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Energy-conserving urban greenhouses for Canada

construction and management

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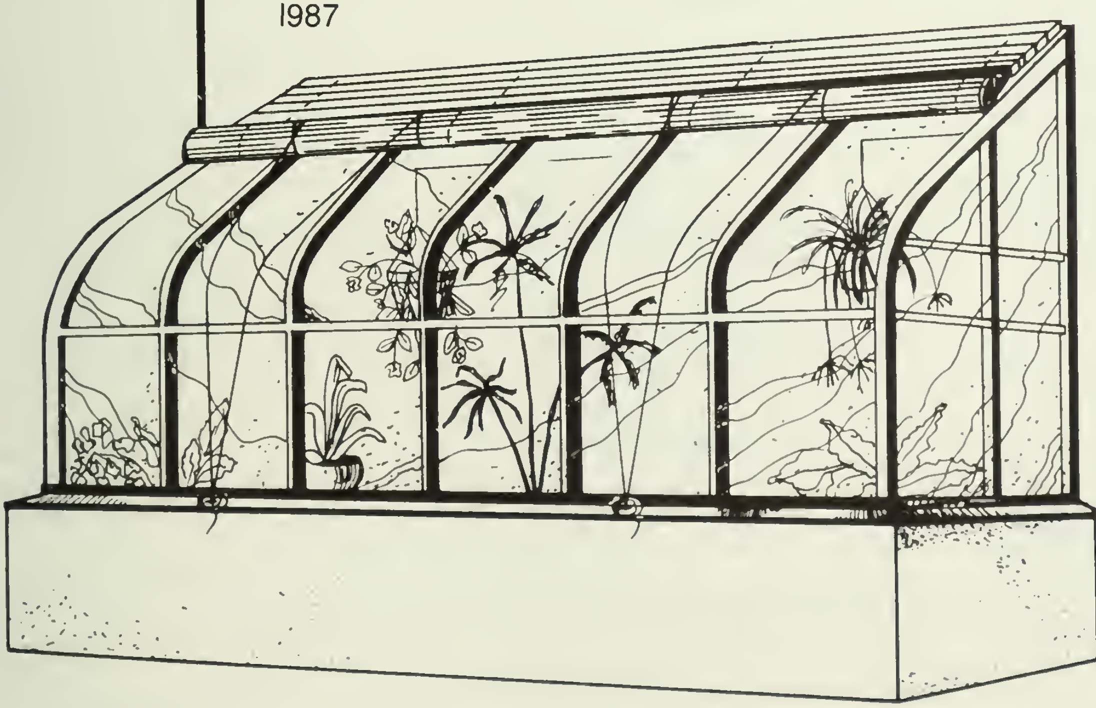

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Foreword

There is a great deal of public interest in both energy-conserving and solar greenhouses today. This interest arises from a desire to grow food at home and to attain additional home heat from a solar source. This book provides basic information on the usefulness of these greenhouses and explains the theory behind their construction and management.

Solar greenhouses, unlike conventional greenhouses, have their primary glazing area facing south. Glazing may also be placed on the roof or on part of the roof. All unglazed surfaces are well insulated to reduce heat losses. Solar greenhouses also contain some material intended mainly for heat storage, such as masonry, moist earth, or water in containers, where excess solar heat can be stored for use at night and on cloudy days. Solar greenhouses represent the optimum in energy-conserving greenhouses. However, other, more conventional structures are classed as energy-conserving greenhouses when they have provisions for seasonal addition of extra layers of glazing, insulating night curtains, foundation insulation, or wall and roof insulation. Heat bills for solar and energy-conserving greenhouses are much less than for conventional greenhouses. Both types can be designed to supply heat to an attached building, thus acting as large solar collectors. Unless stated otherwise in the text, the unmodified term "greenhouse" is used to refer to both solar and energy-conserving structures.

We have attempted to include as much information here as possible to allow the reader to determine whether such a greenhouse would be a worthwhile endeavor. The amount of personal effort required at each step along the way and the costs and benefits of operating a greenhouse are explained. This book emphasizes a personal involvement in the development and operation of a greenhouse and is intended to serve only as a guide. It does not attempt to provide detailed instructions. Other sources of information are cited whenever further details may be useful to the reader.

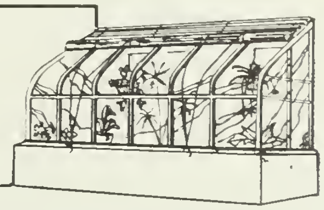
The urban environment offers specific challenges to people considering installing and operating a greenhouse. Some special considerations that are discussed here include building codes, permits, property easements, aesthetics, fire regulations, restricted solar access, airborne pollutants, and ice and snow hazards.

Because energy-conserving and solar greenhouses for northern climates must be more carefully designed than those for more southerly areas, information is contained in this book to ensure that optimum light levels, temperature, humidity, and ventilation for plant growth can be maintained without undue sacrifice of potential net heat gain.

Greenhouse horticulture is more exacting than outside gardening because an ideal growing environment is difficult to maintain artificially. Special skills are required for successfully working within the constraints of a greenhouse. The management information contained in this book applies specifically to gardening techniques that are important to the successful operation of energy-conserving and solar greenhouses located in urban areas in Canada, where the northern winter climate produces shorter daylengths and lower daytime light levels.

Several good books dealing with many of the topics covered in this text have been consulted in the preparation of this book. The most important references are listed in the "Resource Bibliography." *Low-Cost Passive Solar Greenhouses*, a publication of the National Center for Appropriate Technology (NCAT), Butte, Montana, coauthored by R. Alward, has been used as a guide for format and for some specific elements of content. We gratefully acknowledge NCAT's willingness to freely share the information contained in their book.

PART 1
Preliminary considerations



Reasons for building

A well-managed and well-built solar or energy-conserving greenhouse can provide an additional source of heat and fresh food. In fact, a well-designed solar greenhouse attached to the house can cut heating bills by as much as 30%. As well, it can save money on your food bill in winter by providing fresh, tasty produce. A greenhouse can also provide a sunny, indoor living space where you can maintain a spring or summer environment all year round. Besides being an attractive addition to the house, a greenhouse can help to improve the interior climate of your home by supplying increased heat and humidity during those cold, dry winter months. Finally, a greenhouse can provide a stimulating and profitable hobby that offers an interesting outlet for your spare time and energies.

If, however, only one of these benefits offered by a greenhouse is of interest, perhaps you should consider other alternatives.

For example, there are several more cost-effective ways to reduce your heating bill than building a greenhouse, if that is your only objective. The most effective ways of conserving energy are to add extra insulation to the house, to double- and triple-glaze the windows, and to caulk all the joints to eliminate cold-air infiltration.

If the greenhouse is intended only to serve as an attractive extra room (Fig. 1), consider building a solarium instead. The *Solarium Primer* and the *Solarium Workbook* are both excellent books on the subject.

Your food supply, as well, can be increased in several ways that are less expensive than building an energy-conserving or solar greenhouse. Enlarging an outdoor garden or improving your planting and management techniques in the outdoor garden can substantially increase the quantity of food you can harvest and store. Hotbeds and cold frames (Fig. 2) can increase the length of the outdoor growing season. Container gardens (Fig. 2) on balconies and rooftops are limited but useful substitutes for ground-level gardens. Windowsill greenhouses and indoor planter boxes with grow lights can provide some leafy vegetables throughout the winter.

These alternatives to the greenhouse may be able to answer your food production needs. On the other hand, if several of the benefits that can be obtained from an energy-conserving or solar greenhouse are of interest to you, this book offers many suggestions on how to design, build, and manage these structures effectively.

Personal involvement

Operating a greenhouse successfully both as a heat collector and as a food producer requires some commitment in terms of both time and effort.

To use a greenhouse for year-round food production, some complex greenhouse management skills are required. An experienced outdoor gardener willing to learn about greenhouse horticulture will likely become a successful and avid greenhouse grower. Details on greenhouse management are given in the second part of this book. In general, plants in a greenhouse require frequent attention. They have to be watered, fertilized, weeded, thinned, transplanted, inspected, and treated for insect and disease problems. In addition, the greenhouse interior climate has to be maintained within specified limits. Otherwise the plants simply die or become stressed and thus become more susceptible to attack by insects and disease. Extremes in temperature and humidity must also be avoided. Plants can be damaged in an overheated greenhouse, just as they are when the temperatures dip below freezing. Backup heating and ventilation systems are mandatory, and in some cases a cooling system also becomes necessary. These systems may be automatically or manually operated. Both types require attention to ensure proper functioning.

In a greenhouse adequate ventilation is essential, to replenish the carbon dioxide so vital to plant growth and to control high temperature and high humidity. The greenhouse can be ventilated using either outside air or air from the interior of the attached house. Light also has to be maintained at levels high enough to ensure continuous plant growth. Because winter light intensities are very low in Canada, the greenhouse user must maximize the amount of light entering the greenhouse. When insulating curtains or additional layers of movable glazing are used daily, they must be opened at sunrise and closed at sunset.

Using the greenhouse as a solar heater for an attached house is not simply a matter of adjusting the thermostat. The efficiency of a greenhouse as a source of heat depends on the circulation of air between the greenhouse and the main house. The movement of air is sometimes automatically handled by a thermostatically controlled fan. However, it is often achieved simply by opening doors and windows leading from the house into the greenhouse. Opening and closing these doors, windows, or vents at the appropriate times is a routine operation that is essential in preventing overheating of the greenhouse and excessive cooling of the main house. When insulating curtains or shutters are deployed at night to reduce heat loss from the greenhouse interior, they have to be removed in the morning to permit the greenhouse to act again as a solar air heater and as a growing unit. Operating these vents, windows, and doors has to be done routinely if the greenhouse is to be a successful solar air heater. The 5–10 minutes a day required may become an inconvenience, depending on your lifestyle.

Maintaining year-round food production in a typical family-sized greenhouse requires an average daily time expenditure of 1–1.5 hours for completing the routine operations described above. This time input increases somewhat for short periods during planting, transplanting, and crop changeovers.

If no one is at home during the day, consider installing automatic fans to circulate air between the house and greenhouse whenever the greenhouse temperature rises above a specified limit. For homeowners who are often away for several days at a time, the daily chores of looking after a greenhouse may become a burden, unless you can afford to install automated watering, insulating, and heating systems or you have a trustworthy and willing neighbor to depend on in your absence.

Cost

All costs quoted in this publication are based on 1982 prices. Construction costs for solar and energy-conserving greenhouses can vary enormously, depending on how much of the work you do yourself, how big the greenhouse is, how much of the material you can scrounge, and the quality of the materials you buy. Depending on materials and other design constraints, construction costs per square metre of floor space can range from $30 to $1000. The lower figure is for an owner-built greenhouse, using recycled materials

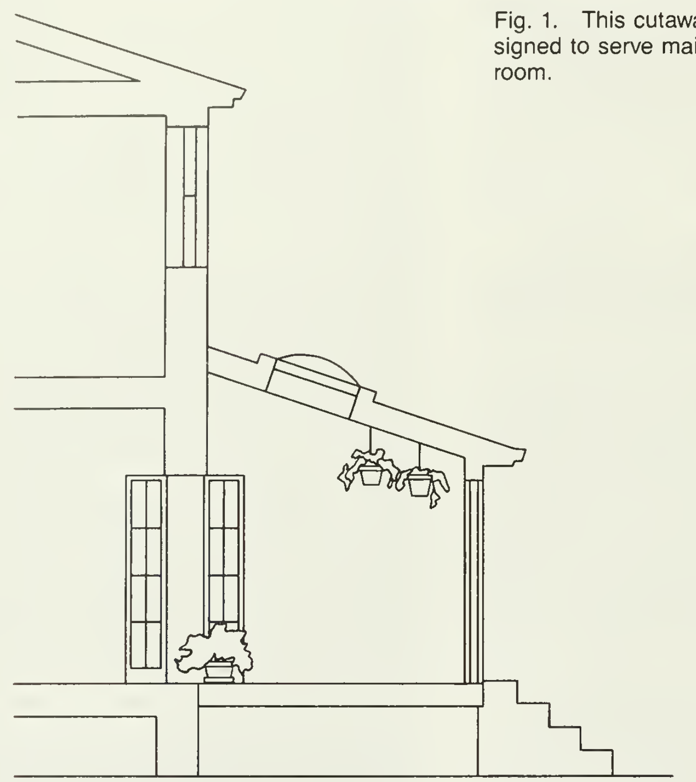


Fig. 1. This cutaway shows a solarium designed to serve mainly as an attractive extra room.

and polyethylene film glazing. The higher figure is typical of an expensive, custom-designed unit (Fig. 3) that is installed by a contractor, using all-new, top-quality materials, often including such features as curved-glass roof-to-wall sections. Attached greenhouses usually cost less than free-standing structures because they are built against an existing wall. Automatic venting and heating systems are more expensive than manually operated systems. Use of inexpensive, less-durable materials does keep initial costs lower, but consideration must be given to replacement cost. Polyethylene film is a case in point. This material is an inexpensive glazing material; however, it requires replacement every 1–3 years, depending on the grade and treatment of the material. The cost of most greenhouses usually falls somewhere between the above two extremes. With all-new materials, including good-quality double-layered fiber-reinforced polyester or standard patio-door thermopane, concrete foundations, and manual controls, an attractive, owner-built attached greenhouse costs about $100–150 a square metre. For a family-sized greenhouse of 20 m^2 the total cost runs about $2000–3000.

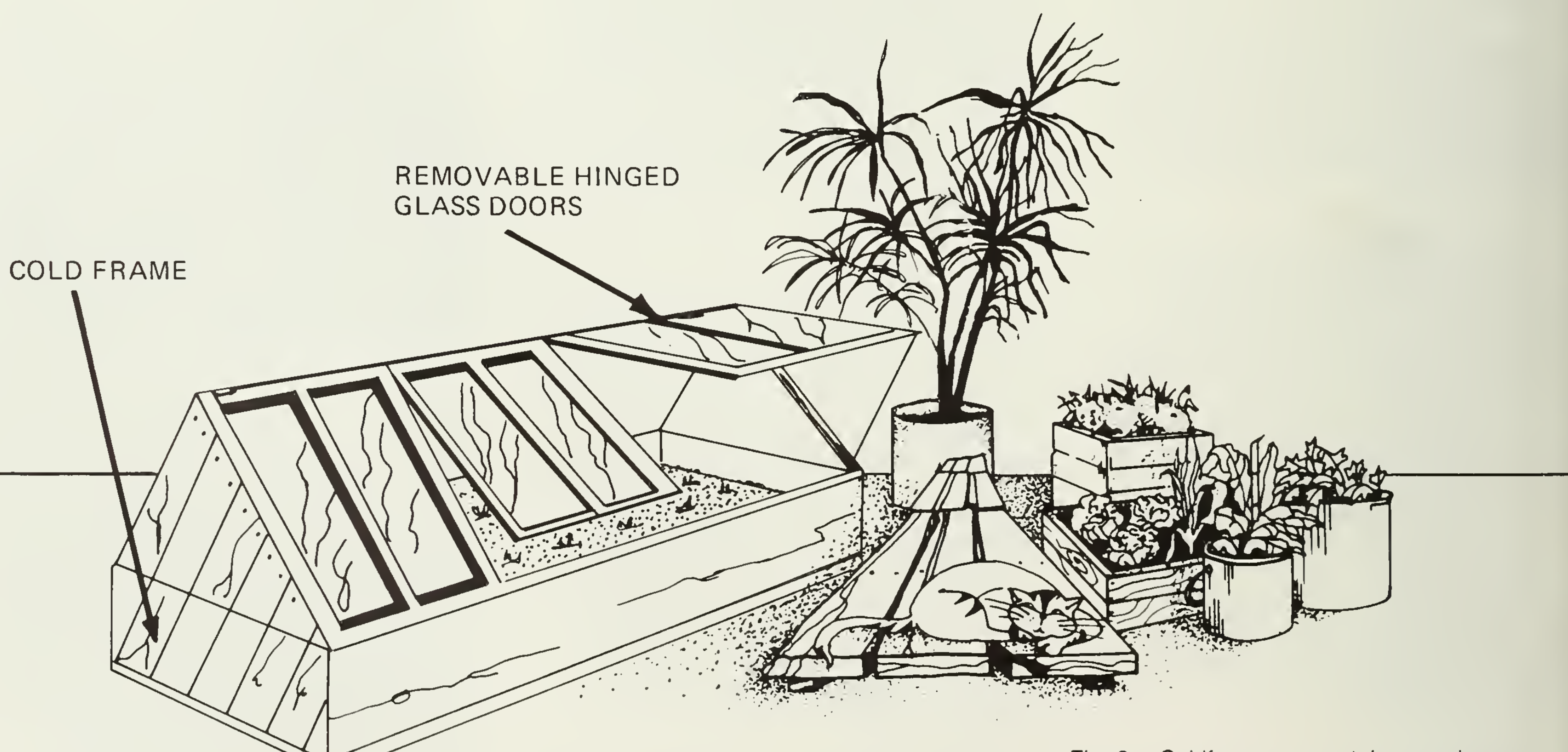


Fig. 2. Coldframes or container gardens on rooftops and balconies can help increase your food production outdoors.

Legal considerations

When planning a greenhouse, a number of loosely defined legal issues may affect what you can actually build and where you can build it. Only a few of these considerations are likely to affect your plans, because codes and regulations vary considerably from community to community.

Generally, the authority to enact and enforce building codes and regulations is vested in the local government, whether it be city, town, or municipality. These local regulations are usually based on a combination of structural safety, fire protection, and sanitation concerns, as well as possibly environmental and aesthetic issues. In most urban communities in Canada, a building permit is required before construction can begin. Failure to obtain such a permit in a municipality that enforces its building codes could result in a fine, or in some cases, enforced demolition of the structure. To obtain a building permit, building plans are submitted to the local building inspector, who determines if they meet existing regulations. In degree of detail required, these plans may vary from simple, clear sketches to complex engineering or architectural drawings. A building permit is usually inexpensive, although in some jurisdictions the fee is based on the value of the construction. Additional permits may also be required for installation of plumbing and electricity.

Copies of local building codes and regulations are available from municipal government offices. However, perhaps talking to other owners in your area who have recently put additions on their buildings would help you determine the best method of going through official channels.

To avoid the possibility of having a sound design rejected by a local building official because of his inexperience with solar greenhouses, perhaps your greenhouse could be described as a more traditional structure, such as an enclosed sunporch or enclosed balcony. The stamp and signature of a recognized professional architect or engineer on the design plans may also be helpful. In a small urban or suburban community, consider engaging the building inspector in the design process from the start. Holding discussions with the authorities periodically throughout the evolution of the design can expedite official approval of the final plans.

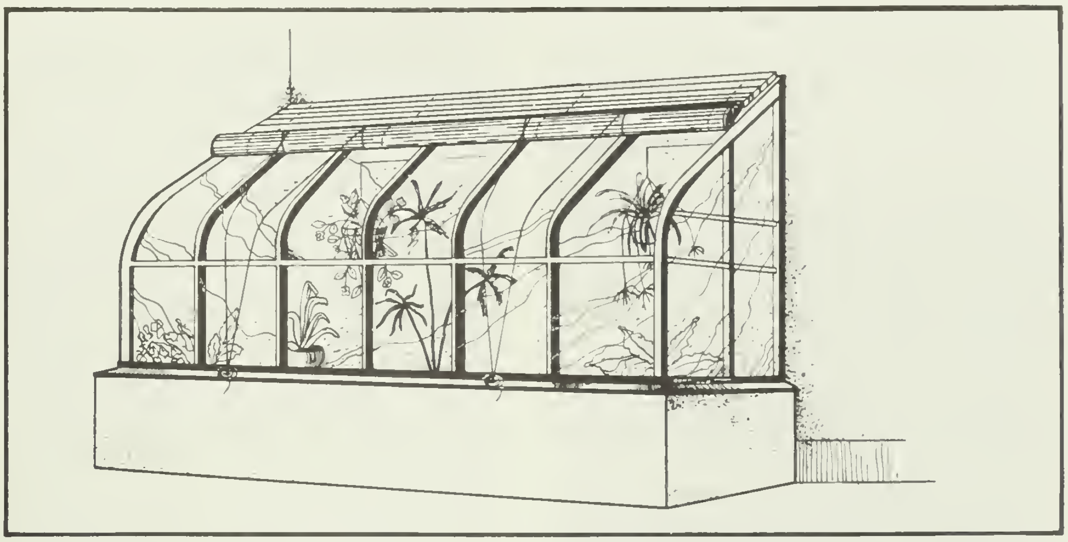
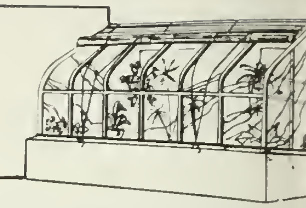


Fig. 3. A custom-designed attached greenhouse using top-of-the-line materials cost about $1000 a square metre at 1982 prices.

Zoning laws may regulate where you can build your greenhouse, as well as its appearance. These regulations deal with allowable uses for the zoned area, by specifying whether the property is residential, commercial, or industrial. They also specify set back, side clearance, and maximum lot coverage, affecting where you are allowed to locate the greenhouse on your property. They may impose certain other limitations affecting, for example, a proposed rooftop greenhouse. Finally, they may control certain aesthetic matters that might restrict the exterior appearance of the building. In a planned community, a subdivision, or a condominium development, restrictive covenants may limit the kinds of retrofit activities that are allowed. These regulations, imposed either by the developer or by an association of neighborhood residents, are often meant to maintain a sense of external building conformity. Because such covenants may be legally binding, you are well advised to examine them closely before initiating the design process.

Insurance coverage for a solar greenhouse is not usually difficult to obtain. In fact, your current homeowner's policy may have provisions for covering attached or detached new structures, as long as these structures conform to local building codes. Check with your insurance agent before starting to build, to ensure that the additional structure is covered either by the existing policy or by a special rider to the policy. In urban areas insurance companies sometimes have no precedent or category on which to base additional coverage. Solar greenhouses have been variously insured as greenhouses, attached inhabited and uninhabited spaces, heating systems, enclosed porches, and unattached buildings. If you are legally obliged to construct the greenhouse according to local building codes, but fail to do so, your insurance company may have grounds for refusing any claim made on the structure.

PART 2
Greenhouse construction



Design considerations

Location

Choosing a site is probably the single, most important factor in any plans to build an energy-conserving or solar greenhouse in urban and residential areas. The amount of sunlight falling on the greenhouse is directly affected by the degree of shading cast by nearby buildings. Site choice also affects the microclimate of your greenhouse. A poor choice could cause drainage, pollution, and safety problems. Furthermore, building regulations may restrict your options.

The greenhouse is best located where it is unobstructed by shade for long portions of the day, particularly during the winter. Greenhouses attached to a larger building should be located on the south wall of the existing structure. Any well-exposed wall facing any direction within 30° from the south is satisfactory. A freestanding greenhouse can generally afford more flexibility in location, as long as it is oriented with its long axis in the east–west direction. Thus the major face of glazing can be applied to the south wall and the permanently or seasonally installed insulation can be applied along the north wall and roof. The greenhouse should also be situated conveniently. Locate the greenhouse against or adjacent to those rooms in the main house requiring the extra heat it generates, or establish it close to the kitchen where the harvested produce can be efficiently processed. Situate an attached greenhouse over existing windows or a door that can provide direct access to the greenhouse from the main house as well as ventilation ports for interior climate control.

Urban greenhouses may be built at ground level on appropriate foundations, on a balcony or porch, or on top of a flat shed, garage, or house. Any location that offers enough space for a greenhouse big enough to meet your needs is satisfactory, as long as other design considerations can be adequately integrated.

Sunlight—Sunlight is required to provide much of the space heating for the greenhouse interior. It also supplies the light energy that plants need for growth. To determine where the maximum amount of sunlight on your property can be obtained, study the path the sun traces across the sky and note the obstructions in its path that cast shading at various seasons and times of day. Obvious obstructions to the sun include nearby buildings and trees, and farther away, high-rises and hills. Remember that the sun follows different paths across the sky in summer and winter. In the summer it rises in the northeast, traces an arc high in the southern sky, and sets to the northwest. In the winter the sun is always to the south. It rises in the southeast, stays low in the sky, and sets in the southwest. Trees or buildings that do not cast shade on your property in the summer may block direct radiation on a winter day when the sun is lower. Some shading in summer can be beneficial, but avoid shading in winter as much as possible.

Once a reasonably good site has been selected, estimate the number of sunlight hours the greenhouse is expected to get at various times of the year. If too much shading occurs in December and January, you may have to consider not using the greenhouse for growing purposes during these months. Alternatively, you could supplement the light levels inside the greenhouse with grow lights or change the site to a sunnier area.

When you have the option of situating your greenhouse on either a southeast or a southwest wall of an existing building, choose the southeast site. On the southeast site the sun starts to heat the greenhouse space earlier in the morning. Early-morning heat from the sun helps protect the plants against freezing and recharges the heat-storage system sooner. Plants also grow better when they get the early-morning light.

Microclimate—The microclimate of your site is determined by the weather conditions that occur at the specific location on which you choose to build. It may be significantly different from the climate recorded at the local weather station, or from the conditions on the street going by your house, or even from the climate on the other side of the house. It is affected by surrounding buildings and vegetation, the slope of the land, windbreaks, and the color of adjacent buildings. Some microclimate effects may be advantageous for your greenhouse, whereas others may create problems.

Some microclimates are beneficial. Locating the greenhouse on the south side of an existing building puts it in an area that is somewhat warmer and often less windy than elsewhere. The south sides of buildings absorb more solar radiation and can also reflect some of this radiation onto the ground in front. Reflected radiation heats up the ground and air immediately adjacent to the south side of the building.

Siting the greenhouse on south-sloping land provides similar benefits to those just described. Winds can also be lower on a south slope, and the soil, slanting more perpendicularly to the sun's rays, absorbs more radiation, thereby heating up earlier in the spring and cooling down slower in the fall.

Locating the greenhouse to take advantage of available windbreaks can greatly reduce heat loss in winter. Nearby buildings or coniferous trees and hedges to the west and north of the greenhouse site act as windbreaks to slow the winter wind before it hits the greenhouse. Decreased winds mean decreased cold-air infiltration and less wind chill, thus lowering heating bills.

Siting the greenhouse to take advantage of summer breezes helps to keep the greenhouse well ventilated, thus cooler, during the summer. Summer winds tend to come from the southwest, whereas winter winds are from more westerly and northerly directions. You can try to take advantage of northwest windbreaks and southwest exposure to provide better year-round weather conditions at your site.

Some microclimates, however, can be detrimental. Where there is a lot of snow in the winter, accumulations of ice and snow on higher roof areas create a potential hazard for the glazing on a greenhouse sited below.

Placing the greenhouse in the vicinity of very tall buildings may expose it to the strong winds they create. You have probably noticed the excessively high winds that sometimes blow around the base of high-rise buildings. These winds could be hazardous to your greenhouse. They definitely serve to increase your winter heat load.

Nearby fences, hedges, and other obstacles can cause snow to drift onto the site of your proposed greenhouse. Check where drifting occurs and try to avoid siting the greenhouse there.

Type

Urban greenhouses can be broadly classed as attached or freestanding. Attached greenhouses are built onto an existing building, making use of available walls or roof sections. When there is no convenient location for a greenhouse to be attached to your building, or when building codes, aesthetics, or space limitations require separate structures, a freestanding greenhouse may be the only alternative. Both attached and freestanding greenhouses can be partially sunk into the ground to take advantage of the insulating effect of the soil in the winter.

As already noted, however, attached greenhouses have several advantages. They are generally less costly to construct. Furthermore, attached to south-facing walls, they are less costly to heat. As well, they act as a buffer for the main structure, reducing heat losses from the south wall of the house. Finally, the direct access to the greenhouse from the main house is convenient and protects the plants from any cold-air shock that could from otherwise arise upon entering or leaving a freestanding building.

Shape

The shape of the greenhouse depends on several factors. As we have already noted, the two primary functions of a greenhouse are to provide an artificial environment suitable for year-round food production, as well as extra heat for the main house. Often design considerations concerning shape come into conflict in greenhouses intended to perform both these functions under severe winter climates. Another consideration concerning the shape of the greenhouse is whether it enhances the looks and value of the building to which it is attached or the property on which it stands. As well, the shape of the structure can play a deciding role in how effectively it satisfies your needs under certain space limitations. Each of these issues is discussed below, addressing the significant features that must be considered. It is up to you to assess the relative importance of each of these concerns in your own case. If your main interest is food production, give more priority to optimum light levels. If you are more concerned with providing an extra source of heat for your home, the shape of the greenhouse should emphasize heat collection. In both cases, the shape of the greenhouse should be tempered by aesthetics and space considerations.

