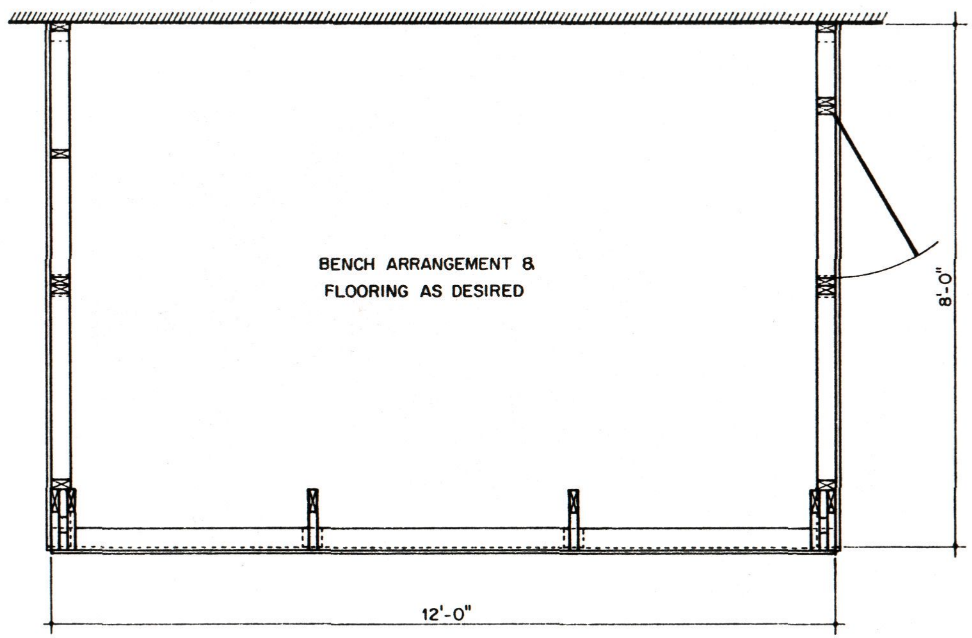
PERSPECTIVE

NO SCALE



SOUTH WALL FRAMING

SCALE: $\frac{1}{2}$" = 1'-0"



BASIC FLOOR PLAN

LENGTH MAY BE EXPANDED IN 4' INCREMENTS

SCALE: $\frac{3}{4}$" = 1'-0"

CONSTRUCTION NOTES:

1. BASIC FRAMING IS 2x4 CONSTRUCTION UNLESS OTHERWISE NOTED. USE ONLY CONSTRUCTION GRADE LUMBER.
2. ANY LUMBER IN CONTACT WITH SOIL SHOULD BE PRESSURE TREATED. CREOSOTE OR PENTACHLOROPHENOL SHOULD NOT BE USED.
3. UNGLAZED INTERIOR WALLS AND CEILING TO BE INSULATED AND COVERED.
4. ALL EXPOSED LUMBER SHOULD BE PROTECTED WITH A COAT OF PRIMER AND/OR AN OIL-BASE PAINT. THE FINAL COAT OF PAINT SHOULD BE WHITE.
5. IF TREATED LUMBER IS CUT, MAKE SURE CUT SURFACES ARE PROTECTED OR NOT INSERTED INTO THE GROUND.
6. COMPACTED CRUSHED GRAVEL OR CONCRETE FOOTINGS MAY BE RECOMMENDED.
7. USE FLASHING AND/OR CAULKING TO PROTECT ALL JOINTS.
8. SIDEWALL FRAMING MAY BE ADJUSTED TO SUIT DOORS, VENTS, FANS, ETC.

CHECK WITH YOUR BUILDING INSPECTOR BEFORE CONSTRUCTION

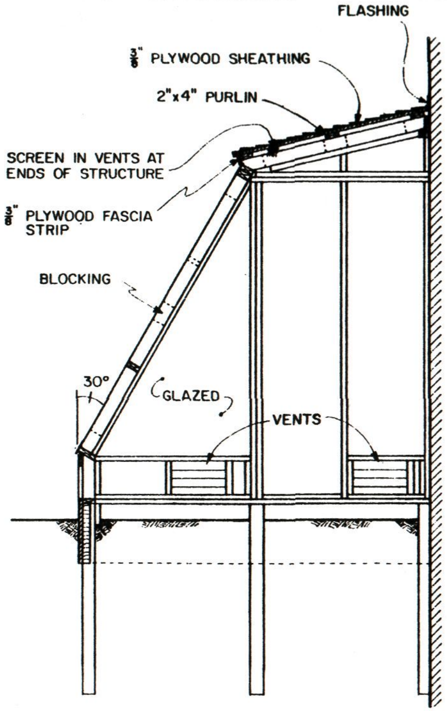
COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS

FOOD ENGINEERING DEPARTMENT
UNIVERSITY OF MASSACHUSETTS

UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

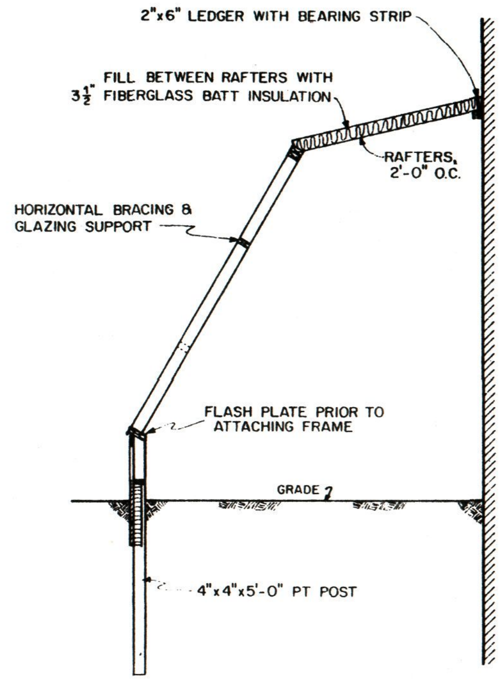
8' x 12' ATTACHED SOLAR GREENHOUSE

SCALE: AS SHOWN	MC 2801	SHEET 1 OF 3
DES. BY RFR	DRN. BY RJG	CHK. BY RFR



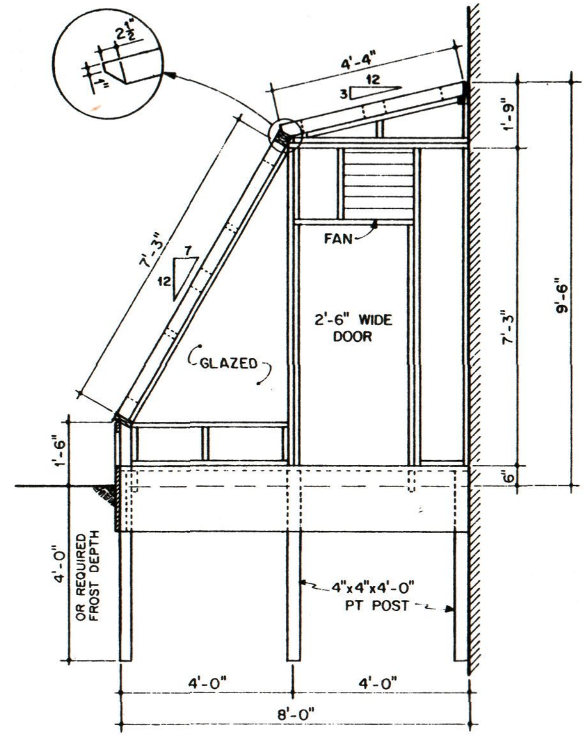
WEST WALL FRAMING

SCALE: 1/2" = 1'-0"



CROSS-SECTION

SCALE: 1/2" = 1'=0"

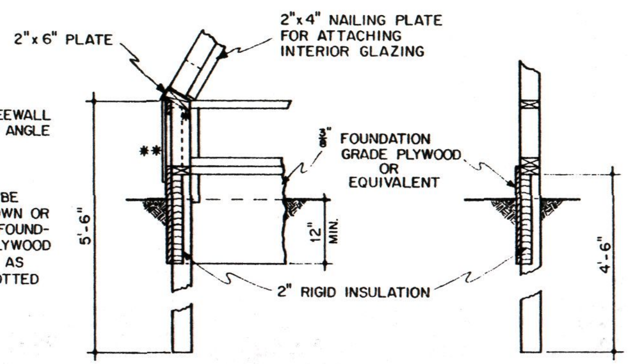


EAST WALL FRAMING

SCALE: 1/2" = 1'=0"