Heat collection—To act as a good solar heat collector, the glazed area of the greenhouse should be as nearly perpendicular to the sun's rays as possible during the winter heating season. This orientation maximizes incoming solar energy and minimizes losses from reflection when energy is needed most. The optimum angle of the glazing for winter heat collection is approximately 15° greater than the latitude at the site. For example, at 50° north latitude, the best tilt for the south-facing glazing is 65°. However, in some cases this angle may need adjustment. In a sunny area with snow covering the ground to the south of the greenhouse during much of the winter, the extra radiation that is reflected off the snow can best be collected using a more nearly vertical south glazing. At a site that is generally cloudy during the winter, a lower slope, for instance latitude plus 10°, may be advisable. In the populated regions of Canada, with the low winter sun, the slope of the glazing from the horizontal can range from 55° to 90°.

Light penetration—The amount of light, rather than heat, is often the limiting factor for plant growth, particularly in areas with cloudy winters. Adequate light is needed year round to promote continuous plant growth. A greenhouse with glazing only on the south wall and roof does not allow enough light to penetrate to the back of the greenhouse during cloudy days in fall and winter. Plant growth in these shaded and darker areas is thus limited. In those regions of Canada with dominantly cloudy falls and winters, for example around southwestern British Columbia and in parts of southern Ontario and the Maritimes, diffuse light is needed from a large portion of the cloudy skies to provide the plants in the greenhouse with enough light to grow. Greenhouses there may require shallower-sloped south glazing, perhaps 30–45°.

In a freestanding greenhouse, the north, insulated wall and the roof should be shaped to allow the maximum amount of sunlight to reach the back of the greenhouse in both winter and summer.

The Brace Research Institute recommends that for a freestanding greenhouse the slope of the north-facing surface should equal the highest angle that the sun reaches in the sky at your site. The maximum solar elevation occurs at solar noon on 21 June. To calculate this angle, take the complement of your site latitude and add 23°. For example, in Saskatoon, at 52° north latitude, the complement of your site latitude is 90° minus 52°, or 38°. Thus the slope of the north wall should be 38 + 23 = 61°. This slope can vary up to 10° with negligible effect on the performance of the greenhouse.

Floor dimensions—Solar greenhouses should be rectangular in floor plan, with the longest axis running in an east–west direction. For attached solar greenhouses the best length is one-and-a-half to two times the width. This length-to-width ratio is the optimum in Canada because the dominant direction from which both direct sunlight and diffuse sky radiation come is the south. Therefore large, south-facing glazing areas can capture this radiation with less reflective losses than similarly large, east- and west-facing areas. Because most of the light enters from the south in greenhouses with this configuration, light distribution is not uniform over the plants. However, white paint on the interior of the north-facing surfaces reflects a considerable amount of light back onto the plants. For a solar greenhouse in which the width is nearly as large as the length, adequate access of sunlight to all parts of the greenhouse is virtually impossible unless you glaze the two end walls, facing the east and the west.

Maximizing growing areas—If space limitations restrict the usable floor area of the solar greenhouse, a structural shape with a steeply pitched, glazed area that covers part of the second story of the house allows a larger collection area and more space in which to grow plants. Some plants can be grown at floor level and others hung in pots at various heights throughout the greenhouse.

Enhancing the site—Solar greenhouses that are visually pleasing and that do not negatively alter the character of their surroundings require careful planning and concern for detail. An attached solar greenhouse should be a natural extension of the main building. Therefore, see that the lines of the addition conform to those of the existing structure. Freestanding greenhouses allow more freedom in shape aesthetically. Nevertheless a freestanding greenhouse should fit comfortably into its surroundings.

Minimizing heat loss—Heat losses due to shape are lowest when the exposed wall-and-roof areas of the greenhouse are minimized for a given interior floor area. Therefore the most efficient shape for conserving heat is offered by the conventional, square floor plan with roof surfaces sloping at 25–39°. However, a square solar greenhouse does not allow enough light to enter at the north side to sustain plant growth there. Therefore although light requirements necessitate a rectangular floor plan, avoid an excessively long, narrow shape that would incur an unnecessarily high heat loss.

Compromise—In virtually all parts of Canada, compromises become necessary when designing an energy-conserving or solar greenhouse, particularly when you are considering aesthetics, light accessibility, heat collection, and heat loss as they pertain to your particular site.

One compromise that balances the conflicting heat and light considerations is a design incorporating a double-sloping glazing on the south wall. The double slope is achieved by building a lower, glazed kneewall vertically from near ground level to a height of 900–1500 mm. From here, a glazed roof section is sloped back at an angle of 15–45° to the horizontal and connected to the wall of the main house (for attached structures) or to a north-sloping roof (for freestanding greenhouses). The vertical glazing on the kneewall contributes to winter heat gain while the shallower roof glazing allows better entry of diffuse light on cloudy days and better penetration of direct and diffuse light in summer to the back of the greenhouse. Depending on the microclimate of your site, you may choose to insulate the less steeply inclined, upper glazed section for the winter, removing the insulation for spring, summer, and fall operations. This option is particularly advantageous in an area with a lot of sunny fall and winter days.

A south, vertical or steeply sloped kneewall provides plants and people with adequate head room, allows you more room for installing heat storage, and provides a place on the outside for snow to accumulate when it slides off the greenhouse roof. Greenhouse designs with glazings or wall sections that slope at an angle of less than 60° right to the floor do not offer these same advantages. Such structures may, however, be easier to construct and seal tightly since there are fewer joints, particularly when the glazing slopes at the same angle from the greenhouse peak to the floor.

Size

Size, like shape, is a critical design consideration for the solar greenhouse. The size of the greenhouse depends on the purpose for which it is intended. It is also strongly influenced by the space limitations of the site. A greenhouse on a balcony, porch, or garage roof must be sized to fit the appropriate available space. However, an attached or freestanding greenhouse at ground level offers more flexibility.

For a significant reduction in home heating costs, an attached solar greenhouse should have a glazed area that is at least 10% of the floor area of the main house. For a residential floor area of 180 m^2, for example, the minimum amount of glazing required is approximately 18 m^2.

Solar greenhouses used as a major source of food require a floor area of approximately 6 m^2 per person. An area of this size includes sufficient space for adequate walkways and heat storage in the greenhouse. For a family of four, a greenhouse of 24 m^2 is in order.

A greenhouse used only to supplement vegetable supplies throughout the winter can be reduced in size by half. Generally the smallest sizes considered practical are 2.5×4 m for an attached greenhouse and 3×6 m for a free-standing greenhouse. Greenhouses any smaller than this incur costs for construction and supplementary heating that are too high for the limited growing area they offer. These minimum size restraints do not apply to greenhouses built on a balcony or porch.

Light

To maximize the amount of light energy that is obtained through the glazing, the support structure should be made as light as possible while remaining capable of providing adequate strength. The heavy glazing supports of post-and-beam construction, though strong and cheap, tend to reduce the amount of radiation entering the greenhouse. Each layer of glazing installed in the greenhouse also reduces the amount of light penetrating to the interior. Two layers of glazing, however, do keep heat losses from the greenhouse to a reasonable level. Whether it is worthwhile installing a third layer of glazing to further reduce heat losses depends on what plants you want to grow in the winter when light intensities are low. Houseplants can generally tolerate the lower light levels that result after the installation of a third glazing. However, for vegetable production three layers of glazing may keep light levels below the minimum threshold needed. This light restriction may occur for long enough periods during early morning and late afternoon to shorten the day length to below an acceptable level for adequate plant growth.

Light intensity inside the greenhouse is not significantly affected by the degree of translucency of the glazing. Plants often grow better in the more diffuse light entering through translucent glazings such as fiber-reinforced polyesters and polyethylene film than they do in direct light radiation. People, on the other hand, usually prefer a transparent glazing, through which they can see outside.

Glazing protection

Inclined glazing surfaces must be capable of withstanding the same external loads that regular roof structures are designed to resist. For example, in areas of heavy snowfall, a shallow-sloping greenhouse glazing must be able to support about 1 kN/m of snow. Only a few fiber-reinforced polyesters, acrylics, and tempered glass glazings can withstand this heavy a load, and to do so they must be properly supported. Look at the manufacturer's specifications and warranty information to ensure that the material under consideration is suitable for your project.

When there is danger of ice or snow falling from adjacent buildings onto the roof glazing, incorporate a solid roof section or install a suitable, break-resistant glazing at that point.

Some glazing materials cannot withstand direct exposure to ultraviolet radiation from the sun. Such materials can, however, be used as the inner layer in a combination of two or more layers of glazing materials. The outer, more expensive glazing is chosen for its ability to resist ultraviolet degradation and serves to protect the inner layer.

Heat

The amount of heat retained by a solar greenhouse depends partly on the amount of insulation installed in the opaque walls and partly on the general tightness of the structure against infiltration of cold air. The opaque surfaces of the greenhouse warrant only an average amount of insulation because most of the heat loss occurs through the glazed areas. In most urban areas of Canada the equivalent of 140 mm of fiberglass batt insulation in 38 × 140 mm framing is adequate. In milder climates, such as in the Vancouver and Victoria areas, 38 × 89 mm framing with 90 mm fiberglass insulation is sufficient. Glass fiber and polystyrene insulation are recommended because these materials are not destroyed by moderate amounts of moisture penetrating through the walls. Avoid cellulose insulation, which deteriorates rapidly when it gets wet.

A greenhouse containing very few air leaks retains heat better than a leaky greenhouse. To ensure the general tightness of the insulated walls and roof, use a continuous 100-μm polyethylene vapor barrier on the interior of the studs and rafters and patch all holes in the polyethylene before installing the interior sheathing. Ensure tightness at corners and edges of glazing, roof, walls, foundation, doors, and vents by caulking all joints and cracks with latex or butyl caulking.

The large amount of heat lost through the glazing can be reduced by insulating the glazed area during the night. Insulated night curtains or shutters can be used, but remember to incorporate an area in your design for storing these glazing covers during the day.

An effective heat-storage system is an important element in solar greenhouse design. The location, type, and amount of storage material and its exposure to direct sunlight or warm, circulating air are important design considerations from the points of view of effective use of space and backup heating requirements. Refer to the section "Thermal Storage Systems" for further details.

Rot prevention

Water collecting and sitting on wood surfaces can cause rotting to occur. Ensure that interior and exterior surfaces of the greenhouse structure are sloped to prevent water from accumulating. The interior surfaces must all be sloped inward to shed the water that condenses on them from the moist greenhouse air.

All exterior surfaces should slope outward and slightly down to shed rain water. The proper slopes are particularly important when recycled wood-framed windows and horizontal wood battens are used.

Another way to prevent rot is to use rot-resistant wood. Redwood, cedar, or lumber that has been pressure treated or painted with a copper napthanate preservative are satisfactory. Do not use pentachlorophenol or creosote preservatives to treat wood used in a greenhouse, as these chemicals can damage or kill plants. Use a good water-resistant material for sheathing the greenhouse interior.

Exterior siding, exterior grade plywood, and water-proof sheetrock are all acceptable. Do not use interior-grade plywood, regular sheetrock, particle board, or masonite, even if they are well treated and painted. These materials deteriorate quickly once the surface treatment cracks.

The structural component that is the most prone to rot is the sill, the strip of wood that is attached directly to the top of the foundation. Always use rot-resistant or treated wood for the sill.

To protect all other interior framing and sheathing surfaces, apply a good-quality oil-based primer and two coats of exterior paint. Prime and paint all cuts made in the framing members and all wood surfaces on which the glazing is to be installed. A fresh coat of paint every year or two keeps the wood protected and maintains good light reflection within the greenhouse.

Use only galvanized nails when constructing the greenhouse. The high humidity and condensation within a greenhouse cause nongalvanized nails to rust. Besides being unsightly, rust can eventually deteriorate the shank of the nail, thus reducing its holding capability and permitting entry of wood-rotting moisture.

Design examples

This section describes 11 different solar greenhouses designed to suit various urban sites. Each design contains some of the features discussed previously in this section. Although none of the examples presented here may parallel your specific case in all respects, they should provide you with some ideas that can be incorporated into your design.

Solar greenhouse on a balcony (Fig. 4)

This balcony was converted to a solar greenhouse only after ensuring that the weight of the greenhouse and its contents could be safely supported on the existing structure. Calculations showed double glass to be too heavy, so the owner used two layers of polyvinyl chloride plastic sheet to cover the south wall and the glazed parts of the east and west walls. The glazing material used on the roof was corrugated fiber-reinforced polyester with an inner layer of polyethylene sheet plastic. The balcony floor was insulated from underneath. Approximately half the area of each of the east and west walls and the roof was insulated.

The south-facing wall was built to head height to permit easy access to all parts of the greenhouse and to permit multiple use of this new living space. The roof slope was kept intentionally low to avoid building against the uninsulated upper portion of the brick wall of the main house. A steeper roof slope to include this upper wall would have required that the brick be insulated to prevent large amounts of heat from being lost into the unheated attic. With such a shallow roof angle, the owners have found that they can conserve a lot of heat energy by covering the glazed portion of the roof with moveable insulation panels during the winter.

Portions of the glazed walls on the east and west, as well as the unglazed section of the roof, serve as vents. These vents, along with shading devices, help to prevent overheating in the spring and summer. The door that opens onto the balcony provides the necessary exchange of air between the main house and the greenhouse.

No heat storage device is used. However, the soil in the planter boxes and the brick wall of the main house do have heat storage capabilities.

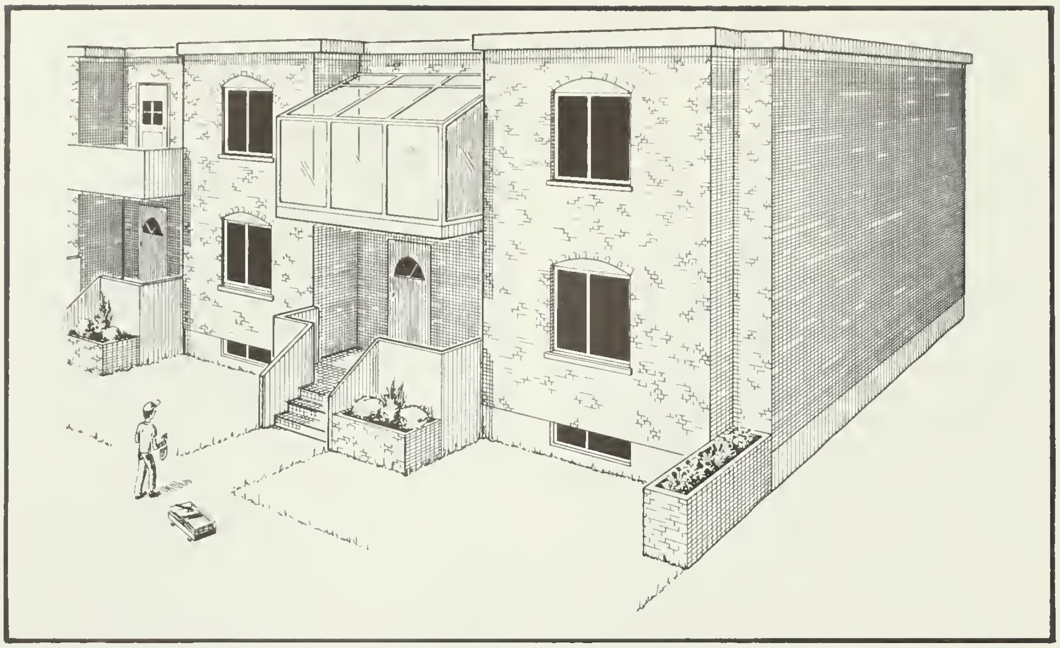


Fig. 4. Solar greenhouse on a balcony.

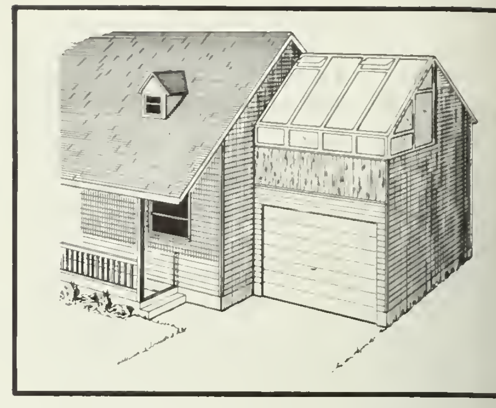


Fig. 5. Greenhouse on a garage roof.

Greenhouse on a garage roof (Fig. 5)

The original low-peaked roof structure of the garage in this example was removed and new framing was installed to support the greenhouse floor. Because the garage was to remain unheated, the greenhouse floor had to be well insulated to minimize heat losses. Double-pane glass was used for all glazed areas, and the north roof and unglazed sections of the other walls were well insulated. The original wall of the main house was modified by replacing a window with a door and adding a large window facing into the greenhouse.

Circulation of air between the greenhouse and the main house is provided by opening the door and by operating a circulating fan. Overheating in summer is prevented by opening the glazing vents and using a fan exhausting to the outside, mounted near the greenhouse peak.

The 40° angle of the roof glazing allows snow to slide off. A roll-down, insulated curtain is used on the inside of the glazing on winter nights to reduce heat losses.

Heat is stored in six water-filled, 200-L drums placed along the back of the greenhouse. An electrical baseboard heater is thermostatically controlled to keep the greenhouse temperature above 10°C.

Converting a ground-floor porch into a greenhouse (Fig. 6)

The porch in this example was originally open on two sides. The roof of the house covered the porch. The concrete foundations for this greenhouse were extended out from the foundations of the house and a floor was constructed from a 150-mm concrete slab placed on top of gravel. Exterior insulation was used on the foundation. The roof line of the greenhouse keeps the same slope as the roof of the house. The upper half of the greenhouse roof, originally the roof of the porch, was left unglazed and insulated. Transparent roof vents were installed just below the solid portion of the roof. An external layer of corrugated fiber-reinforced polyester was used to construct the remainder of this low-angle roof. Calculations showed that this material would be strong enough to support the heavy snow loads that are common in the area. The remainder of the greenhouse was glazed with double-skinned polycarbonate sheet.

No modifications were made to the existing house structure. The door and windows that faced onto the porch now face into the greenhouse and provide adequate air circulation when open. Venting to the exterior in warm weather is provided by a door on the west side leading directly into the greenhouse and by vents in the upper roof.

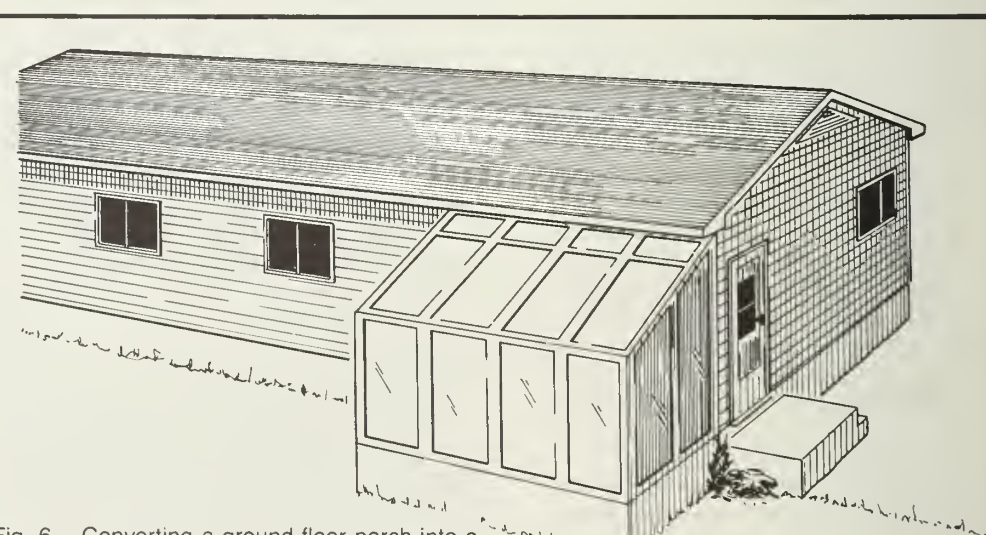


Fig. 6. Converting a ground-floor porch into a greenhouse.

Heat is stored in the concrete floor and in a row of vertical water drums placed under benches at the front of the greenhouse. Electrical baseboard heaters provide backup heat when necessary.

Attached greenhouse with a vertical kneewall (Fig. 7)

This greenhouse is similar to the previous structure, except that instead of incorporating a porch from the original structure into the new greenhouse, the owners constructed a completely new addition against the south wall. The greenhouse covered one of the original doors and two kitchen windows overlooking the backyard. All glazing was thermopane glass.

Natural ventilation to the outside was provided through the vertical lower windows and the upper row of roof windows. Air circulates between the house and greenhouse through two windows leading from the heated basement and through the kitchen windows.

No night-time insulation is used on the glazing. However, during some winters, the owners have had to install a temporary third layer of glazing, consisting of polyethylene film, on the inside of the greenhouse. Although this plastic film obstructs their view for a few weeks, it acts as an effective insulation and does not require daily opening and closing.

Heat is stored in water drums placed along the front of the greenhouse near the vertical glazing. Backup heat is provided by a thermostatically controlled fan pulling warm air in from the heated basement.

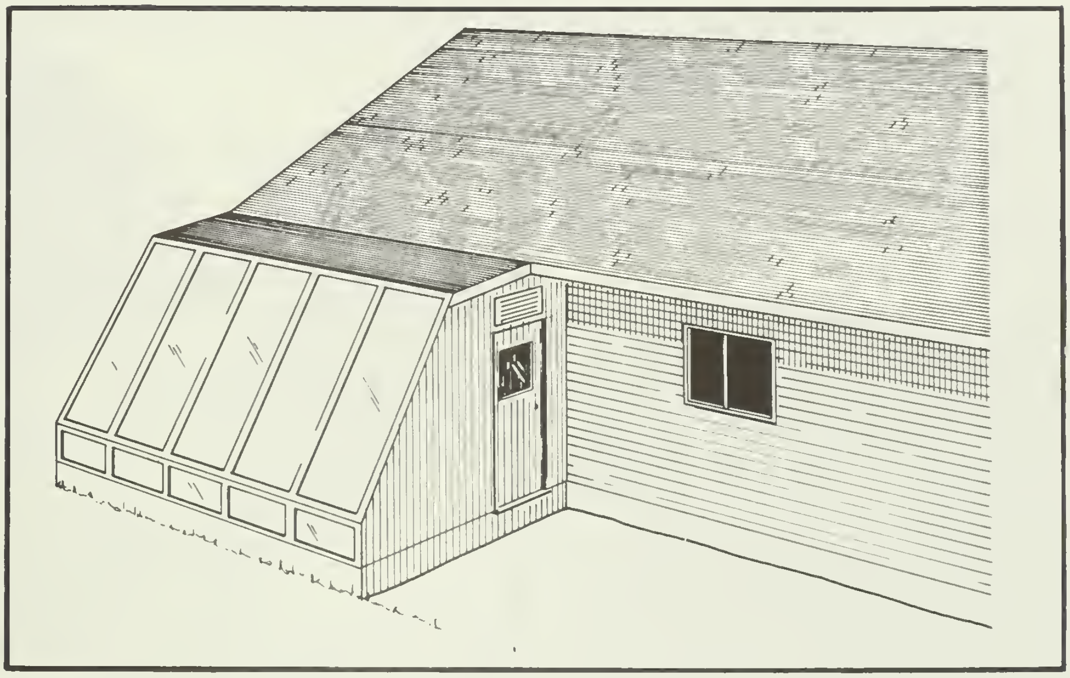


Fig. 7. Attached greenhouse with a vertical kneewall.

Because this house is in a heavy-snow area, a vertical kneewall was used for the glazing near ground level.

Attached pit greenhouse (Fig. 8)

The floor of this greenhouse was sunk 1 m into the ground to take advantage of the insulating effects of the soil at this level. The foundation walls were insulated on the outside to a depth extending below that of the floor. The walls and the nearly horizontal roof were also well insulated. The glazing material used throughout was double-layered polycarbonate.

Ventilation is provided by a fan mounted in the upper part of the east wall, with air entering through an intake vent installed above the door on the west wall. Ground-floor windows, a door, and a small fan at ceiling level provide the necessary air movement between the greenhouse and the adjacent rooms of the main house.

Moveable insulation made of sandwiched plywood and polystyrene panels is placed against all glazing at night. When not in use, this insulation is stacked neatly along the inside of the east wall.

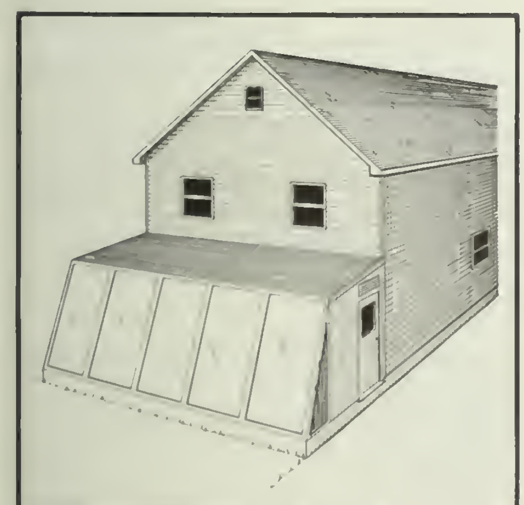


Fig 8. Attached pit greenhouse.

Heat is stored in two rows of water drums stacked one above the other along the back wall. These drums are painted black to absorb the direct rays of the sun Additional heat is transferred to the water from warm air forced to circulate around the drums by fans. No backup heat is provided.

This greenhouse is located in an area with traditionally low snowfalls. Any large accumulation of snow has to be manually removed when it piles up against the lower part of the glazing.

The greenhouse has no water seepage problems below ground level because it was built on well-drained soil that slopes away from the house.

Attached greenhouse with a shallow roof (Fig. 9)

This greenhouse was a prefabricated unit, sold and installed by the manufacturer. The homeowner poured and insulated the concrete foundation. The glazing material used throughout was thermopane glass, supported on anodized aluminum frames.

No air exchange was provided with the main house. The greenhouse interior is maintained at a minimum temperature of 15 C by a thermostatically controlled, gas-fired, hot-water heating system.

The site for this greenhouse receives an average of 2.5 m of snow in the winter. Any accumulation on the shallow roof is soon melted off by the heat lost from the interior through its double layer of glass.

Attached greenhouse on an east wall (Fig. 10)

With no space to build a greenhouse onto the south wall, the owner in this example elected to build an essentially freestanding, Brace-type greenhouse against the east wall of the house. To avoid excessive shading of the glazing, the kneewall of the greenhouse was located flush with the south wall of the house. Also, the first metre of the greenhouse adjacent to the house was left unglazed and insulated.

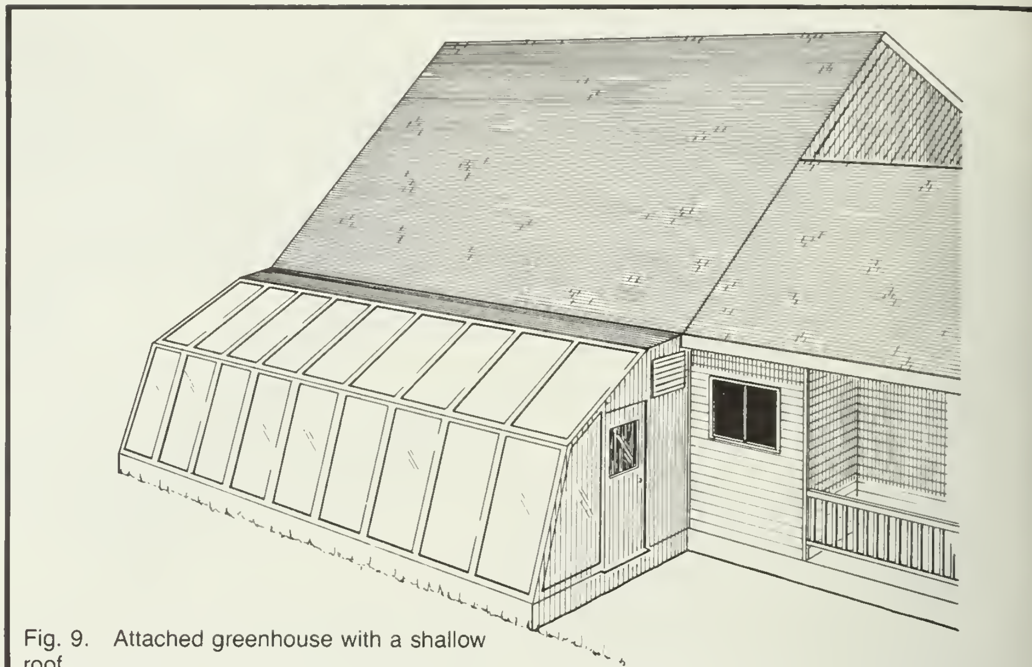


Fig. 9. Attached greenhouse with a shallow roof.

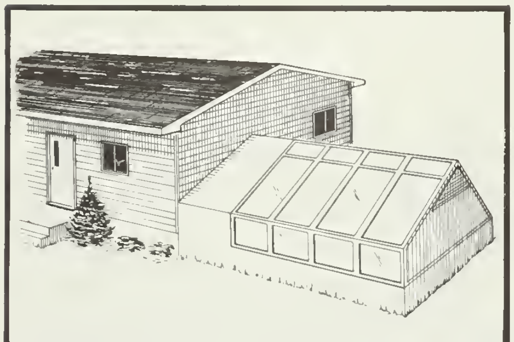


Fig. 10. Attached greenhouse on an east wall.

A floating slab was used for the foundation. This type is more economical than a perimeter foundation but is suitable only on a very few soil types. Perimeter foundation insulation was used. The sloping north wall was also well insulated. The glazing material used was double-layered, fiber-reinforced polyester.

The greenhouse is ventilated in warm weather by opening up vents in the glazed kneewall and the single vent at the peak of the east wall. Air exchange between the greenhouse and the main house is accomplished by using an exhaust fan at roof level and a cool-air-return port at floor level.

Although the glazing is uninsulated, the plants are covered at night by an aluminized plastic film forming a tunnel over the individual beds of plants. These tunnels cut radioactive heat losses from the plants and soil. Furthermore only the space immediately surrounding the plants need be heated when backup heating becomes necessary.

Heat is stored partly in the concrete floor pad and partly in 200-L water-filled drums placed across the back of the greenhouse and under benches at the front of the greenhouse. A circulating fan directs the warmer air that accumulates at ridge level down onto the concrete floor and around the water drums.

This attached greenhouse was designed for year-round cultivation of vegetables. The angles of the glazed roof and the insulated north wall are appropriate for this purpose. The angle of the glazed surfaces, however, allows an excessive amount of solar light and heat to enter the greenhouse during the summer. Therefore the roof glazing is equipped with an external, slatted, wood-and-bamboo shade to partially screen out some of the excess sun in summer.

Freestanding, modified, conventional greenhouse (Fig. 11)

A small, conventional greenhouse built on this suburban plot many years ago was modified to make it more energy efficient. A single layer of glass covered all sides and the roof of the original structure. The new owners completely insulated the north roof and wall and more than half of both the east and west walls. They also insulated the foundation on the outside down to the footings. Then the remaining glazed area was caulked and sealed, and an inside layer of glazing consisting of clear polyvinyl chloride film plastic was installed and well sealed.

Ventilation is provided by an exhaust fan above the east wall door and an air intake near the ridge of the west roof. Natural ventilation was considered too expensive because new window vents would have been required, as well as opening and closing mechanisms for several window panels in the kneewall and near the peak.

No insulation is used against the glass at night. However, aluminized plastic film tunnels as described in the previous example are employed during the winter to reduce heat losses from the plant beds at night. No backup heating is provided because the winters are mild. Heat is stored in 200-L water-filled drums placed in a single row immediately behind the vertical glazing and in two rows stacked against the north wall.

Sections of the east and west walls were glazed to allow more light to enter to greater heights immediately adjacent to these two walls than would otherwise have been possible.

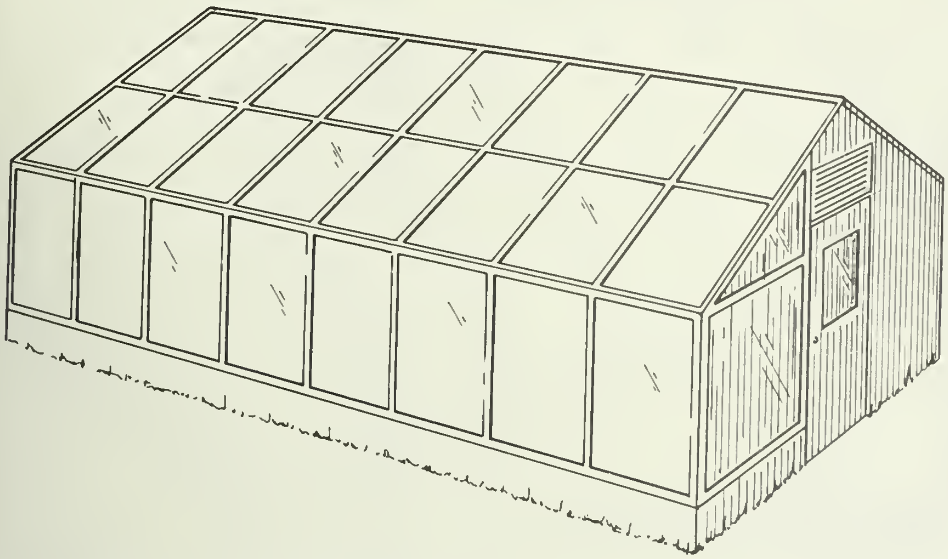


Fig. 11. Freestanding, modified, conventional greenhouse.

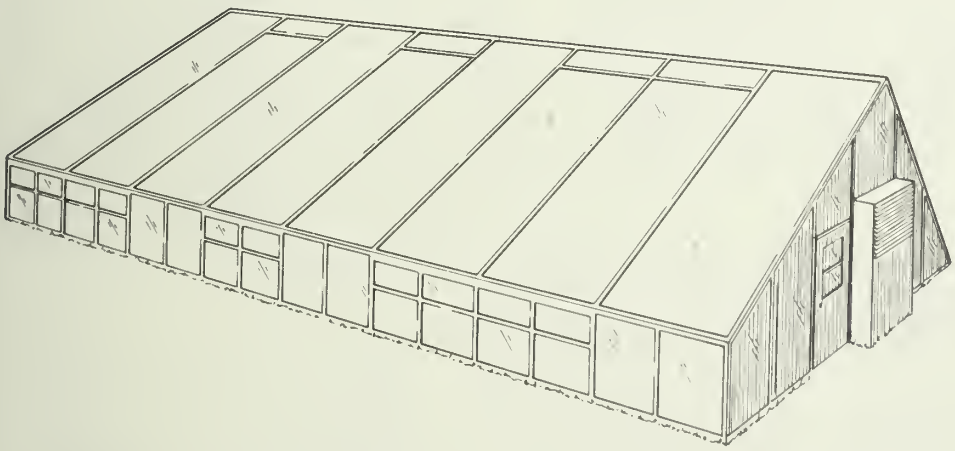


Fig. 12. Freestanding Brace greenhouse.

Freestanding Brace greenhouse (Fig. 12)

This relatively large greenhouse was built on a vacant lot in an urban area. It is run by a community organization to provide a garden nearly all year round for several families, as well as to start seedlings in the spring for other local residents. The greenhouse features a well-insulated north wall painted white on the inside to reflect radiation onto the plants from the north, post foundations, post-and-beam construction, ground-level growing beds, a perimeter insulated 600 mm into the ground, and fully glazed east and west walls. A double layer of glazing was used throughout except on the end walls, which were triple glazed. A good-quality fiber-reinforced plastic was used on the outside and polyethylene film on the inside. The polyethylene film is removed in the late spring, summer, and early fall. The greenhouse is not used from early December until mid February.

Summer venting is provided through low- and high-level vents in the glazing, and when necessary, through an exhaust fan and intake port combination on opposite end walls. Ventilation in late fall, late winter, and early spring occurs through two air-to-air heat exchangers located near the end walls.

Heat is stored in large, drainable water-storage tubes placed along the north wall. No backup heating is provided.

Large freestanding greenhouse (Fig. 13)

The owners of a 10 × 30 m city lot were unable to build a solar greenhouse attached to their residence because of site limitations. They had to settle for a freestanding greenhouse in the backyard.

They constructed the east, west, and north walls from solid concrete blocks, resting on concrete footings. The floor was constructed from a poured slab of concrete 200-mm thick. The foundation walls were insulated on the outside down to the footings. The north, east, and west walls were insulated on the exterior. A double layer of glass was used as the glazing material. The owners put the two layers together themselves.

Entry to the greenhouse is gained through a vestibule. This air-lock entryway protects the plants from sudden blasts of cold air. The greenhouse is used for growing plants and for recreation year round. Therefore, ventilation and heating systems are of considerable significance. All ventilation is to the outside. It is controlled in winter by an air-to-air heat exchanger and in summer by an exhaust fan at peak level and intake vents at floor level. Solar heat is stored in the concrete walls and in two storage bins containing rocks. These bins double as supports for the plant benches. A fan moves warm air from the greenhouse peak down through the rock bins. Backup heat is provided by several thermostatically controlled electrical baseboard heaters.

A major problem, however, has been discovered in the operation of this greenhouse. The owners had automated the heating, ventilating, and plant-watering functions, so that they could leave home for several days at a time, particularly in the winter to go skiing. Unfortunately, the site is in a heavy-snowfall area. During weekend storms snow quickly built up against the sloped glazing, often blocking up to half its area. Because the obscured glazing areas were then no longer efficient as heat and light collectors, the electricity consumption increased markedly during these incidents. This problem could have been significantly reduced had a vertical kneewall been incorporated into the design.

Freestanding greenhouse for a mild climate (Fig. 14)

This small, freestanding greenhouse is located in a backyard garden in a heavily populated suburb of Vancouver. There was not enough room to build an attached greenhouse on the south side of the house. A garage and the proximity of both the neighboring houses and the road combined to make an attached greenhouse impossible.

The east, west, and north walls of the greenhouse were insulated. The roof was made of double-layered, tempered glass, and the glazing material used on the other surfaces, including that on the east and west walls, was two layers of regular window glass. The very low slope of the roof was considered satisfactory for the mild climate of the southern coast of British Columbia, where snow accumulation is minimal. The shallow foundations were insulated on the outside to 300 mm below ground level.

Planting is done directly into the soil floor. Ventilation occurs through lower vents in the side walls and upper vents in the roof. No forced ventilation is used. During warm periods all vents and the door are left open.

Heat is stored in four 2-L drums filled with water and laid on their sides across the back of the greenhouse. Insulating shutters, hinged against the north wall, are swung into place against the roof glazing when nights are cold. The owners operate the greenhouse year round with no auxiliary heat. They use it mainly to grow cooler-season greens and early-spring seedlings.

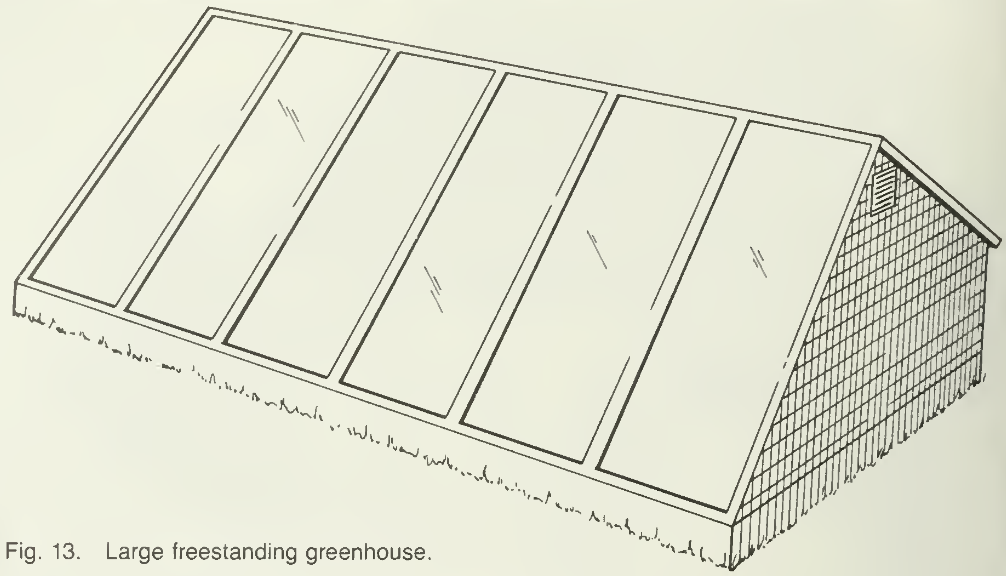


Fig. 13. Large freestanding greenhouse.

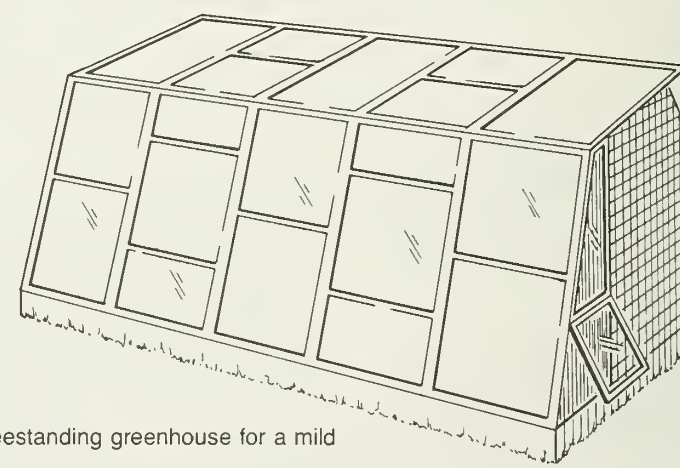


Fig. 14. Freestanding greenhouse for a mild climate.

Construction details

Foundation

The foundation may consist of a wall, a series of piers, or a flat slab, resting on a deeper and wider masonry section called the footing. The foundation supports the whole structure, holding the building in place and keeping it from sinking or shifting on the ground. The footing distributes the weight of the structure over a large area. Foundations and footings also anchor buildings to the ground, an important function in the case of lightweight greenhouses built in areas subject to high winds.

A solid foundation facilitates construction of the greenhouse and ensures the longevity and stability of the structure. Since greenhouses are usually lighter than standard houses, their foundations need not be as large. Generally, the bottom of the footing should rest below the frost line to avoid problems due to heaving. The frost line extends to as deep as 1200 mm or more in some urban areas of Canada. Properly installed foundation insulation helps to protect the foundation from frost heaves. For details, see *Handbook on Insulating Homes for Energy Conservation*.

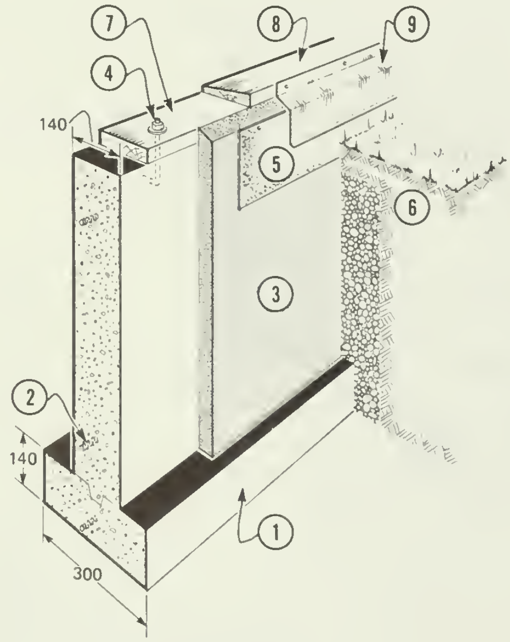
Foundations should rest on undisturbed soil, to avoid problems caused by settling later. When digging inside or outside the installed foundation be careful not to undermine the footings.

Three types of foundations are discussed here: poured concrete (Fig. 15), concrete block installed on poured-concrete footings (Fig. 16), and cedar post (Fig. 17). Details of construction are given in Figs. 15–17. General considerations are presented here in the text. For further information on foundation construction, consult a specialist in your area.

Begin your foundation by leveling an area of suitable size. Mark out the dimensions of the foundation, ensuring that perimeter walls are perfectly square. Measure the diagonals to make sure that they are of equal length. Dig the appropriate trench or holes. Be careful not to damage any existing underground systems such as drainage pipes, sewer lines, or buried cables. You may want to hire a backhoe operator for this job. Then set in the footing forms if necessary (Figs. 15 and 16) and brace them well so they do not bulge when the concrete is poured. In the case of continuous footings (Figs. 15 and 16), install 10M reinforcing bars and overlap them 300 mm at each end. Tie the overlapping ends with heavy wire. Pour the footings. Set in the concrete forms for the foundation wall (Fig. 15) and brace them well. Position the anchor bolts at 1200-mm intervals (Figs. 15 and 16), staggering them so as not to coincide with the insertion positions of the wall studs for the greenhouse. The anchor bolts are used to tie the sill plate, and thus the rest of the greenhouse frame, to the foundation. For post foundations, set in rock or concrete footings in the holes dug at the appropriate locations. Align the posts and ensure they are vertical. Then firmly tamp successive small amounts of earth into the holes around the posts. Continue filling and tamping until each hole is filled and the posts are rigid. For instructions on completing the foundations, refer to the appropriate drawing (Figs. 15–17). Make the top of the foundation at least 150 mm above ground level, to keep the rest of the structure away from the moist earth.

To prevent excessive heat loss through the earth and foundation walls, insulate the perimeter of the foundation on the outside. The thickness and depth of insulation varies with the severity of the winter climate. However, in virtually all Canadian climates, use a minimum of RSI 1.76 to just below the frost line. In areas with greater than 5000 heating degree-days, use RSI 2.5 insulation. The best insulation is blue-colored, rigid, extruded polystyrene, because its resistance to moisture damage makes it suitable for underground use. White polystyrene bead-board usually absorbs some moisture and is therefore not recommended for foundation insulation. Extend the insulation above ground level, high enough to cover the exposed foundation and the sill of the foundation, except in the case of post foundations.

Fig. 15. Poured concrete footing and foundation wall.



1 DEPTH OF FOOTING TO BELOW FROST LINE, OR TO SOLID ROCK
2 10M REINFORCING ROD
3 MOISTURE-RESISTANT RIGID INSULATION BEVELED AT TOP
4 M12 x 200 mm ANCHOR BOLTS 1200 mm OC TO TIE SILL PLATE TO FOUNDATION
5 CEMENT PARGING OR PRESSURE-TREATED PLYWOOD
6 BACKFILL TO 150 mm BELOW TOP OF CONCRETE, SLOPE SOIL AWAY FROM GREENHOUSE FOR DRAINAGE
7 CCA OR ACA TREATED 38 x 140 SILL PLATE
8 38 x 140 BOTTOM PLATE OF FRAME, BEVELED TO SHED WATER
9 INSTALL FLASHING AFTER WALL FRAME IS MOUNTED ON SILL PLATE

To protect exterior insulation from the sun and from physical damage, cover it with expanded metal lath topped preferably by cement parging. Extend the lath from the top of the insulation to 100 mm below ground level. Attach the lath to the foundation wall over the insulation with concrete nails and washers. Trowel the cement parging over the lath. Pressure-treated plywood or cement asbestos board can be used in place of the parging.

Flashing, when used, extends from the sill to ground level, where it terminates with a drip edge. Nail the flashing to the bottom plate of the frame wall. Caulk all flashing joints to prevent water penetration.

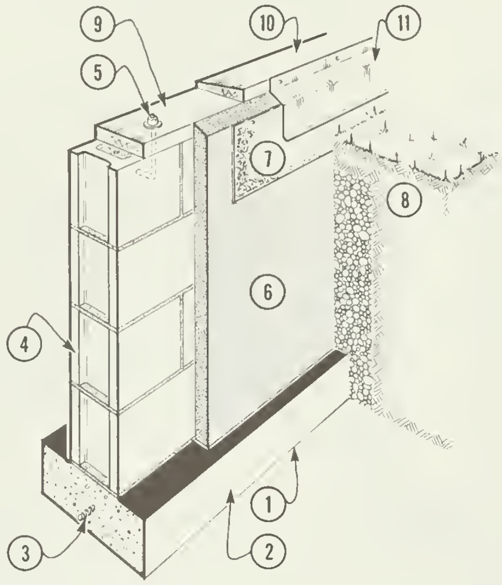
The foundation of an attached greenhouse does not have to be tied into the foundation of the existing house.

A new foundation system is not a relevant consideration when you are building a greenhouse on top of a flat roof or a porch. You must, however, determine whether the existing structure can support the proposed greenhouse. Rooftop greenhouses may incur higher costs and require somewhat more work than ground-level greenhouses because of the increased structural reinforcement of the supporting roof that is often required. Most rooftop additions must be able to withstand wind loads of up to 1.4 kN/m² on all surfaces. Therefore the new structure has to be securely fastened to the supporting roof. Consult a structural engineer to determine whether the roof support structure needs to be fortified and whether lightweight materials are mandatory for construction, thermal storage systems, and growing medium.

Framing

Glazing framing—In greenhouses the glazing frame is usually integrated with the structural frame. The frame serves to support the weight of the glazing, along with that of the expected snow and wind loads.

Fig. 16. Concrete block foundation wall.



1 DEPTH OF FOOTING TO BELOW FROST LINE, OR TO SOLID ROCK
2 140 x 300 mm FOOTING WITH VERTICAL REINFORCING ROD EVERY 1200 mm TO CORRESPOND TO LOCATION OF HOLLOW CORE IN BLOCK. VERTICAL ROD TO BE LONG ENOUGH TO PASS IN TO TOP ROW OF BLOCKS. FILL ALL VERTICAL CORES CONTAINING REINFORCING RODS WITH CONCRETE
3 10M REINFORCING ROD
4 HOLLOW-CORE CONCRETE BLOCKS
5 M12 x 200 mm ANCHOR BOLTS @ 1200 mm OC, INTO FILLED BLOCK CORES, TO TIE SILL PLATE TO FOUNDATION
6 MOISTURE-RESISTANT RIGID INSULATION BEVELED AT TOP
7 CEMENT PARGING OR PRESSURE-TREATED PLYWOOD
8 BACKFILL TO 150 mm BELOW TOP OF CONCRETE, SLOPE SOIL AWAY FROM GREENHOUSE FOR DRAINAGE
9 CCA OR ACA TREATED 38 x 184 SILL PLATE
10 38 x 184 BOTTOM PLATE BEVELED TO SHED WATER
11 INSTALL FLASHING AFTER WALL FRAME IS MOUNTED ON SILL PLATE

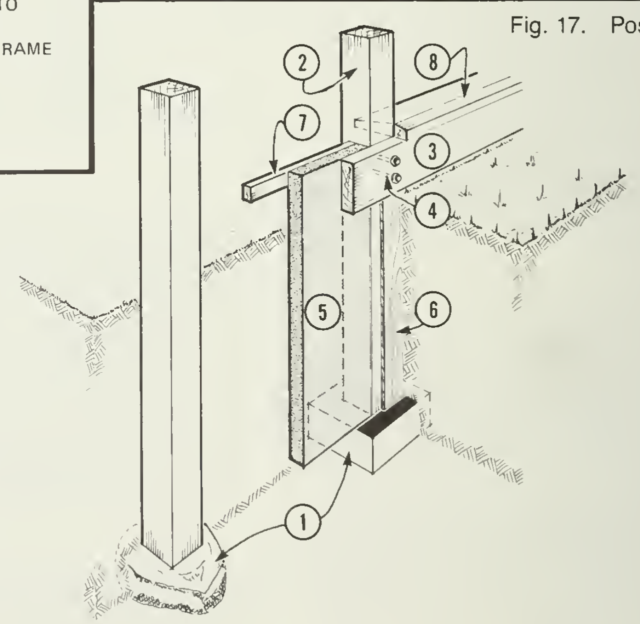
Make the frame no heavier than that which can provide the necessary structural support, so that it blocks as little solar radiation as possible. Although metal frames are strong, do not block much light, and can be purchased from greenhouse suppliers, they are expensive and often require specialized skills for installation. Therefore only wood frames are recommended here for the hobby greenhouse. Most people have the experience and the skills needed for designing and fabricating with wood. Further information on wooden-frame design can be found in *Canadian Wood Frame House Construction*.

The frame supports the glazing and all the solid portions of the roof and walls of the greenhouse. It also serves to tie the greenhouse structure to the foundation and to any attached building. The frame must be strong enough to support the weight of all expected wind and snow loads in your area.

The size of the wood members of the framing determines the load it can support. Table 1 gives the approximate spans considered to be safe for various roof-rafter members and specifies the type of glazing they can support. Assumed in this table are moderate snow loads and winds. In areas that receive a lot of snow or that are subjected to high winds, consult a local architect or construction engineer to ensure that your proposed frame can support expected loads. Fig. 18 illustrates the terminology used. Further guidelines for sizing wood-frame structural members are given in *Canadian Wood Frame House Construction*.

For vertical glazed sections on kneewalls and end walls, less framing support is required than is indicated in Table 1. Tempered or double glass can be adequately supported by 38 × 89 mm members. To accommodate extra insulation in the end walls and any unglazed sections of the roof, however, you may decide to fabricate the entire frame with 38 × 140 mm members. For vertical or steeply pitched kneewalls, support each rafter at its lower end

Fig. 17. Post foundation.



1 CONCRETE OR ROCK FOOTINGS, DEPTH OF FOOTINGS TO BELOW FROST LINE OR TO SOLID ROCK
2 89 x 89 CEDAR OR PRESSURE-TREATED (CCA OR ACA) POSTS, @ 1200 mm OC, TOP OF POSTS TO CORRESPOND TO TOP OF KNEEWALL OR TOP OF VERTICAL GLAZING
3 38 x 140 CCA OR ACA PRESSURE-TREATED SUPPORT BOARD, BOLTED TO POST
4 THROUGH BOLTS
5 MOISTURE-RESISTANT RIGID INSULATION
6 PRESSURE-TREATED PLYWOOD TO PROTECT INSULATION
19 x 38 TO SECURE INSULATION TO SUPPORT BOARD
8 38 x 140 CCA OR ACA PRESSURE-TREATED SILL PLATE BETWEEN POSTS, BEVELED TO SHED WATER TO INTERIOR AND EXTERIOR

NOTE: IF ROUND POSTS ARE USED, MIN. DIAM. SHOULD BE 150 mm

Table 1. Acceptable spans for solid-timber roof rafters*

Rafter size (mm)	Glazing	Rafter spacing (mm)	Rafter span (mm)
38 × 89	single glass	600	2.4
38 × 89	double glass or tempered single glass	600	2.4 with mid support
38 × 89	single glass	600	3.6 with mid support
38 × 140	double glass or tempered single glass	900†	2.4
38 × 140	single glass	600	3.6
38 × 140	double glass or tempered single glass	600	3.6 with mid support
38 × 89	solid roof	400	2.4
38 × 89	solid roof	600	1.8
38 × 140	solid roof	400	3.6
38 × 140	solid roof	600	3.0

*Based on lumber of No. 2 grade or better.
†Representative of the on-center spacing required for one of the standard-size patio door lites.

by a corresponding vertical or steeply pitched wooden frame member.

Use good-quality wood for the frame members. All pieces of wood should be straight, not warped, twisted, or bent. There should be few knots and no unsightly oozing sap.

For frame members that come in contact with a lot of moisture, as does for example the sill plate, use rot-resistant woods such as red cedar or redwood or use wood that has been pressure treated with a preservative containing copper napthanate. In addition, ensure that water can drain off these surfaces. Do not treat wood with creosote or pentachlorophenol. Refer back to the section "Rot Prevention" for further details.

Several structural framing options are illustrated in Figs. 18–21. The center-to-center spacing of the rafters and wall studs can be varied to suit the size of glazing used, as long as all snow, wind, and glazing loads are considered.

Fig. 18 illustrates a typical framing structure used with continuous foundations such as poured-concrete, concrete-block, and slab types. This same frame modified for attached greenhouses is shown in Fig. 19. A frame for use with post foundations is shown in Fig. 20. Fig. 21 illustrates the framing used for a freestanding Brace solar greenhouse.