* CUT TOP OF KNEEWALL POSTS AT A 30° ANGLE AS SHOWN

** KNEEWALL CAN BE GLAZED AS SHOWN OR COVERED WITH FOUNDATION GRADE PLYWOOD AND INSULATED AS SHOWN WITH DOTTED LINES



KNEEWALL AND FOUNDATION DETAILS

SCALE: 3/4" = 1'-0"

IMPORTANT NOTE:

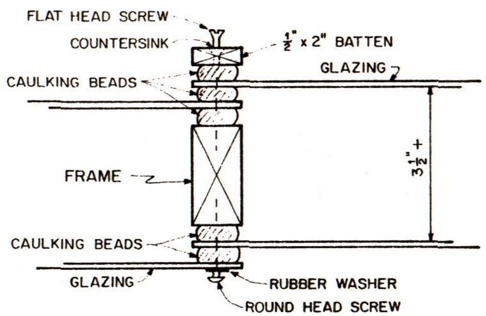
EXTERIOR / INTERIOR FINISH MATERIALS, PLUMBING, WIRING, ETC. ARE OWNER / BUILDER'S RESPONSIBILITIES. TAKE INTO ACCOUNT THE UNIQUE CHARACTERISTICS OF THE GREENHOUSE ENVIRONMENT WHEN MAKING THESE DECISIONS.

A SUPPLEMENTAL NARRATIVE IS AVAILABLE IN CONJUNCTION WITH THIS PLAN

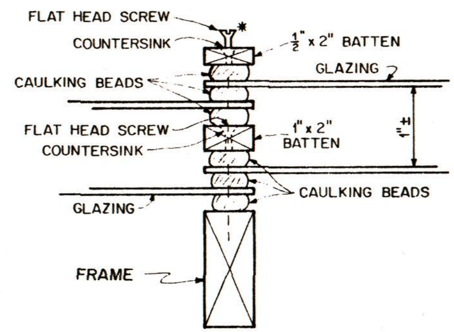
COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS
FOOD ENGINEERING DEPARTMENT
UNIVERSITY OF MASSACHUSETTS
UNITED STATES DEPARTMENT OF AGRICULTURE AND COOPERATING

8'x 12' ATTACHED SOLAR GREENHOUSE		
SCALE: AS SHOWN	MC 2801	SHEET 2 OF 3
DES. BY RFR	DRN. BY RJG	CHK. BY RFR

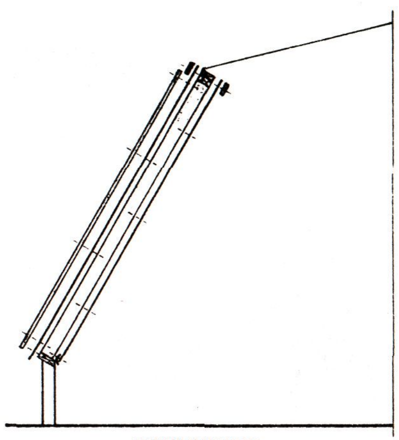
*SPACE SCREWS ALTERNATELY WITH SCREWS IN MIDDLE BATTEN



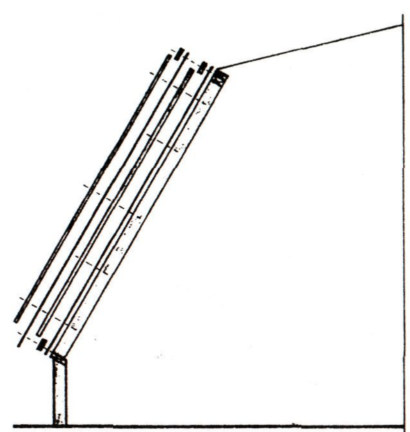
METHOD A



METHOD B



RECOMMENDED



OPTIONAL

EXPLODED VIEWS OF GLAZING DETAILS

NO SCALE

INSULATION NOTES:

1. 3½" FIBERGLASS BATT INSULATION IS RECOMMENDED IN OPAQUE WALLS AND CEILING.
2. OPAQUE WALLS AND CEILING TO BE SEALED WITH 4-MIL POLYETHYLENE VAPOR BARRIER.
3. MOVEABLE INSULATION SUCH AS INSULATED SHUTTERS OR THERMAL BLANKETS ARE RECOMMENDED FOR GLAZED AREAS.
4. RECOMMEND: 2" EXTRUDED POLYSTYRENE INSULATION ALONG FOUNDATION CURTAIN WALL. BURY 12"-18" BELOW GRADE.

VENTILATION NOTES:

1. USE FORCED VENTILATION (FAN) FOR SUMMER COOLING. PROVIDE 10-12 CFM PER SQ. FT. OF FLOOR AREA. CHOOSE A FAN RATED AT 0.125" STATIC PRESSURE.
2. WINTER VENTILATION CAN BE PROVIDED BY EXCHANGING AIR WITH MAIN STRUCTURE THROUGH A DOOR, WINDOW, OR SMALL FAN (APPROX. 100 CFM).
3. INLET VENTS MAY BE HINGED OR LOUVERED. PROVIDE APPROXIMATELY 1.3 SQ. FT. OF OPENING PER 1000 CFM OF FAN CAPACITY.
4. AUTOMATIC CONTROLS, SUCH AS THERMOSTATS, ARE HIGHLY RECOMMENDED FOR FANS, VENTS, AND AUXILLARY HEAT.
5. GREENHOUSE DOOR CAN BE USED DURING MILD WEATHER IN CONJUNCTION WITH VENTS FOR ADEQUATE VENTILATION WITHOUT OPERATING FAN. DO NOT HAVE DOOR OPEN WHEN FAN IS OPERATING.
6. PURLINS ON RAFTERS PROVIDE FOR VENTING SPACE ABOVE CEILING INSULATION. SCREEN IN, DO NOT COVER, OPENINGS AT ENDS WITH HARDWARE CLOTH.
7. SUMMER SHADING MAY BE NECESSARY TO REDUCE OVERHEATING OF STRUCTURE.

FURTHER CONSTRUCTION NOTES:

1. EXTERIOR WALL AND ROOF SHEATHING SHOULD BE AT LEAST ⅜" EXTERIOR GRADE PLYWOOD OR EQUIVALENT.
2. FASTENERS SHOULD BE MADE OF ALUMINUM, BRASS, OR GALVANIZED STEEL.
3. JOIST HANGERS AND FRAMING ANCHORS MAY BE USED TO SIMPLIFY CONSTRUCTION.
4. IF MORE INSULATION IS DESIRED, 2"x6"s MAY BE SUBSTITUTED FOR 2"x4"s USED IN ROOF RAFTERS AND SIDE WALL FRAMING.

GLAZING NOTES:

1. RECOMMEND: 2 LAYERS OF GREENHOUSE (SOLAR) GRADE FIBERGLASS (FIBER REINFORCED POLYESTER)
2. CAULK ALL JOINTS TO DISCOURAGE AIR AND MOISTURE LEAKS.
3. ALLOW THE OUTER LAYER OF GLAZING ON SOUTH WALL TO OVERHANG KNEEWALL FOR RUNOFF OF PRECIPITATION.
4. ALUMINUM BATTENS MAY BE USED IN PLACE OF WOOD BATTENS.
5. POLYCARBONATE OR ACRYLIC PANELS MAY BE SUBSTITUTED FOR FIBERGLASS. HOWEVER FRAME SPACING MUST BE ALTERED TO ACCOMMODATE THERMAL EXPANSION OF PANELS.

CAUTION:

FIBERGLASS GLAZINGS BURN QUICKLY WHEN IGNITED.