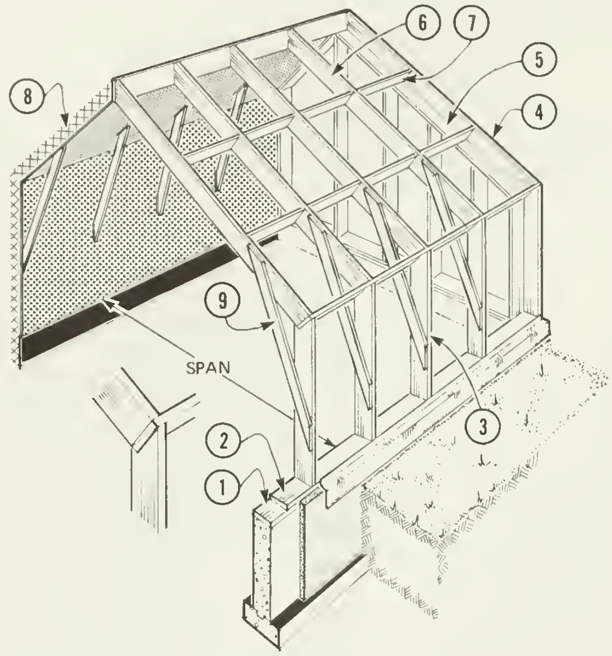
For freestanding greenhouses with floor plans larger than 2.5 × 3.5 m use ties to join the midpoints of opposing rafters. These rafter ties are needed to reduce spreading of the walls and thereby keep the roof from collapsing. They can be made of wood or galvanized cable, but galvanized cable is preferred because it obstructs less light. Generally, tie every second glazing rafter to the rafter opposite it on the adjacent sloping roof section, at midpoint.

For attached greenhouses, a 38 × 140 mm plate (Fig. 20) is fastened by lag screws into the studs of the house wall. This plate is used as a base for supporting the greenhouse rafters.

Additional framing needed to support the various types of glazing that are available is discussed and illustrated in the section "Glazings."

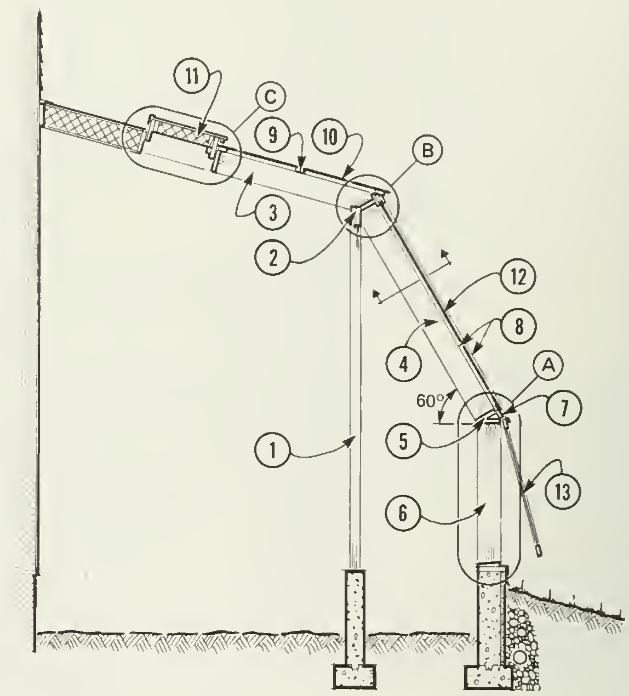
Framing and sheathing for a solid roof and wall—For solid, unglazed sections of the end walls facing east and west, unglazed sections of the roof, and in the case of freestanding greenhouses, the north wall and roof, follow standard framing construction practice. Use the same spacing between the rafters and studs as that used for the glazed areas, and make the wood members the same size. Be sure to calculate whether this rafter-and-stud configuration can support the expected loads exerted by the wind, snow, and wall materials. Acceptable rafter specifications for solid roof framing are given in Table 1.

Fig. 18. Glazing and end wall framing.



1 SILL PLATE
2 BEVELED BOTTOM SILL
3 VERTICAL KNEEWALL, 38 x 140 VERTICAL FRAMING
4 END WALL
5 END WALL TOP PLATE
6 38 x 140 RAFTERS
7 BLOCKING
8 INSULATED NORTH WALL AND ROOF
9 RAFTER BRACING

Fig. 19. Frame for attached greenhouse showing alternate kneewall eave assembly and roof eave assembly.



1 89 x 89 POST
2 2–38 x 140 BEAM
3 38 x 140 CEILING RAFTER
4 38 x 140 GLAZING SUPPORT BEAM
5 38 x 140 EAVE ASSEMBLY
6 38 x 140 VERTICAL SUPPORTS
7 CONTINUOUS 19 x 64
8 19 x 66 GLAZING SUPPORT AND BATTENS
9 GLAZING SUPPORT
10 FRP GLAZING
11 INSULATED UPPER VENT
12 860 x 1930 x 16 TEMPERED THERMOPANE
13 LOWER VENT, HINGED AT TOP, GLAZED WITH FRP

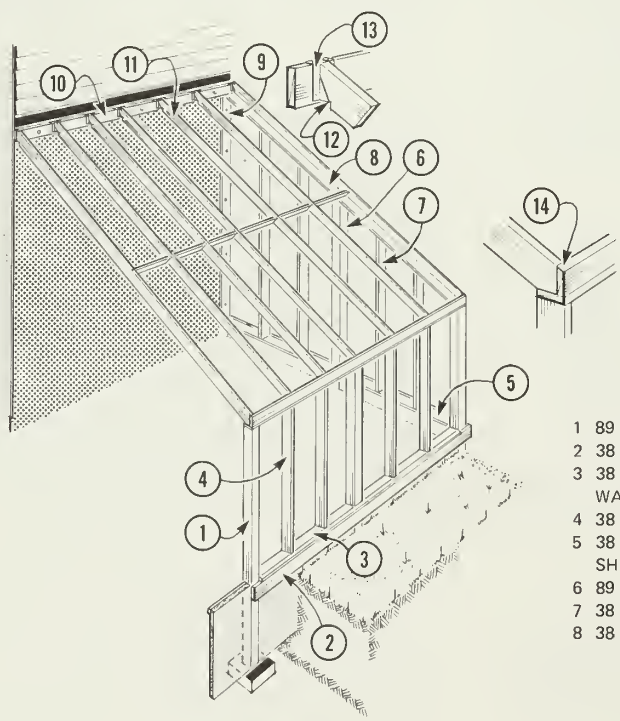


Fig. 20. Glazing and end wall framing with wood post foundation.

1 89 x 89 POST, 1200 mm OC
2 38 x 140 SUPPORT BOARD BOLTED TO POSTS
3 38 x 140 SILL PLATE, BEVELED TO SHED WATER TO INTERIOR AND EXTERIOR
4 38 x 89 VERTICAL SUPPORTS
5 38 x 140 END WALL SILL PLATE BEVELED TO SHED WATER TO INTERIOR
6 89 x 89 END WALL POST
7 38 x 140 END WALL VERTICAL SUPPORTS
8 38 x 140 END WALL TOP PLATE
9 38 x 140 END WALL PLATE BOLTED TO WALL OF HOUSE
10 38 x 140 RAFTER SUPPORT PLATE, BOLTED TO HOUSE
11 38 x 140 RAFTERS
12 NOTCH IN RAFTER TO ACCOMODATE JOIST HANGER
13 JOIST HANGER
14 38 x 140 EAVE ASSEMBLY, TOP BEVELLED TO MATCH RAFTER SLOPE

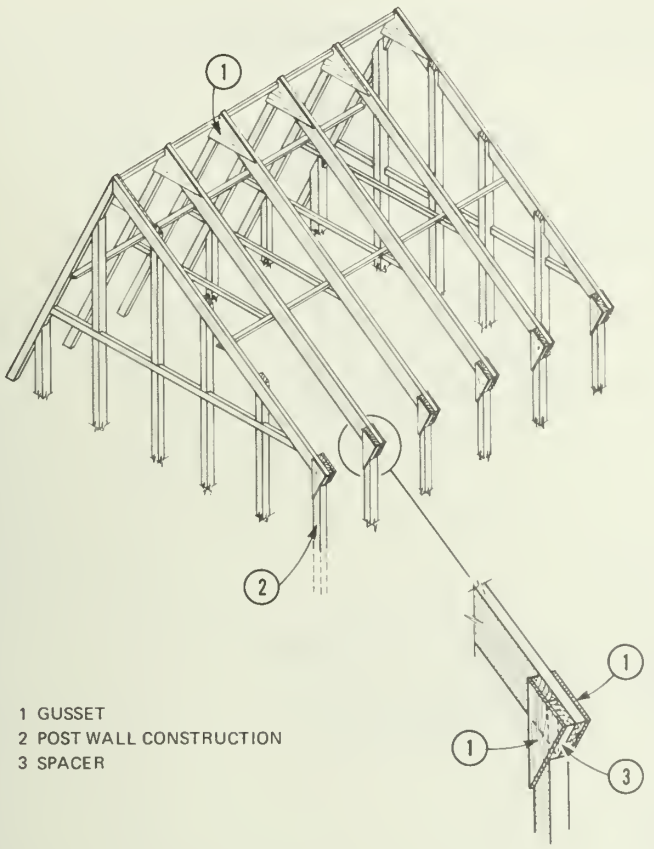


Fig. 21. Framing for a freestanding Brace greenhouse.

Ensure that the covering of the inside of the greenhouse is moistureproof because the interior atmosphere is so humid that during very cold weather water vapor condenses on inside surfaces. To protect the solid portions of interior walls and roof, pay particular attention to the following suggestions.

- Use only fiberglass or polystyrene insulation.
- Use a continuous polyethylene vapor barrier attached to the surface of the studs and rafters.
- Use exterior-quality cover materials on the inside, such as water-proof gypsum board, exterior siding, milk parlor sheathing, or exterior-grade plywood.
- Use galvanized nail and screw fasteners, which do not rust or cause discoloration.
- Prime all interior surfaces.
- Caulk all joints, holes, and cracks with latex or butyl caulking.
- Paint with two coats of exterior paint.

Insulate the solid portions of the roof and walls to at least RSI 3.5. Because most of the heat loss occurs through the glazing, upgrading roof and wall insulation to RSI 4.9 is cost effective only when you plan to put glazing insulation in place at night.

The exterior covering of attached greenhouses should match the covering of the main house. To keep a partially glazed south-sloping roof from leaking overlap the upper edge of the glazing with the covering material used on the solid portion. Corrugated metal roofing material with corrugations corresponding to those in the fiber-reinforced polyester glazing can be purchased and installed. The corrugated metal should overlap the polyester glazing. Use silicone sealant to seal the joint between the metal roofing and the glazing.

Glazing

No glazing material on the market today can satisfy all the requirements of a solar greenhouse. The best choice for glazing depends on your specific application and your resources. Ideally, the glazing material should admit virtually all the solar radiation incident on it while blocking the escape of thermal radiation from inside. It should be highly resistant to impact, so that it can withstand damage from hail and stones. It should also be able to support heavy snow and wind loads, to withstand exposure to extreme climatic conditions for many years, and to resist abrasion, scratching, and chemical attack by atmospheric pollutants. The material should be readily available, inexpensive to purchase and maintain, easy to handle and install, and appear attractive.

Table 2 lists the properties of most glazing materials suitable for greenhouse applications. Table 3 compares some of the advantages and disadvantages of these materials. The information contained in these charts was extracted primarily from the January 1982 issue of *New Shelter Magazine*. The costs are based on early 1982 retail prices from various manufacturers and dealers across Canada.

The final appearance of a greenhouse in an urban area is important. A transparent glazing is also probably preferable to a translucent one, especially in an attached greenhouse.

The glazing material that most meets these requirements is glass. One of the most popular choices is the double-glazed, tempered glass units sold as replacements for patio doors. Produced in a few standard sizes, these units are often substantially cheaper than regular thermopane window panels. However, glass has two major disadvantages: its cost and its fragility. Where vandalism is a problem, glass may not be the best choice. A good polycarbonate plastic is more resistant to breakage, less expensive, and easier to work with than glass. On the other hand, plastics are not as durable as glass. Ultraviolet rays from the sun cause plastic to turn yellow and become brittle. With time, dust and dirt can abrade the surface and variations in the ambient temperature can cause the surface to crack.

Greenhouse glazing should have a high solar transmittance, to allow as much sunlight as possible to enter the structure. The material should also have a low infrared transmittance, to be able to effectively block the escape of thermal radiation to the exterior.

Table 2. Properties of material suitable for greenhouse glazing*

Glazing	Installation	Lifespan (years)	Cost† ($/m²)	Solar transmittance (%) Single	Double
Glass, untempered					
•rigid flat sheets •numerous sizes available •thickness, 2–6 mm •transparent •IR transmittance, ≤2% •impact resistance, very low	•mount bottom edges on compressible neoprene setting blocks •seal edges with butyl tape or silicone sealant •mount on vertical or near vertical	≥50	7–40	85–90	72–81
Glass, tempered					
•same as for untempered glass	•same as for untempered glass •can be mounted at lower edges	≥50	14–60	85–90	72–81
acrylic, single-wall					
•rigid flat sheets •various sizes available •thickness, 3–6 mm •IR transmittance, ≤6% •transparent •max. service temp., 70–90°C	•use mechanical compression fastenings around all four edges •allow for expansion and contraction when mounting •do not use through bolting or nailing •use only silicone as a sealant	25	16–29	89	79
Acrylic, double-wall extruded					
•rigid sheets •width, 1200 mm •lengths, to 4800 mm •thickness, 16 mm •transparent to translucent •no viewing possible •IR transmittance, ≤6% •max. service temp., 70–90°C •impact resistance, medium	•same as for single-wall acrylic, but seal open ends of extrusion channels •use aluminum tape or special sealing strips from manufacturer	25+	20–38	—	83

*Abbreviations: IR, infrared; UV, ultraviolet.

† 1982 price.

(continued)

Table 2. Properties of material suitable for greenhouse glazing (*continued*)

Glazing	Installation	Lifespan (years)	Cost ($/m²)	Solar transmittance (%)	
				Single	Double
Polycarbonate, double-wall extruded (thick sheets)					
•rigid sheets •width, 1200 mm •length, variable •thickness, 16 and 25 mm •translucent •IR transmittance, ≤6% •max. service temp., 90–131°C •impact resistance, high	•same as for double-wall extruded acrylic sheets	10–15	37–75	—	74–77
Polycarbonate, double-wall extruded (thin sheets)					
•rigid sheets •width, 1200–1700 mm •length, 2400–12 000 mm •thickness, 4–7 mm •translucent •IR transmittance, ≤6% •max. service temp., 90–130°C •impact resistance, high	•same as for double-wall extruded acrylic sheets	10–15	13–24	—	74–77
Polycarbonate					
•rigid flat sheets •various sizes available •thickness, 3–6 mm •transparent •IR transmittance, ≤6% •max. service temp., 90–130°C •impact resistance, high	•same as for single-wall acrylic sheets	10–15	20–60	86	74

(*continued*)

Table 2. Properties of material suitable for greenhouse glazing (*concluded*)

Glazing	Installation	Lifespan (years)	Cost ($/m²)	Solar transmittance (%) Single	Double
Cellulose acetate butyrate					
•rigid flat sheets •width, 915–1830 mm •length, 1800–3000 mm •thickness, 1.5–6 mm •transparent •max. service temp., 80°C •impact resistance, medium	•same as for single-wall acrylic sheets	10	7–19	90	81
Fiber glass reinforced polyester (FRP)					
•flexible, flat or corrugated sheets •width, 600–1500 mm •length, 2400–15 000 mm •thickness, 0.6–1.5 mm •translucent •IR transmittance, 2–12% •max. service temp., 90°C •impact resistance, medium	•ensure that fiber glass overlaps support frames by at least 20 mm •predrill holes for fasteners •oversize fastener holes by 3 mm to allow for expansion and contraction •special mounting hardware is available •maximum unsupported span for flat sheet is 750–900 mm and for corrugated sheet, 750–1200 mm	8–12	8.40–17	72–87	52–76
Polyethylene					
•rigid flat sheets •thin film •width, 900–12 800 mm •length, to 46 000 mm •thickness, 100–150 mm •translucent to transparent •IR transmittance, 90% •max. service temp., 60°C •impact resistance, very low •lifespan, 8 mo •UV resistance, 1–3 yr	•same as for single-wall •fasten with battens •wrap around mounting frame before fastening by stapling or nailing •mounting hardware available •maximum unsupported span is 1200 mm	0.66	0.30–0.55	90	81

Table 3. Suitability of greenhouse glazing materials*

Advantages	Disadvantages
Glass	
•excellent transparency and appearance •excellent resistance to UV, weather, and high heat •low thermal expansion and contraction •readily available •noncombustible, chemically inert •low IR transmittance	•low impact resistance •breakage creates safety hazard •heavy, requires strong supports •hard to handle on site •needs careful installation and mounting •homeowner cannot cut tempered glass to size
Acrylic	
•good transparency and appearance •good UV and weather resistance •lightweight •fairly easy to cut to size •low IR transmittance •moderate impact resistance	•high thermal expansion and contraction •susceptible to abrasion •softens under moderate heat •high cost
Polycarbonate	
•high impact resistance •good transparency and appearance •lightweight •low IR transmittance	•questionable resistance to UV and abrasion •high thermal expansion and contraction
Cellulose acetate butyrate	
•high impact resistance •good transparency and appearance •lightweight •moderate impact resistance	•high thermal expansion and contraction •questionable resistance to UV and weathering •softens under moderate heat
Fiber glass reinforced polyester (FRP)	
•very lightweight •moderate impact resistance •easy installation and mounting •readily available	•questionable resistance to UV, surface erosions, and heat •requires occasional surface recoating •high thermal expansion and contraction •hard to eliminate waviness from sheets
Polyethylene	
•very inexpensive •easy to install •many sizes available •very light weight •permeable to CO_2 •very easy to cut to size	•very short service life •poor weather and UV resistance •melts under moderate heat •susceptible to wind damage •possible fire hazard •poor visual appearance •easily torn or punctured •very high IR transmittance

*Abbreviations: UV, ultraviolet; IR, infrared.

The glazing material chosen also determines the type of support system required. Heavy glazings, such as glass, require a heavier support system than lighter glazing materials such as thin-walled polycarbonate or polyethylene film. Heavy support systems serve to block out more sunlight. A good greenhouse design takes into consideration the relationship between glazing material and its support structure, to maximize the entry of solar and sky radiation into the structure.

The inner glazing of your greenhouse need not consist of the same material as the outer glazing. A less expensive, seasonally removable glazing may be more convenient on the interior. Visit a few solar greenhouses in your area to compare the appearance of the various types of glazings that are available and to assess how well they work. A few details necessary for the proper installation of some of the various glazing systems that are available are given below.

Recycled windows—Using recycled windows is one way of keeping the costs low. Use them only on vertical walls because windows are not designed to shed water and snow when mounted on a slope. Recycled windows should be reconditioned before installation. Scrape off old paint, reapply putty, prime, and carefully repaint. Install them as illustrated in Fig. 22-1. Position the window stops so that the exterior surface of the window is flush with the outside surface of the frame. Screw the windows in place so that they can be removed to make any necessary repairs. Polyethylene used as an inner glazing can be installed as in Fig. 22-1, using wood battens.

When recycled windows are used for the inner glazing as well as the outer glazing (Fig. 22-2), vent the air space between the windows to reduce condensation between glazings. Drill a hole with a diameter of 12 mm at the bottom edge of the outer window and another at the top, venting to the outside. When the window is larger than 1000 × 1000 mm, drill two holes at the bottom and two at the top. Insert a loose plug of fiberglass insulation in each hole to act as an air filter, and screen all the holes to keep insects out. Caulk all around the edges of the inner window on its exterior side before installing the outer window. Completely seal all the inner edges of the inner window, specifically all the joints between the glass and sash and the sash and frame, to prevent moist air from the greenhouse from entering the space between the windows.

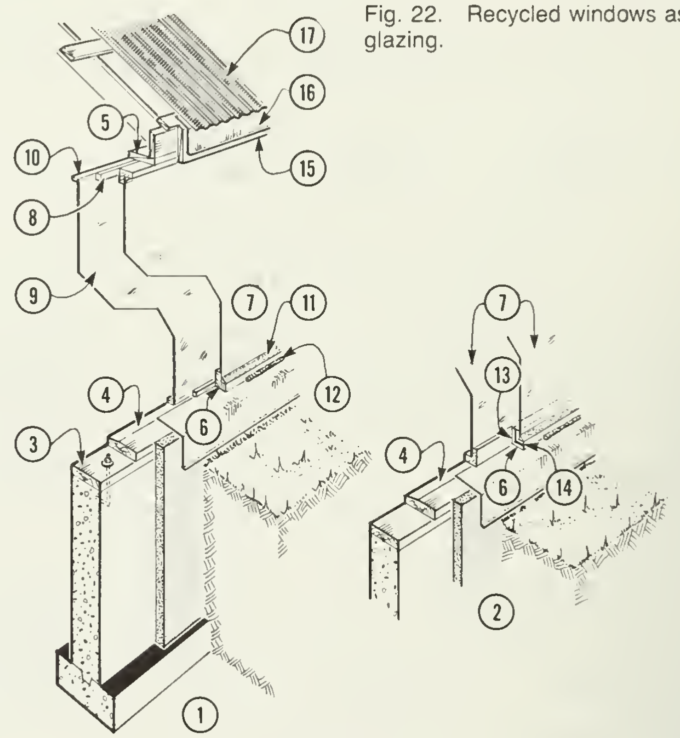


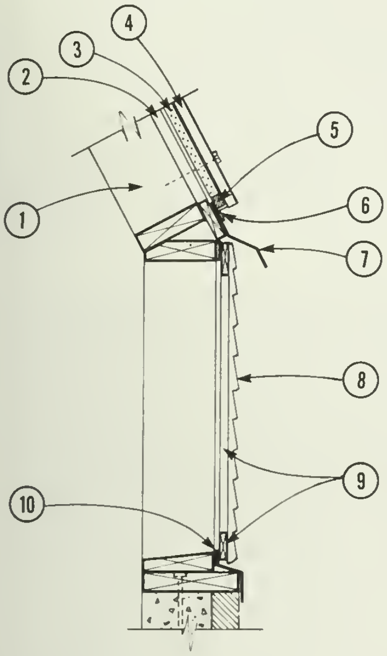
Fig. 22. Recycled windows as vertical wall glazing.

1 RECYCLED WINDOW WITH POLYETHYLENE INNER GLAZING
2 RECYCLED WINDOW WITH RECYCLED WINDOW AS INNER GLAZING
3 CCA OR ACA TREATED SILL
4 BEVELED BOTTOM PLATE
5 BEVELED TOP PLATE
6 BEVELED BOTTOM OF SASH TO MATCH BOTTOM PLATE BEVEL
7 RECYCLED WINDOW
8 WINDOW STOP
9 POLYETHYLENE INNER GLAZING
10 BATTEN
11 NEW PUTTY ALL AROUND
12 BUTYL CAULKING
13 CAULK BETWEEN WINDOWS BEFORE INSTALLING OUTER WINDOW
14 DRILL 12 mm HOLES ALONG BOTTOM OF WINDOW TO VENT AIR SPACE, DRILL HOLES EVERY 1000 mm, MAKE CORRESPONDING HOLES AT TOP OF WINDOW
15 TRIM
16 FLASHING
17 FRP OR OTHER GLAZING MATERIAL ON SLOPED ROOF SECTION

Tempered sealed glass—Tempered sealed glass, or thermopane, can be ordered in any size convenient for your greenhouse frame. However, custom orders can cost a lot of money. For standard-sized patio door lites, purchased at the best price, the cost can be as low as $30–35 a square metre. Patio door lite standard sizes are 860 × 1930 mm and 1170 × 1930 mm. They typically come with a 5-year guarantee against breakage of the seal. Verify that the guarantee is valid for greenhouse use and for units installed on a slope.

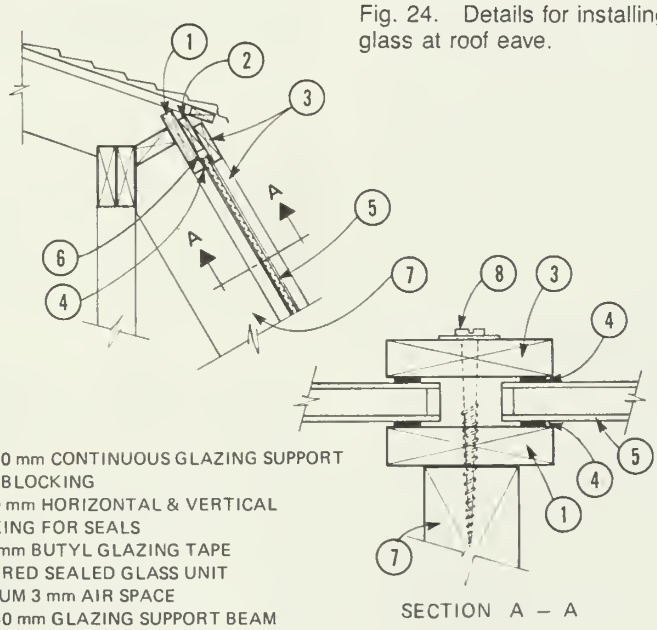
Figs. 23 and 24 show the principal elements of installation of the smaller-sized patio door on a 38 × 140 mm framing of an attached greenhouse. This installation is for unframed glass panels. When installing the glass, leave a space of at least 3 mm all around the outer perimeter, between the glass and any wood or other glass panels, to allow for thermal expansion of materials. Ensure that the surface of the greenhouse frame supporting the glass is not warped and that all framing members are in the same plane. Otherwise, when the battens used to hold the glass panels in place are tightened, the glass or the seal may break.

Fig. 23. Installation of tempered sealed glass and kneewall vent.



1 38 x 140 mm GLAZING SUPPORT BEAM
2 19 x 64 mm GLAZING SUPPORT, CONTINUOUS TOP AND BOTTOM, ALONG SUPPORT BEAMS (1)
3 860 x 1930 x 16 mm TEMPERED SEALED GLASS UNIT
4 19 x 64 mm BATTEN
5 NEOPRENE SETTING BLOCK, 3 mm THICK
6 19 x 38 x 3 mm ALUMINUM ANGLE, 150 mm LONG
7 FLASHING
8 CORRUGATED FRP
9 VENT FRAME
10 WEATHERSTRIPPING

Fig. 24. Details for installing tempered sealed glass at roof eave.



1 19 x 140 mm CONTINUOUS GLAZING SUPPORT
2 19 mm BLOCKING
3 19 x 89 mm HORIZONTAL & VERTICAL BLOCKING FOR SEALS
4 3 x 10 mm BUTYL GLAZING TAPE
5 TEMPERED SEALED GLASS UNIT
6 MINIMUM 3 mm AIR SPACE
7 38 x 140 mm GLAZING SUPPORT BEAM
8 STAINLESS STEEL ROOF SCREWS 400 mm oc

Install 19-mm-thick support pieces for the glazing and apply 3 × 10 mm butyl glazing tape to those surfaces on which the glass is to rest. Set the glass in place. Support it in position with neoprene setting blocks placed along the bottom edge and with aluminum angle screwed into the wood. Place a layer of butyl glazing tape around the perimeter of the glass panel, on the exterior surface, before installing the battens. This glazing tape is used to make a seal at the wood-and-glass interfaces and also to smooth out minor imperfections in the wood surface so that the glass can be compressed against a uniformly flat surface. Continue tightening the battens only until the butyl begins to squeeze out between the batten and the glass. The neoprene support blocks along the lowest edge of the glass are used to maintain an expansion space and to cushion the glass. Do not use a batten along the bottom edge of the glass because it tends to absorb and hold rain and snow.

Polyethylene—Polyethylene film is the least expensive glazing material available and the easiest to install. It is also the least durable. Regular polyethylene may last only 6 months as an exterior glazing. As an interior glazing layer, it can last for 2 years or more. Polyethylene treated against ultraviolet degradation may last 3 years as an external glazing and longer as an interior layer. Therefore when using polyethylene as a glazing material, choose ultraviolet-resistant polyethylene with a thickness of 150 μm as the outer glazing layer and regular polyethylene with a thickness of 100 μm as the inner layer.

When installing polyethylene temporarily, until a more durable alternative can be purchased, build the greenhouse frame to accommodate the permanent glazing. Polyethylene film can be made to accommodate almost any frame spacing that other types of glazing dictate.

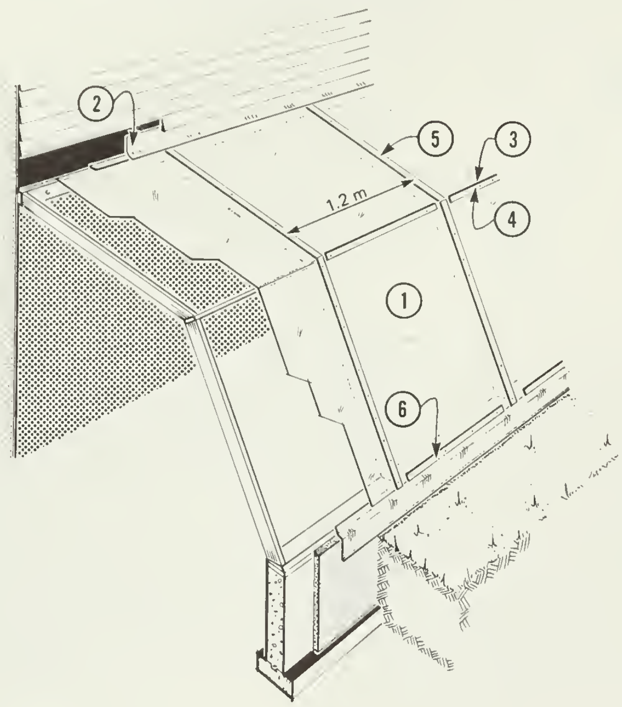
Install the polyethylene as shown in Figs. 25 and 26. Use continuous battens at a maximum of 1.2 m apart, with nails spaced every 200 mm, to hold the polyethylene to all framing supports. Otherwise the film might flap and tear against the frame members. Stretch the polyethylene tight during installation. The more securely the outer layer of this material is battened down, the longer it will last.