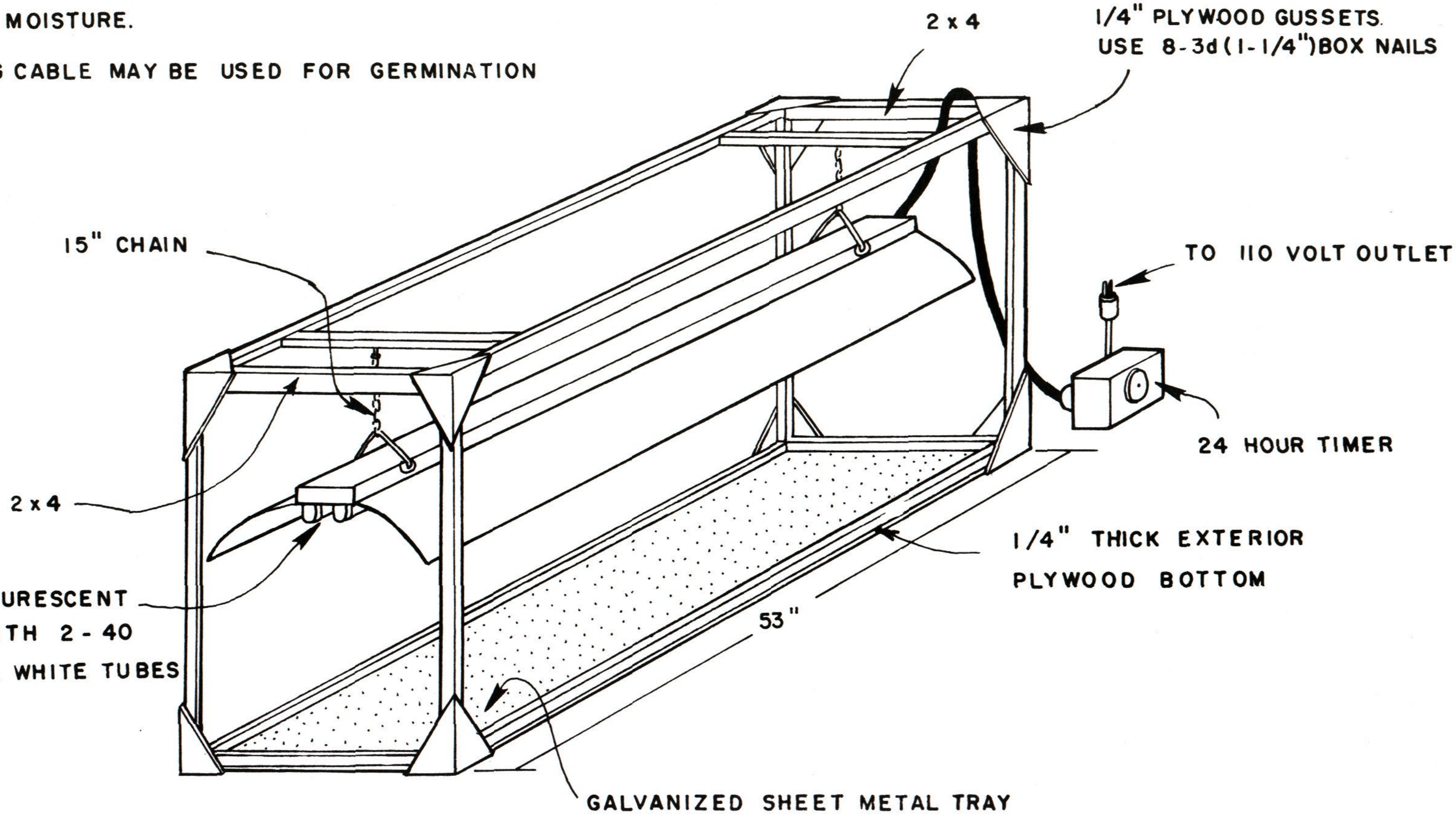
COOPERATIVE EXTENSION WORK IN AGRICULTURE AND HOME ECONOMICS
FOOD ENGINEERING DEPARTMENT
UNIVERSITY OF MASSACHUSETTS
AND
UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

8'x12' ATTACHED SOLAR GREENHOUSE		
SCALE: NONE	MC · 2801	SHEET 3 OF 3
DES. BY RFR	DRN. BY RJG	CHK. BY RFR

NOTES

1. ALL LUMBER IS 2"x 2", EXCEPT AS NOTED
2. IF STRIP FLOURESCENT FIXTURES ARE USED, COVER WITH ALUMINUM FOIL TO REFLECT LIGHT.
3. PAINT ALL WOOD WHITE
4. COVER ENTIRE UNIT WITH POLYETHYLENE TO RETAIN MOISTURE.
5. HEATING CABLE MAY BE USED FOR GERMINATION

NUMBER OF LIGHT UNITS	WIDTH	HEIGHT
1	14"	21"
2	24"	24"
3	36"	24"



GERMINATION GROWTH UNIT

CT - SP 596

page one of one

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