Corrugated fiber-reinforced polyester—Fiber-reinforced polyester (FRP), also called fiberglass, is a very strong glazing that is difficult to break. FRP is available in standard corrugations or in a step pattern resembling the surface of clapboard siding. FRP comes in a variety of qualities and generally in two thicknesses. The lowest-quality material is not suitable for greenhouses. Only FRP with an ultraviolet inhibitor in the resin is durable enough to last several years. The best buy is the FRP that comes with a thin coating on one side that protects the plastic against weather-induced abrasions. Install this glazing with the coated side facing the exterior. The thinner sheets of FRP are best suited to interior glazing and the thicker ones are typically used on the exterior. The corrugated sheets are available in widths of 660 and 1270 mm.

To install corrugated FRP, obtain the necessary instructions from the supplier. A few helpful hints and important points to remember are outlined below and are illustrated in Fig. 27.

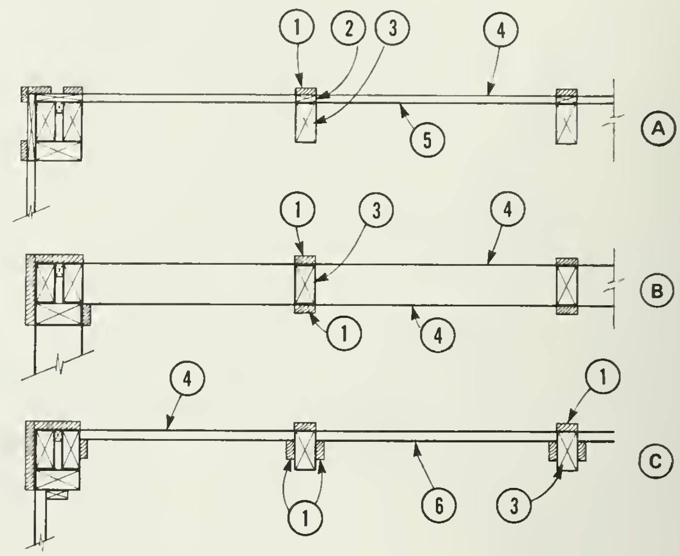
Store the sheets of FRP awaiting installation in the shade in a dry place. Humidity and high temperatures in stacked sheets of FRP cause the surfaces to become milky. Cut FRP with tin snips or a

Fig. 25. Installation of polyethylene glazing.



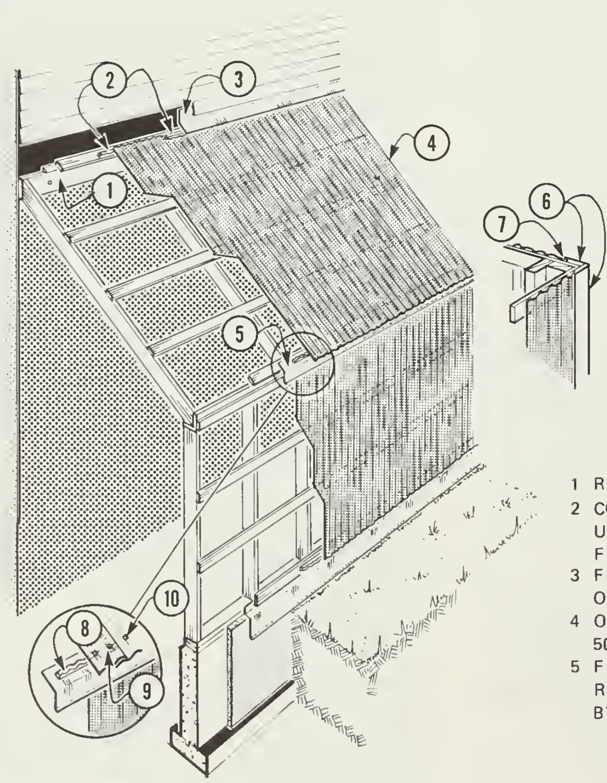
1 CONTINUOUS POLYETHYLENE SHEET
2 FLASHING OVERLAPS TOP BATTEN
3 NO BATTEN AT LOWER EDGE OF ROOF
4 TAPERED BATTEN AT TOP OF KNEEWALL
5 BATTEN
6 BATTENS PLACED TO ALLOW WATER TO DRAIN OFF

Fig. 26. Alternate double glazing details for polyethylene.



1 BATTENS
2 SPACER
3 FRAMING MEMBER
4 CONTINUOUS SHEET HELD BY BATTENS (1)
5 CONTINUOUS SHEET HELD BY SPACERS (2)
6 INNER SHEET TO FIT BETWEEN (3), HELD BY BATTENS (1)

Fig. 27. Corrugated fiberglass glazing.



1 RAFTER PLATE FASTENED TO WALL OF HOUSE
2 CORRUGATED GLAZING SUPPORT STRIPS, UPPER STRIP IS INVERTED TO ACT AS FLASHING SUPPORT
3 FLASHING INSERTED UNDER SIDING AND OVERLAPPING FRP GLAZING
4 OVERLAP SIDE OF GREENHOUSE AT LEAST 50 mm TO ELIMINATE NEED FOR FLASHING
5 FLASHING DETAIL CAN BE ELIMINATED IF ROOF FRP OVERLAPS VERTICAL WALL BY 100 mm
6 RABBETED CORNER STRIPS TO RECEIVE EDGE OF GLAZING
7 CAULK
8 CORRUGATED GLAZING SUPPORT STRIP
9 SILICONE CAULK UNDER FRP AT JUNCTION WITH CORRUGATED SUPPORT STRIP
10 GASKETED NAILS AT PEAKS ONLY ALONG SLOPING GLAZING

carbide-tipped circular saw blade. Predrill all nail or screw holes through the plastic, to prevent the FRP from cracking. Use neoprene washers with fastening nails or screws to prevent leaks. Caulk all joints between sheets of FRP and between the wood frame and FRP with silicone sealant. Silicone is preferable because it does not react adversely with the resin in the plastic and it can absorb movements of the contacting surfaces caused by thermal expansion and contraction.

Use corrugated sealing strips of solid rubber or wood under the ends of the sheets and seal off any remaining air leaks with silicone sealant. Do not use end strips of foam rubber because these degrade within a few years. Fasten wood purlins to the rafters to support the sealing strips and the FRP sheets. The size of purlin selected and the spacing used between them depend on the rafter spacing and the strength of the FRP sheet. Obtain purlin specifications from the supplier of the FRP sheets. Begin installing the FRP at the bottom leeward corner of any sloped area. Then you can overlap subsequent sheets in such a way that wind-blown rain cannot be forced underneath the joints.

Cooling and ventilation systems

Cooling and venting are closely related. The techniques used for one are often used for the other. Cooling deals with keeping interior temperatures in the greenhouse from becoming so high that crop production falls off or that the plants suffer heat-related damage. Ventilation, besides assisting in cooling the greenhouse interior, circulates fresh air around the plants, which provides them with the carbon dioxide necessary for photosynthesis and the oxygen needed for respiration. Ventilation can also reduce the relative humidity in the greenhouse when levels are too high. High humidity stresses many of the commonly grown plants and is conducive to the spread of diseases. Cooling becomes necessary whenever heat builds up to dangerously high levels. It is needed intermittently during all seasons but more often during late spring, summer, and early fall. Adequate ventilation, on the other hand, is a daily requirement for healthy plant production year round.

Thermal storage—Installing a thermal-storage unit reduces the need for cooling and venting inside the greenhouse. A thermal-storage unit absorbs some of the excess heat generated inside the greenhouse during the day and releases this heat at night when the ambient temperature is lower.

Shading—Shading is even more effective than thermal storage in reducing cooling and venting needs. Shading is achieved by using some device inside or outside the greenhouse, or even the greenhouse structure itself, to block out some of the sunlight before it can pass through the glazing.

Roll-down shades of slatted wood, bamboo, aluminum, or woven polyester can be installed outside, along the top edge of the glazing. These shades are unrolled to cover as much of the glazing as necessary during sunny days to maintain the desired interior temperature. Commercially available, slatted shades block between 50 and 75% of the incoming sunlight. The remaining light that penetrates is generally adequate for plant growth. Plastic shades tend to deteriorate after a few summers of exposure to ultraviolet radiation. Wood and metal shades last for many years when well maintained. These shading systems must be firmly attached along the top. To keep the shades from flapping in the wind, weight the bottom edge or install clamps along the sides and bottom to hold the edges down with battens.

Woven plastic shades cost about $10 a square metre; slatted wood shades are about double this cost; and slatted aluminum shades are approximately $35 a square metre. These prices include all hardware for attaching and operating the systems. They can be obtained from commercial greenhouse suppliers.

Another shading technique is to paint the exterior glazing with a shading compound. This compound usually comes as a paste in 4-L containers for $12–15 and is obtainable from greenhouse suppliers. The paste is then thinned with water to provide the desired amount of shading. A 4-L container covers up to 400 m^2 of glass. The coating gradually washes off in the rain, so that by late summer the glazing is nearly clear again. Use soap and water to remove any remaining traces. Avoid using any of the commercially available shading paints that may be toxic to lawns and gardens when they wash off. Furthermore, some compounds are not recommended for certain plastic glazings, particularly the film plastics and the fiber-reinforced polyesters.

Suspending cloth above the plants is another way to provide shade. You can cover the entire growing area or only certain specified areas. Commercially available shade cloth from greenhouse suppliers can reduce light intensities by up to 95%. It can be mounted on overhead wire cables and sliding hooks or draped over simple wooden frames temporarily built over growing beds. This material costs $1–5 a square metre; the more costly materials provide more shade.

Low-sloping north roof sections or opaque sections on the south roof serve to cast shade toward the rear of the solar greenhouse during late spring and summer. Although overheating inside the greenhouse is thereby reduced, the plants in the north part of the greenhouse may suffer from lack of light. In greenhouses in which a lot of shade is cast on the beds along the north wall, locate crops there that do not need much light or leave the north beds unplanted until the sun is lower in the sky.

Natural ventilation—Solar greenhouses are designed to be airtight to help conserve heating energy in the winter. Controlled and adequate ventilation systems are therefore important to the successful operation of a solar greenhouse. During the summer when the demand for ventilation is highest, natural ventilation, as opposed to ventilating with electric fans, is best for routine venting needs. Besides saving energy, natural ventilation can save your crop if the electricity is temporarily cut off on a sunny day.

Natural ventilation makes use of wind. In areas where the wind always blows during the warm, sunny hours of the day, several windows or vents along both ends of the greenhouse are probably all that is necessary to keep the greenhouse air moving and mixing and to keep interior temperatures from becoming too high. In most places, however, the wind is irregular and unreliable, and air movement has to be induced by creating a chimney effect. To create this effect, install vents along the peak of the greenhouse roof and near ground level on the east and west ends. When the greenhouse is more than twice as long as it is wide, install some lower vents in the south wall as well. Then, even on hot, windless days, the warmer, more buoyant air rises and exits through the high openings near the roof, causing the cooler air at ground level to be sucked into the greenhouse through the low vents. Air movement may be slow, but the ventilation provided can be enough to maintain acceptable interior temperatures. Ensure that the total vent-opening area is at least one-sixth of the greenhouse floor area and that the total upper-vent area is 20–30% greater than the total lower-vent area.

All vents can be provided with either a manual or an automatic closing system. Manual systems can consist simply of a pole and slotted board (Fig. 28A) or they can involve a somewhat more sophisticated rack-and-pinion or gear-and-chain drive. Automatic systems range from the simplest and least expensive heat-motor type (Fig. 28B) through to thermostatically controlled types run by an electric motor, driven gears, or a chain drive (Fig. 28 C and D). The heat-motor type is activated by an increase or decrease in the temperataure of its surroundings. Basically it consists of a cylinder closed by a piston at one end and containing a liquid that expands and contracts. As the temperature of the air around the cylinder increases, the liquid inside expands and forces the piston out, thus opening the vent. When the cylinder cools down, the liquid contracts and the piston returns to its original position, thus closing the vent. Some of the cheaper heat motors are not very reliable. They can only lift limited weights of up to 4 kg. Vents weighing less than 4 kg are not heavy enough to seal tightly when they are shut down and unwanted heat losses may occur during the winter. In addition, some of the cheaper heat motors fail to open to their full range after several months of operation. Check out the various brochures on this product before you make a choice. Heat motors range in price from $25 to over $100.

For moving heavy weights, for example a row of heavy ridge vents, a thermostatically controlled electric motor can be used. The size of the motor depends on the weight of the vents. This type of vent operator is relatively expensive and depends on a reliable source of electricity. Ensure that the system you buy comes with a manual override in case of electrical failure. An automatic vent opener, complete with manual override and controls, capable of opening up to 5 m² of insulated or double-glazed vents, costs $400–500.

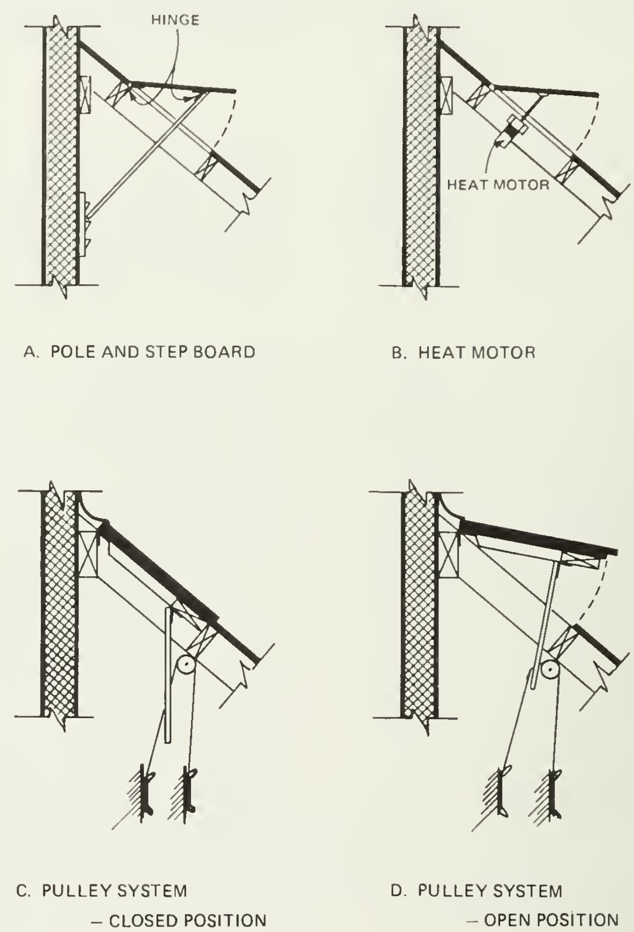


Fig. 28. Vent opening and closing techniques.

Forced ventilation—Forced-ventilation systems make use of fans to move the air. They can be less expensive to install than a series of vents along the roof and in the walls. One relatively small fan can replace several of these other vent openings. Furthermore, the fewer the openings, the less possibility there is of air leakage. However, the energy required to keep the fans running can be costly. Another disadvantage with fans is the noise they make, no matter how well they are mounted. The larger the fan, the more noise it makes. Assess the reliability of the electricity supply in your area when making a decision on the type of ventilation system best for you.

Fan sizing—Manufacturers of conventional greenhouses recommend that in the summer the ventilation system should be capable of providing one complete change of air every 2 or 3 minutes. The solar greenhouse, however, is not glazed on all sides like the conventional greenhouse and contains in addition a large heat-storage unit that provides considerable thermal inertia. Combined with some of the shading techniques outlined earlier, the solar greenhouse requires a lot less interior cooling than the conventional greenhouse. The appropriately designed solar greenhouse in your area may not even require any forced air ventilation at all, but if it does, the capacity of the fan need only be a quarter to a half that required for a conventional greenhouse. Consider a family-sized greenhouse with a floor area of 30 m. For an average height of 3 m, the total interior volume is approximately 90 m³. A conventional greenhouse of 90 m³ requires a ventilation rate of 500–700 L/s. But a solar greenhouse with appropriate shading might only require a fan capable of moving 140–380 L of air per second. The simplest arrangement for a forced-air ventilation system is an exhaust fan situated near the peak of one end of the greenhouse and a vent opening placed low on the wall at the opposite end. Equip the exhaust fan with shutters that are forced open by the moving air when the fan is on and that close by gravity when the fan is off. The vent opening can also be provided with louvers that open inward under the suction of the exhaust fan. Small, good-quality exhaust fans that use limited quantities of electricity can be inexpensively purchased. A fan providing air-flow rates of up to 100 L/s costs up to $100. A complete ventilation system for a family-sized greenhouse, including exhaust fan, motorized air intake louver, and thermostat control, costs about $240.

Glazing vents—Glazing vents are sections of the glazing material that can be opened to allow for air movement between the greenhouse and its surroundings. The vent consists of a frame to which the glazing is firmly attached, a hinge about which the frame pivots, and mechanisms with which to raise, lower, and hold the vent in position. Weatherstripping must be installed around the entire perimeter of the vent opening, so that all air flow is cut off once the vent is closed. Use hooks, eyes, or solid latches to hold the vent closed tightly enough that the weatherstripping is compressed between the perimeter surfaces of the vent and the greenhouse frame. All glazing vents should be double glazed and should swing open to the outside so that they do not interfere with plants growing inside. Generally vents are hinged along their uppermost surface and are appropriately flashed so that no water can enter. Vents in corrugated glazing material, however, require a bit more care. Corrugated glazing material normally comprises only the outer layer of a double-glazed surface, with flat, rigid glazing or film glazing on the inside. Use normal weatherstripping for the frame except at the corrugated ends of the glazing, where special corrugated weatherstripping has to be used between mating corrugated sections to properly seal the interface between the glazing and the frame at the corrugation.

Vents in solid portions of the wall and roof—Vents in the solid portions of the wall and roof are best made to fit between the studs or rafters of the existing frame. For details of various types of roof vents, see Fig. 29. Be sure that the frame of the vent fits snugly into the greenhouse framework when the vent is closed and that molding and weatherstripping are appropriately placed.

Ventilation in an attached greenhouse—Use the door and windows of the original structure to provide winter ventilation to the attached solar greenhouse. A small fan capable of handling 100 L of air per second can be installed high in the common wall to assist air circulation.

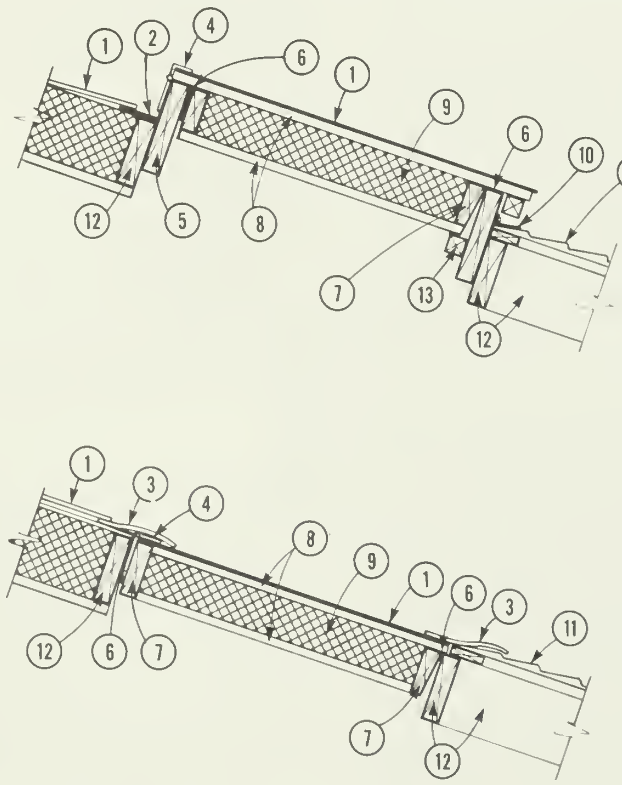


Fig. 29. Two types of solid roof vent.

Thermal storage systems

Storage of excess solar heat is one of the principal features that differentiates solar greenhouses from conventional ones. Excess heat generated in a solar greenhouse during sunny days is absorbed by a thermal-storage unit. The extraction process keeps the greenhouse cooler during the day. The stored heat can then be released when the greenhouse temperature drops at night or during cloudy periods. The heat is absorbed into the storage unit either passively or actively. A passive system requires no mechanical device of any kind, whereas an active system requires a fan or blower to circulate warmed air throughout the mass. Systems for the passive storage of solar heat are generally the most efficient, least expensive, and easiest to install and maintain. On the other hand, a passive system must usually be located in direct sunlight where it occupies valuable growing space. Active storage systems can be located well away from the growing space. However, installation of active-storage systems can be expensive and somewhat more complex than that of passive ones. At the very least they require an additional insulated volume and depend upon mechanical equipment for proper functioning. A few passive and active heat-storage systems using water, rock, concrete, and Glauber's salt are discussed below. Water, rock, and concrete store sensible heat. In other words they store heat as an increase in temperature of their mass. Glauber's salt stores heat by changing from the solid to the liquid phase at a precise temperature.

Table 4. Heat capacity of materials used for heat storage

Material	Density (kg/m³)	Heat capacity* (KJ/m³.°C)
Water	1000	4.19 × 10
Rock	2200	1.60 × 10
Clay brick	2000	1.65 × 10
Concrete	2200	1.60 × 10
Soil (medium moisture)	1600	1.80 × 10
Mud (saturated soil)	1900	3.00 × 10
Glauber's salt solution	1460	374 × 10

*At specified temperatures.

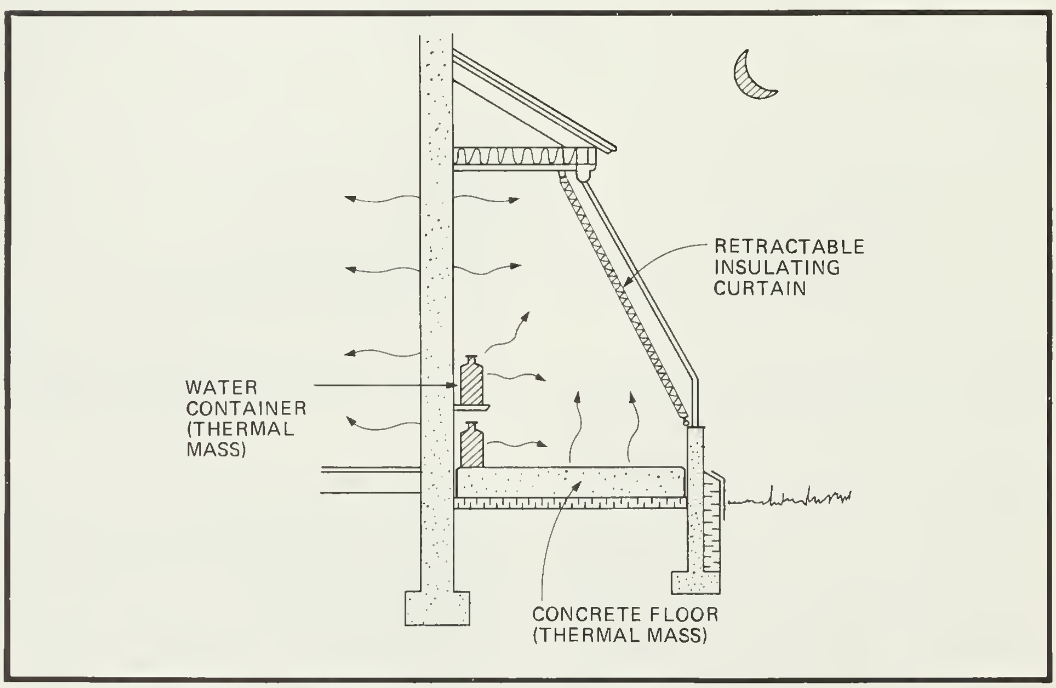


Fig. 30. An effective passive heat-storage system. The natural movement of air in the greenhouse serves to distribute the heat to and from the thermal masses.

Passive heat storage

Storage mass—Table 4 gives typical heat capacities for the storage materials listed above as well as for some other common materials.

For the most effective passive-heat storage, locate as much of the storage mass as possible in direct sunlight. A thermal mass exposed directly to the sun stores about three times more solar heat than an equivalent mass situated in shade. A heat-storage mass located just behind a south-facing, glazed kneewall or stacked up along the north wall (Fig. 30) effectively stores three times more heat than a similar mass located under the plant beds in the shade. The larger the thermal mass in the greenhouse, the more stable the daily temperature. Therefore out-of-the-way heat storage is often necessary to augment storage that is directly exposed to the sun. Install the shaded storage so that air can move freely above and below the unit along its sides. Natural convection and other air movement within the greenhouse then serve to carry heat to and from the storage unit.

Water is the most compact of the low-cost, sensible-heat-storage materials. For a given volume of heat-storage space it has approximately three times the heat storage capacity of rock or masonry and up to twice that of mud.

Although water is virtually free, the cost of the containers must be considered. Recycled containers such as 5-L plastic milk and juice jugs, 25-L honey or oil tins, and 200-L steel drums are commonly used in solar greenhouses. These containers can often be obtained free or at very little cost. The 200-L drums, cleaned out and ready to use, are easily obtained from used-drum dealers at $6–20 each. Good-quality drums are also available from oil merchants, some larger car dealers and repair shops, and chemical factories. Drums that have not already been cleaned inside and out before they are bought must be washed thoroughly before use in the greenhouse. Otherwise they may still contain dangerous chemical residues on the inside and potentially hazardous stains on the outside. Clean them well with a solvent such as kerosene or turpentine and rinse with water. Prime the exterior with antirust paint. Add rust inhibitor to the water used to fill the drums. Also add a small amount of motor oil. Oil floating on the surface of the water reduces evaporation from the drums and keeps the level of oxygen in the water low. Low oxygen levels in the water decrease the potential for rust formation.

Do not place water drums directly on the floor. Instead mount them on bricks or treated lumber. This arrangement reduces erosion of the bottoms of the metal drums, caused by condensing moisture. It also allows air to circulate under the heat storage units, thus increasing the rate at which heat can be transferred to and from storage.

Other water containers especially made for storing excess solar heat include fiberglass tubes and tanks in standard diameters of 300 and 450 mm and heights of 1200, 1500, 2400, and 3000 mm. These nonpressurized containers are usually equipped with plumbing fittings for interconnections. Dyes can be used in the water for decoration or improved absorption of solar radiation. Galvanized steel tanks, tanks that nest when they are stacked, and tanks that fit between studs in standard wall framing are also available.

Be sure to support large containers of water from below. Set tall cylinders, or several containers that are being stacked on top of one another, on a horizontal surface. Secure the water containers in place before filling them with water. Containers with capacities greater than 50 L are difficult to move when filled. When filling a container, leave about 25 mm at the top to accommodate volumetric expansion of the water as it cycles through the temperature extremes.

Water containers sometimes leak. Metal containers are more prone to leaking than are the specially manufactured plastic tubes and tanks. Nevertheless, make sure that the floor under all water containers is well drained so that damage to the greenhouse is minimal in case of leakage.

Another problem with water is that it can easily freeze during normal Canadian winters and damage the containers. With a large heat-storage unit in a well-insulated greenhouse, particularly one equipped with a backup heating system, freezing is not likely to occur.

When the greenhouse is not designed for use over the coldest winter months, however, use a drain-down system to remove the water from the storage containers over the winter. The most convenient method for draining the water from the tanks is to siphon it off. Another option is to attach a water-tight spigot at the lowest point on each container from which the water can be drained.

With a large heat-storage mass housed in large containers, interior temperatures of well below freezing must be sustained for several days before the water begins to freeze solid. This situation is not likely to occur in a maintained greenhouse. However, this example does demonstrate the leeway you have before freezing damage to the storage containers can occur. In a maintained greenhouse, a backup heating system ensures that the interior air temperature does not drop below some minimum set point, for example 5°C. This temperature, then, represents the lowest limit that can be attained by the water in the thermal-storage containers. It is not economical to fill all the storage containers with an antifreeze solution. It is far less costly to install an adequate sized backup heating system.

Rock and concrete, as heat-storage media, store about one-third as much heat for a given rise in temperature as an equal volume of water. Therefore for equivalent heat-storage capacity in a greenhouse, a much larger volume of rock or concrete is required than that of water.

There are definite advantages to using rock or concrete. Because these materials remain unaffected by low winter temperatures, the greenhouse can be left unattended over the winter without fear of damage to the heat-storage system. Furthermore, rock and concrete can serve as an integral part of the greenhouse structure on the floor while acting as the thermal storage mass. Dual use of these materials lowers the costs associated with the heat-storage system. Rock ordered in bulk by the truckload is a cheap thermal-storage material. The expense lies in the container needed to hold the rock in place. Rock in bulk costs $10 a cubic metre. Poured concrete put in place costs $170–250 a cubic metre. This cost can be reduced to $120–170 a cubic metre by providing your own labor.

Crushed rock or concrete floors need not be more than 100 mm thick in nonactive storage systems, unless a thicker floor is required for added strength. Heat absorbed at the upper surface of the floor does not penetrate further than 100 mm under typical daily variations in radiation and temperature. Similarly, any vertical concrete mass exposed only on one face should not exceed 150 mm. Any additional mass would have no economic value.

Glauber's salt is a thermal-storage material that makes use of latent heat, or heat of fusion, associated with the change in phase from a solid to a liquid. Heat is stored by liquefying the solid storage material and is recovered when it solidifies again. Glauber's salt, one of the most widely used phase-change materials, has a freezing point that ranges between 5 and 32°C, depending on additives. At about 24°C this salt has four times the heat-storage capacity of an equal volume of water that cycles through a temperature change of 10°. The real advantage to using a phase-change material such as Glauber's salt in a greenhouse is its large heat capacity contained in a small volume. This high efficiency significantly reduces the space required for thermal storage, thus freeing more space for growing plants.

Glauber's salt is packaged and marketed as ceiling and floor tiles, stackable trays, storage wall units, and cylindrical tubes. All packaging is fabricated to allow ease of heat transfer to and from the container. Per unit of heat-storage capacity, Glauber's salt is about 10 times more expensive than water in 200-L oil drums or about the same price to twice as expensive as water stored in commercially bought thermal-storage tanks.

The problems associated with using phase-change materials are gradually being eliminated as further improvements are made in both materials and containers. Some phase-change materials now on the market claim to be able to maintain a given level of performance through thousands of freeze–thaw cycles.

Estimating heat-storage requirements—A greenhouse can be heated entirely by the sun as long as it is furnished with a large enough thermal storage system. Usually, however, trade-offs are made between costs for thermal-storage and backup heat-

Table 5. Suggested quantities* of heat-storage materials for passive solar greenhouses

Degree-day zone (°C)	For season extension		For season extension	
	Free-standing	Attached	Free-standing	Attached
Water (L/m^2)				
up to 3500	80	40	120	80
3500–5000	100	80	160	120
5000–6500	120	100	200	160
6500–8000	140	120	240	200
Masonry (m^3/m^2)				
up to 3500	0.20	0.10	0.30	0.20
3500–5000	0.25	0.20	0.40	0.30
5000–6500	0.30	0.25	0.50	0.40
6500–8000	0.35	0.30	0.60	0.50
Glauber's salt (m^3/m^2)				
up to 3500	0.02	0.01	0.03	0.02
3500–5000	0.02	0.02	0.04	0.03
5000–6500	0.03	0.025	0.05	0.04
6500–8000	0.035	0.03	0.06	0.05

*Quantities are per square metre of glazing.

ing systems and between space requirements for thermal storage units and growing beds. When food production is a prime concern, the amount of thermal storage located inside the greenhouse is usually minimized.

An attached greenhouse can manage with less heat storage than a freestanding greenhouse in cold weather and some excess heat generated in the greenhouse on warm days can be vented into the house.

Table 5 gives the recommended quantities of water, masonry, and Glauber's salt per square metre needed to operate a passive solar greenhouse. The masonry is assumed to be stone, concrete, or bricks of moderate density, stacked no more than 200 mm thick. Half the south face of the storage mass is assumed to be exposed to direct sunlight for at least 4 hours a day.

The calculations on which the figures for Table 5 are based assume a well-insulated, double-glazed, low-infiltration greenhouse that employs no night insulation for the glazing.

Active heat storage

A thermal-storage mass that is isolated from the growing area and that requires fans or blowers to move interior air to and from the storage area for extraction and release of heat is known as an active thermal-storage system (Fig. 31). Active storage systems are commonly used to maximize the growing space within the greenhouse. The least expensive and least complicated type of heat-moving system for a family-sized solar greenhouse consists of a blower mounted near the highest point in the greenhouse, forcing warm air through ducting to a heat-storage mass located at a lower level or at ground level.

The thermal-storage mass is usually located under the greenhouse and consists of an insulated rock bed. Well-insulated thermal-storage areas are also sometimes built off one end or behind the greenhouse. Occasionally, a part of the greenhouse is sectioned off and the thermal storage mass is placed inside. All active systems rely on electrically driven fans or blowers to move the heat back and forth, a mechanism (often a baffles) to ensure uniform heat distribution throughout the storage mass, and a well-insulated storage area, or alternatively, a space that loses its heat predominantly to the greenhouse interior.

Active thermal-storage systems tend to incur higher installation costs than passive storage systems. They require an external power source to make them function and periodically they require maintenance and repairs to operate smoothly.

A rock bed is perhaps the most commonly used active thermal-storage system for solar greenhouses. The rock bed is usually placed under the greenhouse, with its surface serving as all or part of the greenhouse floor. The rock bed is typically quite shallow, with a maximum depth of 500 mm. The walls of the rock bed are typically made of concrete or concrete block and the top consists of a reinforced concrete slab. Air can be distributed throughout the rock bed by various means. A horizontal-flow rock bed system can distribute air through the side entries of hollow concrete blocks or through perforated corrugated plastic drain pipes. A vertical-flow rock bed can be constructed from spaced bond beam concrete blocks, overlaid with expanded metal lath to direct the air. Consult *A Guide to Rock Bed Storage Units*, a publication of the National Research Council of Canada, for further details on theory, construction, and cost of these active storage systems. Rock bed thermal-storage units typically cost $450–600 a cubic metre installed, including fans, dampers, controllers, and ducting. By doing the work yourself, these costs can be reduced to between $350 and $450 a cubic metre. Per unit of storage capacity this system is about twice as expensive as passive systems using water stored in commercially bought thermal storage tanks or about 20 times as expensive as water stored in 200-L drums.

Numerous arrangements can be devised for recovering heat from the greenhouse by blowing warm air through voids in a concrete slab floor. In one system 125 mm of concrete is laid on top of corrugated steel decking. Heat from warm air passing through the channels formed by the corrugations in the decking is transferred to the steel, and from the steel to the concrete. Extruded polystyrene insulation is placed under the corrugated steel. Another system consists of concrete blocks placed on their sides with the voids aligned to form channels through which warm air can pass. The supply-and-return manifolds are formed by leaving space between rows of blocks. These spaces are covered with corrugated steel decking and 100 mm of concrete is poured over the surface. A third system makes use of a floor slab comprising dozens of corrugated plastic drain pipes with a diameter of 200 mm. The drain pipes are set in concrete, and 100 mm of concrete is poured on top. The drain pipes act as air channels through the slab. The cost of these systems, excluding fans, dampers, controls, and ducting, is between $40 and $50 a square metre. More details concerning these units can be obtained from the May 1982 issue of *Solar Age Magazine*.

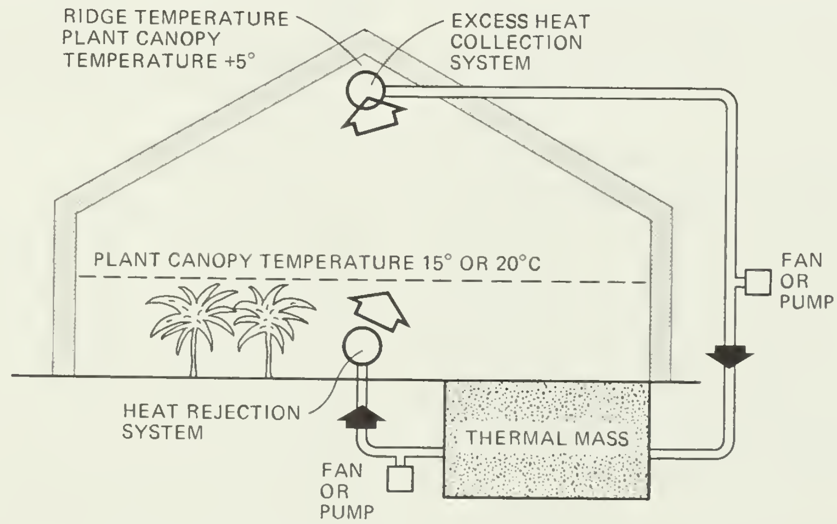


Fig. 31. In an active heat-storage system the thermal mass is isolated from the growing area. Fans and blowers move the heat to and from the thermal mass.

Backup heat

A greenhouse designed to be heated entirely by the sun is an expensive undertaking. If this option interests you, contact a solar greenhouse designer in your area. A less expensive plan is to rely on solar energy for heat under most weather conditions but to install a backup heater for operation during long, cold, cloudy days and very cold nights when enough solar energy cannot be generated to maintain an acceptable temperature range. When you are producing food year round in the greenhouse, a backup heater is good insurance against crop loss.

Heaters come equipped with thermostatic or manual controls. Thermostatically controlled heaters automatically turn on when the temperature falls below a preset minimum. Automatic operation is convenient in the early morning, in the middle of a cold night, or during absences of longer than a day. Manually controlled heaters are at least $20 less expensive than thermostatically controlled heaters, but they require more vigilance during the colder months.

Heating from the main building can often be used to supply an attached greenhouse with additional heat. Ensure first that the existing furnace or heaters in the house can indeed handle the extra load imposed by the heating of the greenhouse. Oil and gas furnaces are typically oversized in most Canadian residences built before 1970. Unless these systems have been downgraded in size as a means of conserving energy in the home, they likely have sufficient capacity to act as a backup system for an attached greenhouse. In these cases, simply extend the heat-supply network of the main house and locate one or more heat outlets in the greenhouse. Another way of gaining access to heat from the main house for heating the greenhouse is by ensuring good air circulation between the two structures. Simply open the windows, doors, and vents between the adjoining structures wide enough to maintain an acceptable temperature in the greenhouse.

For freestanding greenhouses and those attached greenhouses that are unable to use the heat supply of the main house, several backup heat options are available. Perhaps the least expensive to buy and install are the electric baseboard type of heaters. These are the most common choice for attached greenhouses and are becoming popular for small, freestanding structures. Their main disadvantage is the high cost of electricity as a heat source in most areas. However, when the greenhouse is well insulated and reasonably air tight, very little electric heat is needed.

Electric heaters are usually equipped with built-in thermostats. If yours is not, buy a separate thermostat to plug in line with the heater. Electric heater appliances should include fans to ensure forced-air circulation to all parts of the greenhouse. Electric heaters require a separate, heavy-duty electric line and receptacle. A 120-V, 1650-W electric heater with built-in circulating fan and thermostat costs approximately $75. A 220-V, 4000-W heater with fan and thermostat sells for about $200.

To estimate the size of electric heater needed for your greenhouse, use Table 6, adapted from the publication *Low Cost Passive Solar Greenhouses*, published by the National Center for Appropriate Technology. Table 6 assumes that the greenhouse is built to conform to the insulation, infiltration, glazing, and heat-storage standards presented in Table 5. It also assumes that night insulation is not being utilized.

Using the data from Table 6, the minimum size of electric heater required as a backup system for a freestanding, season-extending greenhouse with a glazing area of 15 m^2 in Edmonton (5589 degree-days) is

$$15 \text{ m}^2 \times 110 \text{ W/m}^2 \text{ of glazing} = 1650 \text{ W}$$

Heaters burning natural gas, oil, propane, or wood can also be used as backup heating systems in greenhouses. Wood stoves tend to be more time consuming and inconvenient to operate than the others. Depending on your location, however, wood can be an inexpensive energy source. A good-quality airtight wood stove, approved by the Canadian Standards Association and capable of heating a 25-m^2 greenhouse throughout the night, costs between $300 and $600. Chimney installation, heat-shielding materials for nearby flammable objects, and fans for heat distribution add a further $100–200 to this cost. Follow the manufacturer's guidelines for installation. Locate the stove centrally and provide enough stove and pipe shielding to allow the stove to be placed within 500 mm of beds and benches.

Heaters burning natural gas, propane, kerosene, and oil all make good backup heating sytems. Greenhouse manufacturers and suppliers sell these heaters. Their smallest units may be just the size you require. To determine the size of gas- or oil-burning heater needed, use the sizing chart for electric heaters in Table 6. These values in Table 6 must be increased by a factor of 1/0.8 to account for the lower efficiency of gas and oil furnaces. The steady-state efficiency of gas and oil furnaces is about 80%, whereas electric heaters are 100% efficient. Since the heat-output capacity of gas and oil heaters is still commonly expressed in British thermal units (BTU) per hour, multiply the wattage figure in Table 6 by 3.4 to obtain the number of British thermal units you need per square metre of glazing area. Then multiply this figure by the total number of square metres of glazed area in the greenhouse to give you the output capacity of the oil or gas stove you require. For example, a freestanding greenhouse with 30 m^2 of glazing being used for year-round production in Montreal (4471 degree-days) requires a gas- or oil-fired heater with a minimum output rating of

$$30 \text{ m}^2 \times 1/0.8 \times 110 \text{ W/m}^2 \text{ of glazing} \times$$

$$3.4 \text{ BTU/h per watt} = 14\,025 \text{ BTU/h}$$

This figure represents a very small gas or oil heater. Commercial greenhouse suppliers would probably not be able to supply units of less than 20 000 BTU/h output. Household-appliance dealers and hard-

Table 6. Minimum recommended capacity of electric heaters for passive solar greenhouses

Degree-day zone (°C)	Minimum heater capacity* (W/m² of glazing)			
	For season extension		For year-round operation	
	Free-standing	Attached	Free-standing	Attached
up to 3500	60	50	60	50
3500–5000	90	60	110	90
5000–6500	110	90	130	110
6500–8000	130	110	150	130

*These figures have been determined using 5°C as the minimum interior greenhouse temperature. Although no productive growth occurs at such a low temperature and warm-weather crops cannot survive such extremes, this minimum is sufficient to prevent cool-weather plants from freezing.

ware stores often stock smaller oil space heaters suitable for use in a greenhouse. These units typically cost less than $200. A gas space heater with a capacity of 20 000 BTU/h from a greenhouse supplier costs between $350 and $500.

Virtually all heaters burning gas, oil, propane, or kerosene require chimneys to vent the combustion gases from the greenhouse. The only exceptions are a few through-the-wall heaters that are installed much like window-mounted air conditioners. These units are sealed from inside the greenhouse. They draw their combustion air from and expell combustion gases to the outdoors. No chimneys or flues are required with these systems. Most fossil-fuel-fired heaters require, besides a chimney, access to an adequate air supply to support combustion (Fig. 32). A small duct leading from outside, through the wall, and terminating close to the heater suffices. Space heaters burning oil or gas offer thermostatic or manual controls.

With an automatic ventilation system used in combination with a vented gas- or oil-fired heater, thermostatic controls become essential. If the heater were to continue to operate after the automatic ventilation system had been triggered, the lower pressure created in the greenhouse by the venting fans would cause a downdraft to occur in the chimney. A downdraft could bring the combustion gases back into the greenhouse and cause harm to plants and people. To prevent a downdraft from occurring, set the thermostat on the ventilation fan a minimum of 5°C higher than the thermostat on the heater.

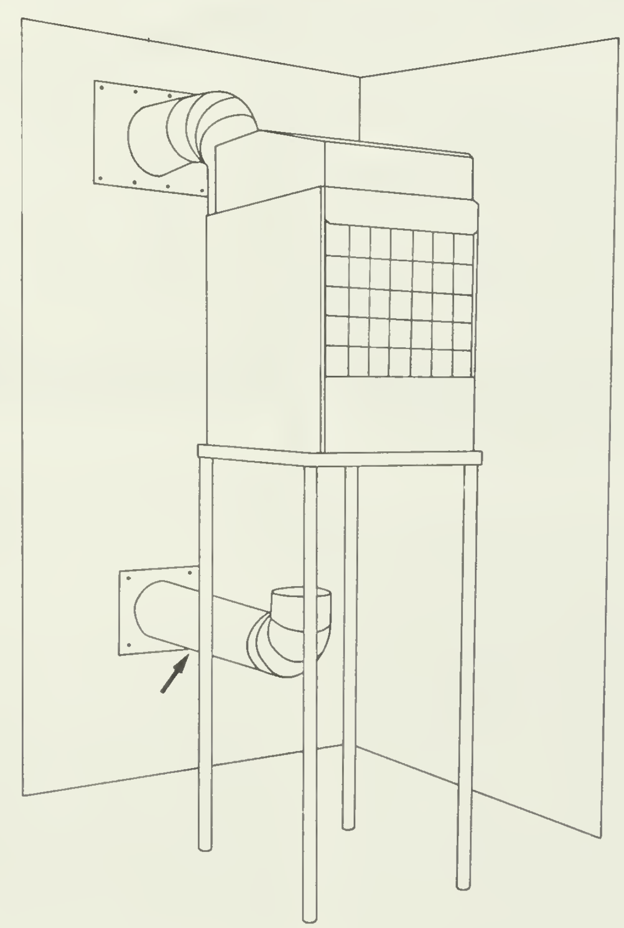


Fig. 32. A small gas-fired unit heater can be used to supplement a solar-heating system. Note the supply of fresh air to the heater.

Environment

A solar-heated greenhouse is designed to provide a controlled environment for growing plants all through the year. Nevertheless, maintaining an artificial environment requires constant attention. The successful grower must know the environmental needs of each crop and how to use the systems in the greenhouse to achieve proper conditions for growth.

To grow well, plants need temperatures within specific ranges; relative humidity levels between 60 and 80%; a carbon dioxide level around 300 ppm, close to that in the atmosphere; and adequate light.

The grower learns how to use the greenhouse and its systems as a tool to create and maintain this good plant environment. Temperature is managed by proper heat-storage capacity in the greenhouse, proper ventilation, and seasonal backup heating. Relative humidity and carbon dioxide levels are managed by proper use of the ventilation system. Inadequacies in light levels and day length can be compensated for by using artificial lights to start seedlings, by scheduling crops in the correct season, and by locating crops in the greenhouse according to their light requirements.

The layout of the greenhouse can be planned to take advantage of various climatic zones found within the greenhouse. Appropriate alternatives for placement of thermal storage areas, walkways, growing areas, and the various crops must always be considered.

Temperature

Solar greenhouses differ in their capacity to capture, store, and release heat, depending on their design. In Canada however, almost all solar greenhouses require some sort of auxiliary heat to keep temperatures on winter nights above a minimum of 6–10°C. Refer to the section "Backup Heat" in the "Construction" segment of this text for a thorough discussion of this subject.

Locate all auxiliary heating systems so that the heated air does not blow directly onto any of the growing areas. Place the heater toward the center of the north wall away from growing beds, either on the floor or on a small stand. A perforated, polyethylene tube attached to a small blower and leading from the heater can also be used to distribute the warm air.

All greenhouses require cooling during the summer and many must also be cooled during sunny days in the spring and fall, and even in the winter. The ventilation system, composed of ridge and kneewall vents, a side-wall intake vent, and an exhaust fan, comprises the cooling system in the greenhouse. It pushes hot air out of the greenhouse while drawing in cooler air.

The section "Cooling and Ventilation Systems" describes the various systems that are available and how they are best used to control temperature.

Relative humidity and carbon dioxide

The ventilation system, besides serving to remove excess heat from the greenhouse, also controls the relative humidity and the carbon dioxide content of the greenhouse air.

Air drawn in from the outside contains about 300 ppm of carbon dioxide. Air drawn in from a well-insulated house usually contains even higher concentrations of carbon dioxide, because during respiration people extract the oxygen component and expel air enriched with the carbon dioxide component. Because plants need carbon dioxide to produce sugars, they grow best in environments rich in this element. Commercial vegetable growers increase the content of carbon dioxide in their greenhouses to about 1500 ppm for some crops. Although this level is impractical for the home grower to maintain, the carbon dioxide level should be elevated as high as possible. A closed greenhouse may contain as much as 500 ppm of carbon dioxide at dawn, but on a sunny day levels may drop to less than 200 ppm in only a few hours when no fresh air is admitted. Low carbon dioxide levels slow growth significantly.

During the summer in dry climates, greenhouse air can become too dry for optimum growth. Increase the humidity around the plants by misting gently with a fog nozzle. A fine mist can be added to the air over walkways and beds alike. Walkways and floor surfaces can also be watered; as the moisture evaporates, the greenhouse air becomes more humid.

During the winter healthful levels of carbon dioxide and a relative humidity in the correct range may be particularly difficult to maintain. Attached greenhouses can exchange air directly with the home. However, freestanding greenhouses must be vented to the outside. Try to vent during the sunniest part of the day. Even so, on some cold days you may have to operate the heater while you vent, just to maintain the correct temperature. An interior circulating fan used during these periods disperses the excess humidity around the plants, thus reducing the chances of fungus diseases, and increases the plants' access to carbon dioxide.

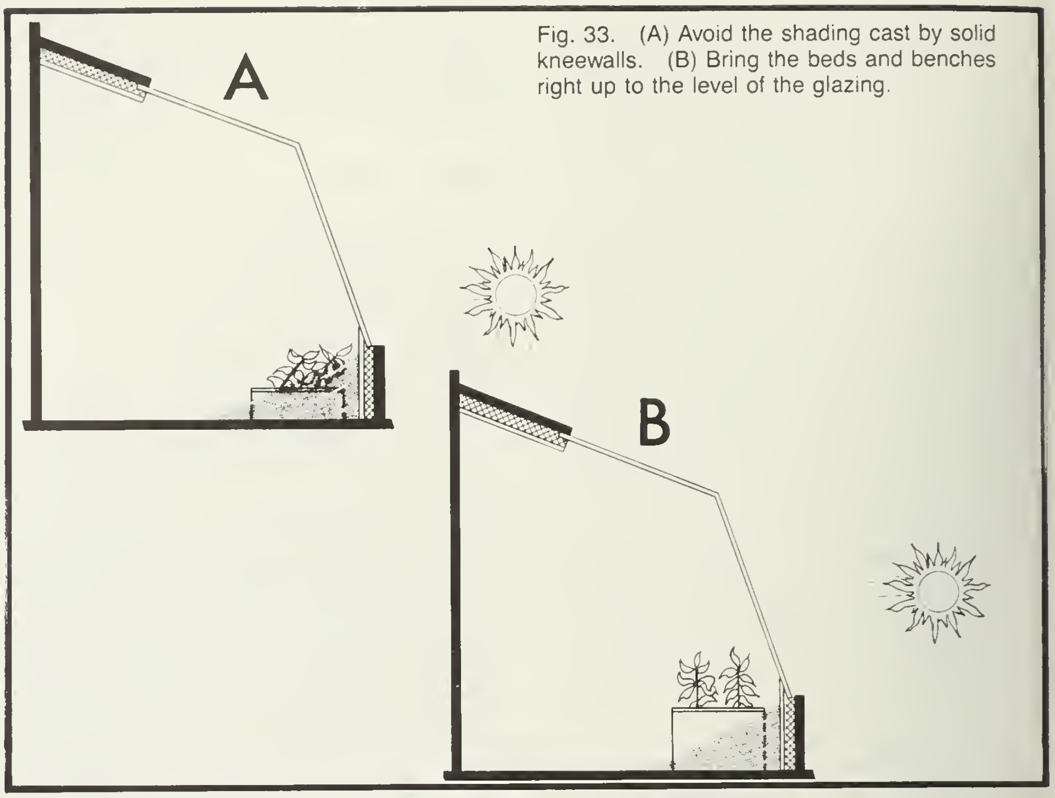


Fig. 33. (A) Avoid the shading cast by solid kneewalls. (B) Bring the beds and benches right up to the level of the glazing.

In larger, freestanding greenhouses and greenhouses attached to well-insulated homes, use an air-to-air heat exchanger to solve problems with both relative humidity and carbon dioxide while minimizing increased heating costs. Incoming, cool air drawn into the heat exchanger from outside is warmed by the warm interior air that is being exhausted. The two airstreams are separated in the core of the heat exchanger by thin-walled materials that allow heat transfer but no mixing of the air streams. Thus, heat is recycled and relative humidity and carbon dioxide levels are both adjusted.

Greenhouse design

For greatest thermal efficiency, the width of most attached solar greenhouses must not exceed 4.5 m. This rather narrow width limits the ways you can lay out the floor plan.

The best growing area is usually right up against the glazing, extending midway toward the back wall. This area generally receives the most light. Obviously the extent of this area varies somewhat, depending on the size of the insulated roof, the presence of any exterior obstructions that may shade parts of the interior, and the extent of insulation in the east and west walls. Use the following guidelines to determine the exact extent of the best growing area in your case and to optimize its use.

- To avoid the shading cast by solid kneewalls, bring beds or benches right up to the level of the glazing (Fig. 33). Adjust the greenhouse design to ensure adequate headroom for plant growth on the south side.
- Unless circulating fans are in constant use, cold air settles and remains at ground level. In greenhouses built at a level lower than that of the adjoining house, ensure that plant benches and beds are at least as high as the floor of the adjoining building, to keep plants raised out of the cold air that settles at floor level.
- Plants growing flush up against the glazing retain the cold air at plant level. Therefore leave a narrow space of 50–75 mm between the glazing and the bed or bench to allow the cold air to fall to the floor. This space also ensures that plants are not directly exposed to condensation dripping from the glazing.

Heat-storage placement

When water is being used for heat storage, you must determine the best location for the storage containers. Although the sunniest location is the most efficient place for heat storage, it is also the best place for growing plants. Some tradeoff therefore becomes necessary in laying out the components of the greenhouse.

Two good locations for passive heat storage containers are directly behind a south-facing, glazed, vertical kneewall and high along the north wall where they are directly exposed to the winter sun. When benches rather than beds are used for growing plants, storage containers such as 200-L drums can be used as bench supports along the north wall. There the drums are well exposed to winter sun and interfere least with optimum growing areas.

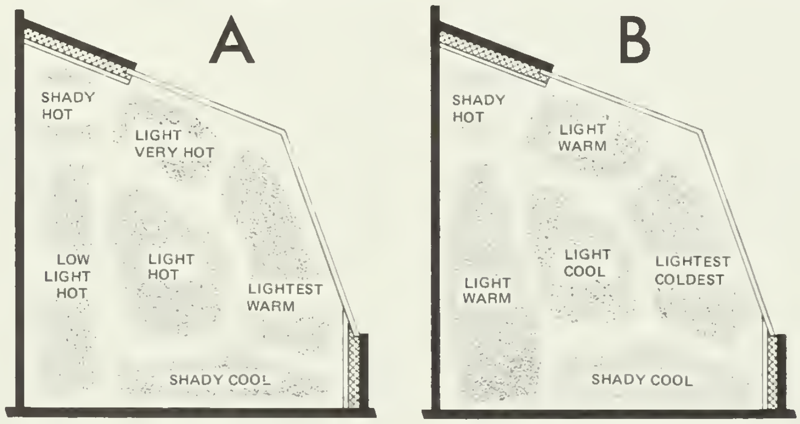


Fig. 34. The climatic zones in greenhouse change with the seasons: (A) spring, summer, and fall; (B) winter.

Interior climatic zones

Before finalizing a floor plan, consider first the various light and temperature zones within the greenhouse (Fig. 34). The variety of environmental conditions these zones offer can be used to produce specially selected crops with different requirements for growth.

Because hot air rises, the warmest areas are always toward the peak of the greenhouse. Shelves laid across double-tiered barrels on the north wall provide a good environment for starting seedlings, because germination benefits from the warmer air at this level. Furthermore the barrels do double duty, serving as heat storage containers and as bench supports. Use slatted or wire-mesh shelving to ensure adequate air circulation around the plants and the heat-storage containers. The air movement improves heat flow and aids plant growth.

The area immediately adjacent to the glazing is the brightest spot in the greenhouse but it is also subject to the greatest fluctuation in temperature, particularly when no night curtains are used. Despite temperature extremes, this location is the most appropriate for growing beds or benches. If the east wall does not contain a door, extend the growing area along the east end for maximum exposure to morning light.

The shadiest area is along the north wall, especially in the spring, summer, and fall when the sun is higher in the sky. This area is best suited for heat-storage containers, as well as for those plants that benefit from shading during those months. Regardless of the layout, always place taller plants such as tomatoes, cucumbers, and melons toward the back. Otherwise the tallest plants tend to prevent the available light coming in from the south from reaching shorter plants behind them.

Beds and benches

The type of growing containers you choose depends on which plants you want to grow. Fairly deep beds that can accomodate deep root systems are best for growing vegetables. Deep-feeding plants such as broccoli, tomatoes, melons, and cucumbers flourish in 60 cm of soil, whereas shallower-rooting crops such as lettuce and other greens do well in 30–45 cm. Between 45 and 60 cm of soil serves most other vegetable crops. Deeper beds have the added advantages of requiring less-frequent watering and feeding and of contributing to overall heat storage. Moist earth is an excellent heat-storage medium.

Garden-type growing beds can be dug in existing soil left exposed on the floor of a ground-level greenhouse. Greenhouses on rooftops, porches, or second storeys obviously require raised beds with some sort of bottom. When you have access from only one side, make the beds no wider than 100 cm. With a walkway on either side, the width can be extended to 150–180 cm. However, if ease of access is not essential and you need to maximize your growing space, wider ground beds can be built, as long as boards or stones are interspersed throughout for entry into all areas.

Raised beds—To build an enclosed, raised bed, use boards rather than plywood. The laminating glue used in plywood sheets tends to weaken with constant exposure to water; subsequently, warping occurs. Use boards at least 20 mm thick. Thicker boards do not rot through as quickly as thinner wood. Provide adequate drainage by drilling holes 20 mm in diameter at intervals of 150 mm in the bottom of the beds. Cover the holes with screening to prevent soil from falling through or from plugging them up. Screen the bottom of a slatted bed entirely, leaving 13-mm spaces between boards. As the boards swell in contact with moisture, the spaces tend to close up somewhat.

Ground beds—When the original soil of the greenhouse floor drains easily, a slightly raised bed dug into the ground is an option that saves the cost of construction materials. Furthermore, in-ground growing beds provide conditions most closely resembling those of an outdoor garden. These beds help to alleviate some of the problems inherent in container growing, such as the rapid drying out of the soil medium, and allow earthworms and other naturally occurring, beneficial soil organisms easy access to the greenhouse beds.

To build in-ground beds, simply excavate down 60–90 cm. Put 10 cm of washed gravel at the bottom of the bed for added drainage if the soil is clayed. When the foundation insulation does not extend down as deep as the excavation, lay styrofoam insulation along the foundation wall. Use stones pressed into the side of the bed, a low masonry wall, cinder blocks, or scrap lumber to hold the soil in place.

Benches—Grow seedlings, ornamentals, and any other potted plants on raised benches. Plants placed at waist height benefit from the warmer air at this level. Use the space under the benches for shade-loving plants, as well as for cuttings and freshly transplanted seedlings.

Any sturdy support can serve as a bench. Commercial growers frequently use heavy screen tacked onto a wooden frame. The screening allows easy drainage as well as some air movement from below. A 50-mm lip nailed around the periphery of the bench prevents pots from being knocked off and can contain a shallow bed of pea gravel. Pots are set on top of the gravel for better drainage.

Space savers—Hanging pots can increase available growing space by as much as one-third and offer a way to utilize the warmer, sunny areas toward the greenhouse peak. Many trailing ornamentals, as well as some vegetables, can be grown suspended in hanging pots. Cherry tomatoes, nasturtiums, thunbergia, and cascading petunias are some plants that grow well in hanging baskets.

Vertical growing not only decreases the amount of bed space plants occupy but also increases yield and prevents disease problems that result from leaves and fruit lying directly on the soil. Many vegetables such as cucumbers, peas, melons, and tomatoes can be grown vertically. Install a thick, overhead wire or trellis in the greenhouse before planting these crops in the bed. The wire or trellis should be 1.8 m high. Suspend string such as nylon fishnet twine from the wire to the plant. Plants that have tendrils, such as cucumbers, peas, and melons, voluntarily climb the string once their tendrils have been wrapped around it in a few places. Tomatoes must be trained. Tie the string loosely around the base of the plant. As the plant grows, gently wind the growing tip around the string.

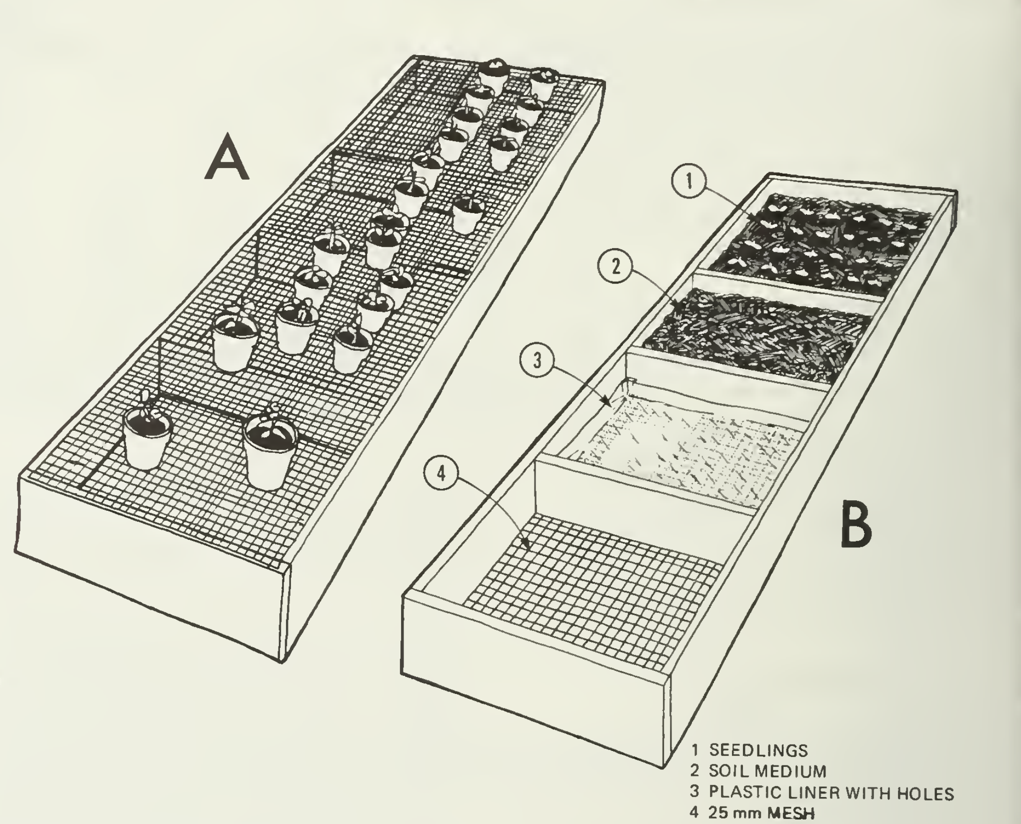


Fig. 35. This handy portable bench (A) converts to a shallow bed (B).

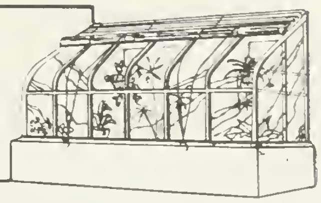
Convertible beds and benches—Most urban gardeners probably hope to grow a combination of food, ornamentals, and seedlings in the greenhouse. For multiple use of growing space, the managers of the Natick Community Farm in Natick, MA, have designed some handy portable benches that convert to shallow beds (Fig. 35). The beds are framed with 38 × 235 mm boards. The bottoms are made from 25-mm wire fencing. The wire bottom is lined with plastic, in which holes are punched for drainage. Shallow crops such as lettuce and other greens are grown in these beds in fall and winter.

In the early spring, the soil medium and liner are removed and the beds are turned upside down to serve as benches for seedling trays. Drums or other supports placed under these convertible beds elevate them to a comfortable working height.

Walkways

Leave spaces of 45–60 cm for walkways. To accomodate a wheelbarrow in the greenhouse, a central aisle of 90 cm is needed. Avoid soil walkways, which become very muddy. Gravel is a good material for a walkway. It also serves to augment the heat-storage capacity. A concrete walkway also works well, but be sure to install a drain to remove any excess water used in cleaning and upkeep.

PART 3
Greenhouse management



Growing plants in a small hobby greenhouse can be rewarding. The species that can be cultivated vary from common vegetables such as tomatoes and cucumbers to the most exotic orchids and tropical plants. The amount of enjoyment realized depends on the rate of success, which in turn is related to the number of problems encountered. The operation of a hobby greenhouse involves considerable experimentation. A green thumb is usually only developed after substantial first-hand experience.

Many reliable books and manuals are available to amateur gardeners, most of them written by people with many years of experience. Before investing in a greenhouse, the hobbyist should read as much information on the subject as possible. This book is only intended to provide the basic information necessary for the novice greenhouse gardener. To obtain further details, a list of available information is included in the "Resource Bibliography."

Growing media

Soil

Soil is the oldest and most common medium used for growing plants. It is a complex mixture of inorganic and organic components. The most stable soil component is its mineral content, classified as sand, silt, or clay. Sand feels harsh and gritty and the grains do not hold together readily. Sandy, coarse-textured soil is easy to work and drains easily, but it does not retain plant nutrients well. Silt particles are smaller than sand. They feel smooth between the fingers and pack together more tightly than sand. Silty soil therefore contains smaller air spaces than sand, with resulting slower drainage, and it does not hold together well when dried out. Clay particles are even finer than silt. Because of their different physical and chemical makeup, they actually absorb moisture and nutrients. Clay soil particles swell when water is added, closing the pores, compacting, and impeding drainage.

Loam is defined as a medium-textured soil containing sand, silt, and clay in balanced proportions. The term alone is vague, and soils are usually described as sandy loam, clay loam, and so on, depending upon the proportion of these particles.

Tilth refers to the structure of the soil, namely the way in which particles of sand, silt, clay, and humus form granules of soil. Tilth may be improved by addition of various synthetic soil conditioners known by a variety of trade names and by the abbreviations of their chemical names, such as VAMA, CMA, and HPAN. As these compounds do not contain nutrients, they are not substitutes for humus.

Humus is the dark, organic component of soil derived from animal and plant residues. Humus improves the tilth of the soil and provides nutrients. Organic material such as animal manure, fallen leaves, grass clippings, and sawdust are useful sources of humus. Humus-forming materials such as well-rotted manure, leaf mold, or peat moss may be purchased from garden supply stores. Most field soil must be specially prepared for use in pots or greenhouse benches by increasing its porosity and water permeability. If suitable field soil is not available, soilless growing media should be used.

Composting

Composting is a means of returning to the soil as humus a great amount of organic material that might otherwise be discarded. The best way to make compost is to use layers of vegetable matter between layers of nitrogen-enriched soil. There are many ways of composting. The typical aerobic compost pile is frequently turned over, in order to admit air for oxygen-requiring microorganisms. The mix should be kept moist to facilitate the decomposition process. Also important for the process are the naturally occurring microorganisms that are abundant in good soils or in animal manures. If use of manure is undesirable, nitrogen-containing fertilizers and microorganism-containing products such as Gro-zyme® or Fertosan® can be added to the compost pile.

Ready-made compost bins of wooden slats or wire mesh may be purchased (Fig. 36). A ready-to-use compost should be black or dark brown, crumbly, and without odor. Composting may not be convenient for a small greenhouse operator or home gardener because of the time and space it requires.

Soilless media

Soilless media have become important items in the production of container-grown crops. Commercial soilless media are mixes of organic and inorganic components; they are light in weight and have high capacities for aeration, water holding, and cation exchange.

The usual components of the mix are sphagnum peat, vermiculite, perlite, composted bark or sawdust, sand, polystyrene foam, and calcined clay. These media can be amended with dolomitic limestone (3–15 kg/m^3), superphosphate (1.5–3.0 kg/m^3), trace elements (75–125 g/m^3), and calcium or potassium nitrate (1.2 kg/m^3). If needed, a wetting agent (120–200 g/m^3) may be included. These added nutrients provide nutrition comparable to a soil of moderate to low fertility.

Soilless media are not cheap to buy or to make, but the quality is known and the performance predictable. Soil, on the other hand, is quite variable and may need to be sterilized, stored, and handled. A grower who formulates his own mix, soilless or not, should plan to make a better mix than the formulations found commercially. For best results you need the very best root medium available.

Germinating mixes

Germinating mixes can be purchased or made from easily obtained ingredients such as vermiculite, perlite, and sphagnum peat in equal parts; soil, sand, and perlite in equal parts; or soil, vermiculite, and peat in equal parts.

The University of California mix contains one part fine sand to three parts peat moss. To each cubic metre of this mixture are added 100 g potassium nitrate, 100 g potassium sulfate, 1 kg superphosphate, 2.5 kg dolomite, and 2 kg calcium carbonate lime.

Soil pasteurization

Conditions often found in a greenhouse such as high heat and moisture levels, low availability of plant nutrients, and the continuous culture of only a few species of plants encourage development of plant disease organisms. Therefore, destruction of these organisms in the growth media, greenhouse bench, or pots by either physical (steam) or chemical means is necessary. These treatments also control nematodes, insects, and weeds.

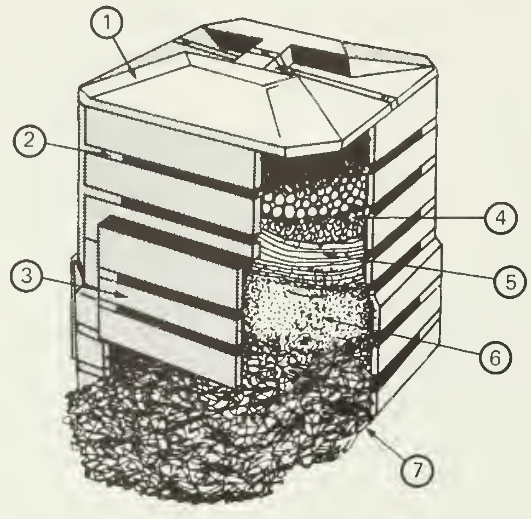


Fig. 36. Compost bin.

1 Lid sheds rain and snow, recirculates moisture.

2 Air vents allow efficient aerobic bacteria to breathe, preventing unwelcomed odors.

3 Doors slide up to remove dark, sweet smelling compost.

4 Microorganisms break down the material which is kept moist and well aerated in the composter.

5 Bacterial activity raises the temperature (to 57°) destroying weed seeds and disease bearing organisms.

6 Larger microbes break down the material further, increasing the fertility and aerating the compost.

7 Finished compost.

Never use ordinary garden soil for sowing seeds or growing plants in containers. Prepared potting and seed mixtures sterilized to destroy weeds, pests, and diseases should be used instead.

Soil is pasteurized to eliminate harmful organisms without destroying the beneficial ones. If it is heated at too high a temperature, the beneficial microorganisms are killed and the soil becomes sterile. Sterile soil is subject to a greater degree of infection by disease-causing fungi and bacteria, extensive ammonia release, manganese toxicity, higher salt levels, and destruction of soil organic matter.

If a greenhouse is heated by a central water system, you can pasteurize the soil by steam. The steam should be kept at about 70°C to avoid the hazards of overheating.

Small amounts of soil can be pasteurized in an oven. Put the moist soil in a metal baking pan for 30 minutes at an oven temperature of 80°C.

Soil can also be sterilized by chemical means. Use 40% formaldehyde (formalin) as follows: dilute 30 mL in 1.4 L of water and sprinkle this dilution evenly on a layer of soil 2.5 cm thick and 60 cm square. Mix the soil well and cover with plastic for 12 hours. Before using the soil, air it for 24 hours or more until all odor disappears. Use rubber gloves. Formaldehyde is toxic. Therefore read the label and use precaution.

Several other chemical fumigants may also be used, but with caution. Carefully read all directions on the labels and follow them meticulously. Some residues may remain in the soil after fumigation and affect the germination and growth of plants. The label should specify the waiting period before planting.

Small electric sterilizers can also be bought rather cheaply. Some use dry heat; others work using steam passing through the soil. Take care to avoid overcooking the soil.

Pots, tools, benches, and shelves should also be cleaned and disinfected before using. Pots, trays, and flats can be sterilized by dipping them in a solution containing one part of 10% Chlorox® or Javex® to nine parts of water. Allow the chlorine in the solution to dissipate completely before using the containers. At least 24 hours is usually required.

Water

Water, a basic component of plant tissue, may make up as much as 85% of the weight of a living plant. Water maintains the turgor pressure; so when water is scarce, the cells of the leaves collapse and the plant wilts. Most of the water taken up by the root system is transpired into the air through leaves in the form of water vapor.

For best results the amount of water available in the soil must be balanced against the amount the plants transpire. Therefore, plants growing in bright sun or under lights at warm temperatures need more water than plants at cooler temperatures and must be watered often. On the other hand, when plants are overwatered, the roots are unable to get air (oxygen) and the plants literally drown. Overwatering causes the following symptoms:

- light green or yellow leaves
- leaves with brown edges or tips
- a sparse root system with few root hairs and with larger portions of the root soft, mushy, or rotten. The damaged root system cannot take up water and nutrients; therefore wilting, lower growth rate, and nutrient-deficiency symptoms result.

Underwatering shows first in the young, soft leaves as wilting at the tip. The soil in the pot, when rubbed between the fingers, feels dry and dusty, the root system is dry, and the root hairs are destroyed. As a result of chronic lack of water, the leaves are smaller, the internodes are shorter, and the plant develops a hardened appearance. The margins of the leaves may be burned in extreme cases.

Moisture meters can be inserted into the soil in the pot to measure the relative moisture content and thus determine the water requirements. However, no sensing device can substitute completely for the judgement of an experienced person.

Water the plants thoroughly, letting the water drain out of the pot. Repeat the watering when the top layer of the soil mix becomes dry.

Germinating seeds and young plants have special requirements for water: seeds must absorb water for germination and a new seedling must establish shoot and root systems. Availability of water at this stage of growth is critical. Likewise, an actively growing plant also exerts a heavy demand for water. As the plants mature the need for water may diminish but the warmer summer temperatures again increase the demand. Under conditions where the amount of light and temperature is lower and growth of plants is slower, the need for water is less. The need for water depends also on the soil mix; the ideal mix drains readily to prevent drowning yet retains enough water for good growth.

Besides the amount, the quality of water is important. High salt content is a common problem. A conductivity meter gives a good measure of the total soluble salts in the water. The electrical conductivity of good water is not more than 75 units. A reading between 75 and 200 units is permissible, but at readings above 200, plants may be damaged.

Chlorination of city water normally does not affect greenhouse crops. However, fluoridation of water does cause injury to some crops. Fluorides in water may cause browning or burning of foliage plants such as lilies, dracaenas, and spider plants. If fluoride damage is suspected you may consider using rainwater or distilled water, or raising the pH level of the growing medium to tie up the fluoride.

The temperature of the water should be about 15°C or a bit higher. Most house plants are of tropical origin and may not tolerate cold water. When watered with cold water, the plant is subjected to a shock treatment that stops or hinders the growth processes.

In a small greenhouse, the watering can, although uneconomical, is the traditional method of applying water. However, use of a garden hose with a nozzle is a more rapid method. Use breakers and nozzles to prevent damage to the plant material and to keep the root media from being washed out of the pot or bench. Use a superfine nozzle for watering freshly planted seed pots or flats.

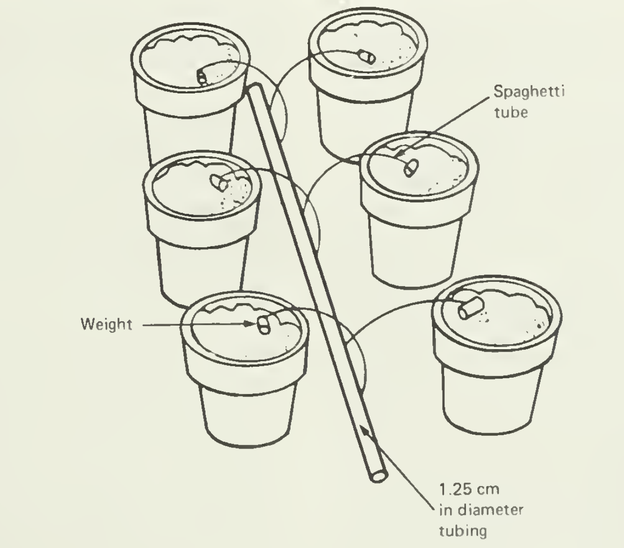


Fig. 37. An automated watering system.

Several automatic or semiautomatic watering systems can be used in the greenhouse. A perimeter watering system consists of a plastic pipe placed around the perimeter of the bench with nozzles that direct water onto the root media below the foliage. With a tube watering system (Fig. 37), water is supplied by a thin tube to each individual pot. A capillary-mat watering system permits a pot to pick up water by capillary action through the bottom of the pot. This system has several advantages:

- constant attendance is not required
- growth may be better
- feeding of plants may be simplified by use of timed-release fertilizers
- each plant gets the required amount of water
- humidity in the greenhouse can be increased to the benefit of the tropical plants. Caution: unless you have good air circulation, high humidity may increase disease
- the system is simple and relatively cheap

Water can be supplied to the mat by a polyethylene pipe and spaghetti tubes, each one supplying a 30 × 30 cm area of the mat. Keep the mat constantly moist but not dripping wet and never permit it to dry out completely. Pots with multiple drainage holes in the bottom are best suited for this method. When the mats are first installed, water the plants from the top to start the capillary action. A wetting agent can also be added to the water used to soak the plants from the top, to aid water absorption. Keep the bench level, although a slight difference of 2–5 cm may be tolerated. Cover the bench with a black or clear polyethylene sheet before you install the mat. Manual valves in the watering system, rather than automatic ones, are probably the best for the small grower.

Light

Photoperiodism is the response of a plant to the relative length of light and dark periods within a 24-hour cycle. Depending on the plant this response may determine different things, such as red or white pigmentation of poinsettia bracts, the flowering of chrysanthemums, or tuber formation in dahlias.

Plants are classified according to this response as being short-day, long-day, or day-neutral plants. The short-day plants flower only when the night period becomes critically long. For example, poinsettias require a 12-hour dark period for flowering. Chrysanthemums, kalanchoes, azaleas, and Rieger begonias also require short days to flower.

Long-day plants respond to a day length that is longer than the dark period. For instance, asters develop tall stems and initiate flowers only under long days.

Day-neutral plants, such as roses, do not respond to differences in the length of days.

Facultative short-day or short-night plants flower at any length of day but flower faster under particular photoperiods.

The day-length response depends also on the temperature. In the chrysanthemum, for example, as the temperature goes up (within limits) the critical night-length becomes shorter.

The controlling mechanism in plants that are photoperiodically sensitive is the phytochrome pigment that serves as the light receptor.

In the greenhouse the day length is controlled by drawing shade cloth over the benches in order to increase the dark period. Supplementary lighting is also used to extend the light period. The light intensity for photoperiodical control of flowering is relatively very low, only 1 watt per 30 × 30 cm area.

Photosynthesis is the process whereby carbon dioxide (CO_2) is converted to carbohydrate, needed by the plant for growth and maintenance. Plants depend on energy received via natural or artificial light to activate the process, which can be summarized by the equation:

CO_2 + water + energy (light) =

carbohydrate + oxygen

Respiration is the opposite of photosynthesis and results in the release of energy used for various functions of plant growth.

Carbon, as CO_2, is an essential plant nutrient and is present in the atmosphere at a concentration of 0.03%. Since plants respond to a higher concentration of CO_2, it may be profitable to increase the CO_2 content of the greenhouse air. Levels of 1000–1500 ppm, or 0.1–0.15%, of CO_2 are commonly used in greenhouses and are not harmful to humans. Increasing the CO_2 to these levels has resulted in greatly increased growth, earlier maturity, and higher yields. Lettuce can be produced in 20% less time, and tomato yields can be increased by more than 50%. For best results increase the levels of other plant nutrients when CO_2 levels are raised.

Higher levels of CO_2 are effective only during the light period, when greenhouse vents are not open. The additional CO_2 may be supplied by propane or natural gas burners, injection of CO_2 gas, or dry ice. Home greenhouse operators can burn alcohol in a kerosene lamp. The CO_2 level can be measured with commercially obtainable kits.

Light is the source of energy for photosynthesis and carbon fixation. It therefore regulates the rate of vegetative and reproductive growth in the plant. The amount of lighting needed for photosynthesis and subsequent growth, 10–20 watts per area of 30 × 30 cm, is many times greater than the 1 watt needed for photoperiodism. Growth depends on the quantity and quality of light under which the plant is grown. Plants grown under full summer sunlight grow rapidly, whereas a reduced amount of natural light in winter results in a slow growth rate. Greenhouse crops are subject to light intensities as high as 130 000 lux (lx) in summer to below 3200 lx on cloudy winter days. In many cases, the light saturation point is reached at about 32 000 lx. The lux is a unit of illumination equal to the direct illumination on a surface that is everywhere one metre from a uniform point source of one metric candle (the candela). The lux is equivalent to approximately one-tenth of a foot-candle. Generally, light-intensity requirements vary from crop to crop.

The quality of light is also important. The visible spectrum, from 400 to 700 nm, is used primarily in photosynthesis. Artificial light must provide a combination of fluorescent light (rich in blue) and incandescent light (rich in red). Combined lighting is obtained by supplying about 10% of the light intensity with incandescent lamps. Some fluorescent lamps emit a spectrum similar to that required for photosynthesis. High-intensity discharge lamps, metal halide lamps, or high-pressure sodium lamps can also be used.

Lamps decline in efficiency with age and should be replaced when they begin working at a low efficiency. Reflectors can be used to increase the amount of light reaching the plants. The number of lamps of a specific wattage required to light a certain area for a precise purpose is calculated as follows:

$$\frac{\text{(growing area)} \times \text{(watts per area of } 30 \times 30\text{ cm)*}}{\text{watts per individual lamp}}$$

- * Light of 10 watts per area of 30 × 30 cm is required for germinating seed
- * 15 watts are needed for low-energy plants in the 530–5300 lx range, like amaryllis, bromeliads, *Cordyline*, *Ficus*, fittonias, and *Hedera*
- * 20 watts are required for high-energy plants, such as azaleas, chrysanthemums, coleus, crotons, cyclamens, hydrangeas, poinsettias, *Portulaca*, and roses

Plant nutrition

Some 16 or 17 elements are necessary for plant growth. Carbon (C), hydrogen (H), and oxygen (O), are fundamental components of the plants and are supplied by air and water. Nitrogen (N), phosphorus (P), and potassium (K) are used in relatively large amounts and are the main ingredients of the all-purpose fertilizers used to maintain nutrient levels in soil.

Commercial fertilizers

A formula showing the NPK rating appears on every bag, for example, 5-10-5. These figures represent the percentage of nitrogen (N), phosphorus (P), and potassium (K) in the nutrient mixture. The fertilizers with a higher NPK rating are more concentrated and usually more expensive.

A zero in the formula means that the particular element is missing; for example, an NPK rating of 0-0-20 indicates that the mix does not contain nitrogen and phosphorus but does contain potassium at 20%. The standard practice is to dissolve high-analysis fertilizers in water to make a concentrated solution, which can be diluted as required using an injector in the water line, or it can simply be diluted in a watering can before use. The most common fertilizer grade used in greenhouses is 20-20-20, with essential micronutrients added.

As the plants grow, the levels of nitrogen and potassium in the root media change and adjustments may become necessary.

These all-purpose fertilizers are generally made from inorganic chemical compounds, such as ammonium sulfate or ammonium nitrate for nitrogen, superphosphate for phosphorus, and sulfate or chloride of potassium for potassium. Nutrients may be supplied also from organic sources such as bone meal, which contains 3–5% N and 20–35% P. Nutrients from organic sources are released relatively slowly and thus overfertilization with them may be less likely to damage the plants.

Slow-release inorganic fertilizers are usually made by combining nutrients with chemicals that retard their breakdown or by coating particles of fertilizer with plastic substances through which the nutrients slowly leach out.

Trace elements, although usually present in soil, may not be available to plants because of alkalinity. Iron (Fe) deficiency, for example, results in chlorosis or yellowing of the foliage. Minor elements can be bought to add to any fertilizer used. Minor elements are of particular importance if soilless growing media are used.

Osmocote®, available in a wide variety of formulas, is a soluble fertilizer encased in a polymer resin coating that acts as a semipermeable membrane. The rate of release is somewhat temperature-dependent; the rate of release increases in warm soils and decreases in cold soils. Urea formaldehyde, a synthetic organic nitrogen fertilizer, also acts slowly, and the release of nitrogen to the plants depends on soil microorganism activity.

The chelates are made by encircling the desired micronutrients such as iron, manganese, zinc, and copper with organic chemical compounds. The chelated forms of these elements are the most commonly used in greenhouses.

Excessive use of fertilizer may cause chemical salts to accumulate in the soil. Salts cause damage to roots as well as to the leaf tips and margins. The first symptoms of this disorder are usually slow growth and the yellowing and wilting of leaves. Excess salt can be removed by flushing the soil thoroughly with clean water two or three times. Fertilize moderately after this treatment to replace the lost nutrients.

Foliar feeding is the spraying of soluble nutrients on leaves. Although not a substitute for feeding through soil or media, this method may be useful in certain instances when the plant is damaged or under stress, or when it lacks minor elements. Plants with poor or diseased root systems can benefit from foliar feeding.

Feeding programs

The ideal nutritional program should provide all essential elements continuously. However, some may be applied to the growing media before planting.

Most growing media have a high acidity, with correspondingly low pH values, because they contain a large proportion of peat. Finely ground limestone (2–10 kg/m^3) provides enough calcium and magnesium to raise the pH value of the soil adequately. Phosphorus can be added at 1 kg/m^3 of soil. These additions are sufficient to provide the required amounts of calcium, magnesium, phosphorus, and sulfur.

Nitrogen and potassium are easily soluble and need to be applied periodically, except when slow-release fertilizers are used.

Two programs are commonly used. In the first, nitrogen and potassium are applied at a low level (200 ppm) each time the plants are watered. In the second, fertilizer is applied weekly. Here the concentrations range from 200–400 ppm for bedding plants to 720–750 ppm for heavy feeders such as chrysanthemums and poinsettias.

In the greenhouse, growing conditions are variable and the best way to establish a good feeding program is to experiment within the guidelines and maintain records of results.

Soil tests

Soil testing gives an estimate of the nutritional level of the soil. Operators of home greenhouses can buy soil-test kits that use colorimetric comparisons to indicate the levels of nutrients, as well as soil acidity.

More elaborate and precise soil testing is done by some provincial and university laboratories. The sample taken must be representative of the soil to be tested. Mail the soil sample to the laboratory without delay; if too wet it can be air-dried before shipping.

The laboratories provide the gardener with an interpretation of the results. However, the grower's experience is essential in translating the results into an effective program for adjusting the levels of nutrients. Best results are obtained from monthly soil sampling to determine trends in nutrient levels and minimize sampling errors.

pH

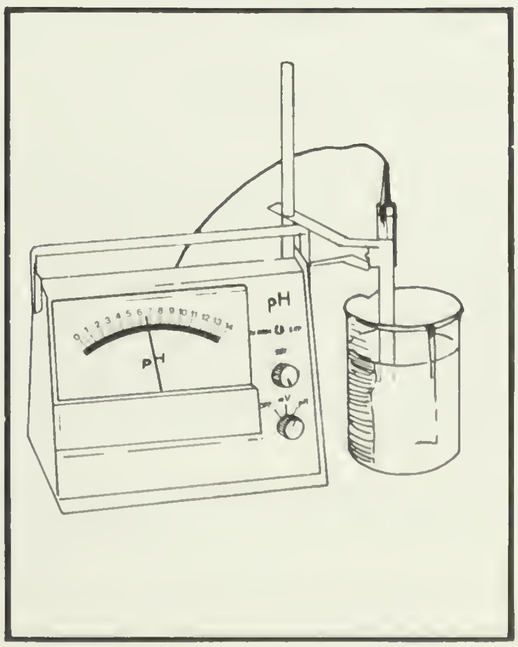
The pH value of the soil is a very important factor in plant growth and nutrition. Acidity and alkalinity are measured on the pH scale from 0 (pure acid) to 14 (pure alkali) (Fig. 38). From the neutral point, at pH 7, the numbers increase or decrease in geometric progression; for example, soil at pH 5 is 10 times more acid than soil at pH 6. Slightly acid soil (pH 6.5) is preferable for most plants. Exceptions are azaleas, which require a soil pH of 4–4.5 for good growth. The pH level of the soil controls to some extent the availability of all essential plant nutrients. Nutrients are most readily available when the pH value is 6.2–6.8. Values much lower or higher, depending on the species, may be detrimental to growth.

The pH value of soil is increased by the addition of finely ground limestone. To decrease the pH and increase acidity, add elemental sulfur or peat moss. Peat moss works more gradually than sulfur and improves the soil tilth at the same time. To test the soil pH, use a paper tape such as Hydrion®. First, mix one part soil with two parts of tap water. Then immerse the tape in the solution for 30 seconds and compare it with a color scale. Use tweezers instead of fingers, to prevent a false reading caused by contaminants on your fingertips.

Nutrient deficiencies

Foliar analysis is used to measure the quantities of elements taken up by the

Fig. 38. Acidity and alkalinity are measured on the pH scale from 0 to 14. Slightly acid soil, pH 6.5, is preferable for most plants.



plant. Much work has been done to determine the optimum levels of nutrients in the leaves. Standards exist for many crops. Generally, the testing laboratory reports the results in a numerical way, indicating nutrient levels from deficient to very high.

The nutrient deficiency in plants can also be estimated with experience by visual observations, and in many cases such a diagnosis is very successful.

Nutrient deficiencies and imbalances, whatever their causes, are corrected by application of the deficient element or elements. It is safe to apply a mixture of micronutrients when symptoms of a single micronutrient deficiency appear, provided the mixture has not been already applied. However, care is needed because micronutrient excesses are difficult to correct. Phosphorus can be added as part of a complete fertilizer (N-P-K) or as diammonium phosphate. To add calcium, use calcium nitrate; magnesium, magnesium sulfate; sulfur, magnesium sulfate or ammonium or potassium sulfate; iron, iron chelate or ferrous sulfate as a foliar spray; manganese, manganese sulfate; zinc, zinc sulfate or zinc chelate; copper, copper sulfate or copper chelate; boron, borax; and molybdenum, sodium or ammonium molybdate. Textbooks and other sources should be consulted regarding the concentrations to be used.

The dominant effect of deficiency of all the essential elements is reduced growth. Deficiency symptoms are easier to compare when the plants are observed during growth. Proficiency in diagnosing deficiencies is gained with experience only.

Growth regulators

Growth retardants and promoters are important tools in the production of greenhouse flowers. They influence root formation, flower induction, and vegetative growth. Chemicals such as B-9®, Cycocel®, and A-Rest® regulate the growth (height) of flower crops and are most commonly used. Growth promoters, like indolebutyric acid, are used to promote the rooting of cuttings.

There are several factors to consider for the successful use of growth regulators:

- Plant vigor—a healthy plant tolerates the use of chemicals better than a weak plant.
- Growth habit—the variety determines the dosage; a weak-growing variety requires less than a strong-growing variety.
- Light—plants grown under low light intensity may require less growth retardant than those under high light intensity and should not be treated during the high heat period of the day.

Growth regulators are generally more effective on younger plants. Be sure to use the correct concentration of the chemical; follow the directions on the label and measure carefully.

Growth retardants may be applied as a soil drench. Here the roots must be well developed before application (a good root system is critical for use of A-Rest® on Easter lilies). Use enough to wet the entire root mass. A pot size of 10 cm requires 90 mL of drench; 15 cm needs 180 mL; 20 cm, 240 mL; and 25 cm, 300 mL.

Spray applications are easier, but the foliage must be uniformly covered. Leaves should be turgid to prevent damage and should be kept dry for 12–24 hours after spraying to prevent the chemicals from washing off. Use a separate sprayer and clean it thoroughly after each application to prevent unnecessary damage from residues.

A single application is the most economical but is prone to mistakes; a split application using one-half of the suggested concentration 1–2 weeks apart reduces the chances of damage to the plants.

B-9® can be used to control height of bedding plants, chrysanthemums, hydrangeas, and poinsettias. A-Rest® can be used as a soil drench to control height of chrysanthemums, lilies, and poinsettias. Cycocel® applied as a spray or drench can control the height of poinsettias.

Gibberellins have been featured as plant growth regulators in advertisements describing gigantic cabbages. The main use of gibberellins, however, is in regulation of flowering; for example, they enhance formation of male flowers in cucumbers, which is useful in plant breeding. Gibberellins can also be used to stimulate berry enlargement in seedless grapes in greenhouses and to break the rest period of potatoes.

Ethylene is a gaseous plant hormone active at virtually all stages of plant development, from seed germination to plant senescence. Flowering of some ornamental bromeliads is promoted by ethylene. In cucumber production, increased femaleness can result in an earlier and increased yield. The role of ethylene in accelerating ripening or senescence of fruits, vegetables, and flowers has been recognized for many years: ripening of tomatoes is promoted by ethylene. On the other hand, ethylene may cause abrasion of leaves and flowers and the premature aging of flowers, as occurs in carnations.

Gardeners with home greenhouses can experiment with several natural or synthetic regulators of plant growth. However, one has to be familiar with these chemicals to obtain the desired results, and the recommendations must be followed to the letter.

Containers

Pots manufactured from clay, plastic, compressed paper, or peat are the most commonly used containers in hobby greenhouses. The standard greenhouse flowerpot is as high as it is wide. The so-called bulb pans are half as high as they are wide.

Clay pots have been used for many years. They are porous and permit the exchange of air and moisture through the walls. They are quite heavy and are becoming rather expensive and difficult to obtain. Algae growth on the outside of clay pots is a problem and they must be cleaned from time to time.

Plastic pots are light and nonporous and do not support growth of algae. Because the exchange of air and water is not possible through the walls, the soil does not dry out as rapidly as it does in clay pots. Therefore take care not to overwater the plants, and use a more porous soil mix than you would in clay pots. Plastic pots with side drainage are commonly used with the capillary-mat watering system, where single-hole drainage pots do not work well.

Pots made from compressed paper are used only once and discarded. Plants to be sold are less acceptable in these pots because the containers tend to break.

Peat pots are used only for plants intended for transplanting; the whole system, both plant and pot, are transplanted

A key to symptoms of mineral deficiency

Symptoms		Element deficient
A.	Older or lower leaves of plant mostly affected; effects localized or generalized.	
B.	Effects mostly generalized over whole plant; lower leaves more or less dryed or fired.	
C.	Plant light green; lower leaves yellow, drying to light brown; stalks short and slender when element becomes deficient in later stages of growth	**nitrogen**
CC.	Plant dark green, often developing red and purple colors; lower leaves sometimes yellow, drying to greenish brown or black; stalks short and slender when element becomes deficient in later stages of growth	**phosphorus**
BB.	Effects mostly localized; lower leaves mottled or chlorotic, with or without spots of dead tissue, showing little or no evidence of drying up.	
C.	Leaves mottled or chlorotic, typically reddened, sometimes with dead spots; tips and margins turned or cupped upward; stalks slender	**magnesium**
CC.	Leaves mottled or chlorotic, with large or small spots of dead tissue.	
D.	Spots of dead tissue small, usually at tips and between veins, more marked at margins of leaves; stalks slender	**potassium**
DD.	Spots generalized, rapidly enlarging, generally involving areas between veins, and eventually involving secondary and even primary veins; leaves thick; stalks with shortened internodes	**zinc**
AA.	Newer or bud leaves affected; symptoms localized.	
B.	Terminal bud dying, after the appearance of distortions at tips or bases of young leaves.	
C.	Young leaves of terminal bud at first typically hooked, finally dying back at tips and margins, so that later growth is characterized by a cut-out appearance at these points; stalk finally dying at terminal bud	**calcium**
CC.	Young leaves of terminal bud becoming light green at bases, with final breakdown here; in later growth, leaves becoming twisted and stalk finally dying back at terminal bud	**boron**
BB.	Terminal bud commonly remaining alive; younger or bud leaves wilting or chlorotic, with or without spots of dead tissue, and with veins light or dark green.	
C.	Young leaves permanently wilted (wither-tip effect), without spotting or marked chlorosis; twig or stalk just below tip and seedhead often unable to stand erect in later stages when shortage is acute	**copper**
CC.	Young leaves not wilted; chlorosis present, with or without spots of dead tissue scattered over the leaf.	
D.	Spots of dead tissue scattered over the leaf; smallest veins tending to remain green, producing a checkered or reticulating effect	**manganese**
DD.	Dead spots not commonly present; chlorosis sometimes involving veins, making them light or dark green in color.	
E	Young leaves with veins and with tissue between veins light green in color	**sulfur**
EE.	Young leaves chlorotic, with principal veins typically green; stalks short and slender	**iodine**

Source: *Diagnostic Techniques for Soil and Crops*, American Potash Institute.

into soil. Peat pots are fragile and difficult to handle individually; they should be placed in racks or flats. Roots usually grow through the walls of the pot, but in most cases, it is advisable to tear the pot before transplanting.

Less labor is required when the plant or seed is placed initially in the pot where it will grow to maturity, but this method uses more space and care must be taken when establishing small plants in a large volume of soil. In packs or flats the trend has moved from wooden flats to plastic ones, in particular the so-called Cell-Pak. Cell-Paks are small plastic-molded containers with 4–12 cells per pack and with 2–12 packs in each flat of 52 cm. The packs are made in several sizes and in multiples to fit flats made for this purpose; they are lightly joined and easily separated.

Plastic flats are made by several manufacturers. The flats made of 50-gauge plastic are stronger and may be reused after dipping in a sterilizing solution. Some of the containers commercially available today are shown in Fig. 39.

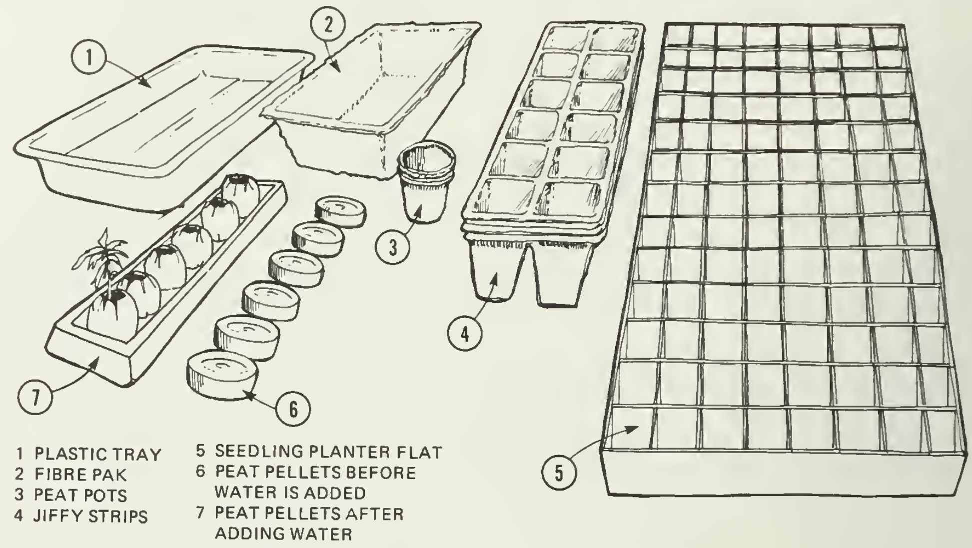


Fig. 39. Many kinds of containers are commercially available.

Plant propagation

Plants in the hobby greenhouse are usually started sexually or vegetatively. Sexual propagation is done from seeds. Vegetative propagation is accomplished by taking cuttings from the tips, stems, or leaves or by taking root sections, then applying methods such as air or ground layering or grafting. Propagation by tissue culture is a specialized procedure, and the amateur gardener should assemble reliable information and adequate equipment before attempting it.

Seeds

The storage life of seeds varies with the species and the conditions under which they are stored. Under normal storage conditions, for example, cyclamen will not germinate after 2 years; chrysanthemum, 3 years; onion, 4 years; and spinach, 7 years.

Buying fresh seeds from a reputable firm and sowing in the recommended season is the best way to achieve success. Sow the seeds as thinly and evenly as possible in 12.5-cm pots, seed pans, or plastic seed trays. For seeds that take a long time to germinate, incorporate a seed-protectant fungicide in the mix to prevent their rotting.

After sowing, cover the seeds with a layer of seeding mix, ideally as deep as the seeds are thick. Place the pots in a tray of water or spray the potting medium with a fine mist until moist; then label the pots and cover them with glass or plastic (Fig. 40).

Unless directions specify otherwise, seeds of most greenhouse plants germinate well at 18°C. Plants requiring a warm greenhouse may need a temperature of 18–24°C to germinate.

When the first two to four seed leaves have appeared on each seedling (Fig. 41), transplant the new plants individually to flats or pots filled with potting mix. As a preventive against damping-off disease, drench the soil with a fungicide recommended for this purpose. After transplanting, move the plants to a well-lighted greenhouse but protect them against direct sunlight for a few days.

Seeds of several species are difficult to germinate because they are dormant. Dormancy, in very general terms, may be caused by an impermeable seed coat, chemical inhibitors in the seed coat, or internal factors such as a rudimentary embryo.

Seeds with hard coats germinate if their coats are scratched or broken; this process is called scarification. Large seeds can be scarified by filing or cutting a nick through their seed coats, rolling them in sharp sand or abrasives, or rubbing them between layers of sand paper.

Commercial operators sometimes soak hard-coated seeds in concentrated sulfuric acid. This process is not for home gardners. Hot water immersion (77–100°C) is another, more acceptable method.

Seeds that need after-ripening germinate best after moist chilling (stratification). Soak the seeds in water for 24 hours, drain them, then place them in a mix of one part sand to one part sphagnum peat. Use about three times as much mix as there is seed and keep it moist during the chilling period. Place the mix containing the seeds in a polyethylene bag or container that permits aeration and store it at 2°C for 1–4 months, depending on the species. Remove the seeds and sow them at a cool temperature of about 18°C.

If you like to experiment, try a chemical treatment instead of chilling. Seeds can be soaked for 24 hours in a solution containing 5 ppm of 0.5% potassium gibberellate. If the dormancy is not broken by this method, increase the strength of the chemical. Seeds can be also treated with ethephon (Florel®) in 300 ppm solution for 5 minutes. Potassium nitrate in a 0.2% solution may speed germination if the seed is placed on blotter paper in a small dish and moistened with water as needed.

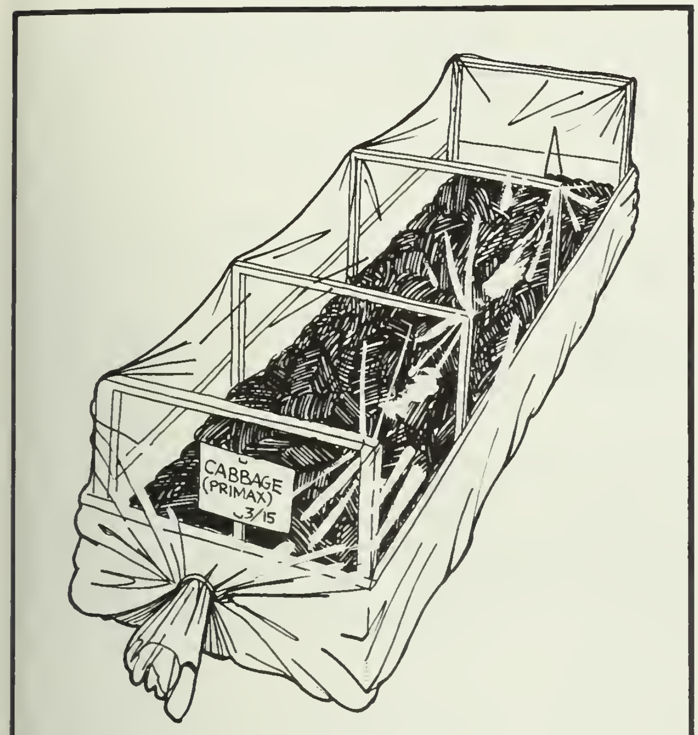


Fig. 40. Propagating plants by seed.

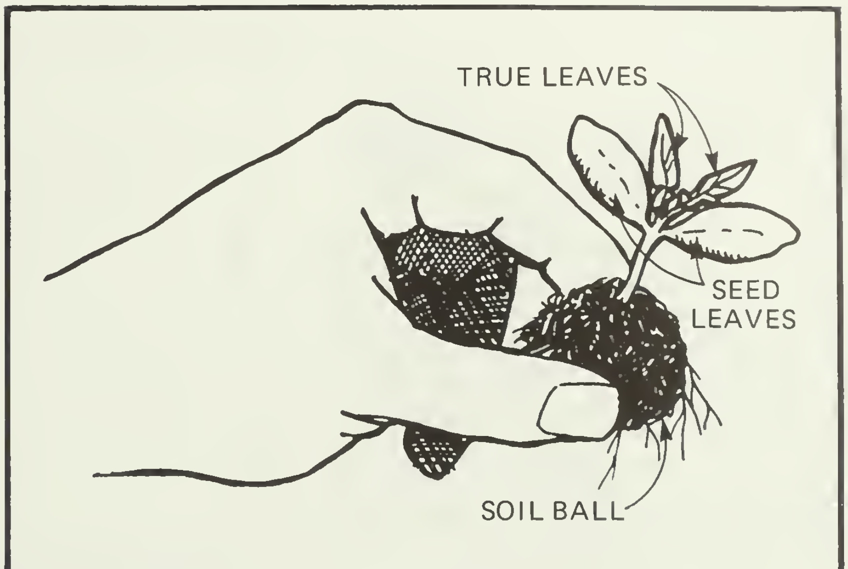


Fig. 41. Seedlings can be transplanted after they develop two to four seed leaves.

Orchid seeds are very small; the plants are also difficult to propagate and grow rather slowly for flowering. Extract the seeds from the pod and soak them in calcium hypochlorite solution for 5–10 minutes, until they sink. Rinse the treated seeds in pure water and pour them onto a nutrient medium in a flask or test tube. The seeds take several weeks to germinate, 6 months before the plants can be transplanted into larger flasks, and a year before transplanting into pots. The culture medium is best bought from a scientific supply house.

Ferns are best propagated from spores, which are much like the seeds of other plants. Sow the spores over a pasteurized mix of two parts peat to one part vermiculite, cover the container with glass, and keep it at a root temperature of 21°C and an air temperature of 18–24°C. Spores germinate and produce prothallia, which must be transplanted and spaced out. When the prothallia produce sporophytes, they should be transplanted again and in 3–6 months young mature plants may be obtained.

Vegetative propagation

There are several ways to grow new greenhouse plants from existing ones. Some plants respond better than others. The easiest techniques are to propagate from cuttings of the stem or leaf, from division of parent plants, and from grafting. Unless there are specific reasons, only healthy plants should be propagated.

Use of stem cuttings is the most popular method for propagation. With a sharp knife, cut off healthy shoots without flowers or flower buds at a few centimetres just below a leaf joint (Fig. 42). For better results dip the base of the cuttings in a hormone-containing rooting powder. Place the cuttings gently into the rooting mix to just below the lowest leaf. Because the normal growth factors have been interrupted, the cuttings must receive the best growing conditions possible.

When a leaf, bud, stem, or root is cut, excessive water loss must be prevented. The best way to minimize water loss is to water the cutting well and place it under an intermittent mist to provide adequate humidity. Additional watering may be needed, but take care to avoid overwatering.

Maintain the temperature of the rooting media at 18–29°C, depending on the species. An electrical heating cable, properly installed, is helpful.

Energy for the growth of new roots comes from photosynthesis. Therefore, leave an adequate leaf surface on the cuttings to ensure survival.

Because most rooting mixes contain little or no plant nutrients, fertilize the cuttings as soon as the first roots appear. Osmocote®, at 15 mL for each 30 × 30 cm area, may be used.

Foliar feeding, using RaPidGro® (23-19-7) for instance, may also be beneficial. The stock plants themselves should be fertilized before taking cuttings. A better cutting is obtained from a well-maintained stock plant than from a poor one.

Ficus, lilac, and rose can be propagated from hardwood cuttings taken in late fall. Junipers, yews, and arborvitae also root readily. Spruces, pines, and firs are best propagated from seeds or grafting (especially blue spruce).

Begonias, African violets, and peperomias can be propagated from leaf cuttings. The large vein on the underside of the leaf is cut and dusted with rooting hormone, and the leaf is pinned on the rooting medium (cut veins down) and misted frequently. Alternatively, a closed propagation case can be used.

Rex begonias and *Euphorbia* can be propagated by petiole leaf cuttings using hormones and mist.

Fig. 42. To obtain a stem cutting for propagation, cut a few centimetres below the leaf joint.

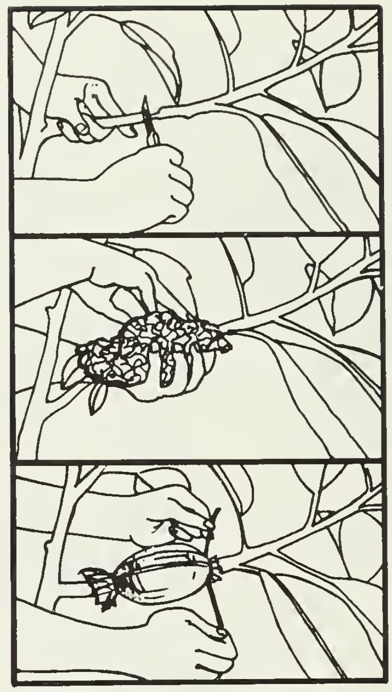


Fig. 43. Air layering is not as hard as it looks.

Leaf bud cuttings, consisting of the leaf blade, petiole, and axillary bud, can be used to propagate rhododendrons, jade plants, and lemons. Use a hormone dip and keep the bottom of the rooting mix at 23–27°C.

Root cuttings are best taken from young plants in the dormant stage or during the dormant season. If the plant normally flowers in the fall, take the cuttings in the spring; if the plant flowers in the spring, take the cuttings in summer, after bloom. Roots have polarity and must be orientated when planted.

Ground layering is done by burying 1-year-old stems that are 15–30 cm long. Treat the wounded stem with rooting powder before layering.

Air-layering is best done by selecting an area of last year's growth on an actively growing branch. Cut the bark of the stem 15–30 cm back of the tip and the area treated with rooting hormone. Place moist sphagnum peat around the cut area, cover it with polyethylene film, and tie both ends down around the branch (Fig. 43). Grafting is defined as joining parts of two plants to make a single plant. Grafting is most frequently used on woody plants. However, grafting of cacti is also common. Those plants that cannot be propagated well from seeds, like blue spruce, must be grafted.

The plant part to be grafted is called a scion; the plant that receives the scion is called the stock. To obtain a successful graft, the cambium layer, which is the actively growing tissue in woody plants, of the scion must be held in close contact with that of the stock so that they can grow together. Careful matching of the cambium layers is therefore essential.

Veneer grafts are used for spruce, juniper, and pine species; whip or tongue grafts and side grafts are suitable for deciduous trees like mountain ash, lilac, and poplar; T-bud grafts are used for peach, apple, and rose species; cleft grafting is used for apples; and bridge grafting is used to repair injured tree trunks. T-budding is the most important method of grafting for home greenhouse operators. Use a sharp knife and sterilize it after each cut. Take the scion from vigorously growing plants and likewise ensure that the stock plant is healthy. Although grafting appears to be a drastic procedure, it is really fairly simple and a home gardener can use it conveniently to obtain unusual plant displays, with cacti for instance.

Tissue culture

The aseptic culture of plant cells and organs is a procedure used in research and on a commercial scale. Commercial tissue-culturing increases the efficiency with which marketable, immediately usable, high-quality plants can be produced. Under suitable conditions, new plants can be reproduced from small pieces of plant tissue, even from a single cell. The cloned plants that result, evolving from the same plant, have exactly the same characteristics as the parent. Virtually all marketable orchids are commercially clonable through tissue culture. Many laboratories can now propagate some 300 different crop plants by these methods.

Propagation by tissue culture requires specialized equipment and facilities and knowledge of plant physiological processes. The home-greenhouse operator may find the study of this procedure an interesting hobby.

Vegetables

Many vegetable crops can be grown in a small home greenhouse as a satisfying hobby. Vegetables can be harvested at their peak of maturity and freshness. Also, the varieties not commonly obtainable in markets can be grown. We describe only a few of these vegetables here, without any attempt to recommend specific varieties. The description of varieties is best left for the catalogs of reputable seed houses. Interplanting of vegetables such as lettuce and radishes with tomatoes and cucumbers may be a good way to utilize the greenhouse space.

Tomatoes, cucumbers, and lettuce

Three systems can be used for producing tomato or cucumber transplants. One is to broadcast seed in flats containing a soilless mix. When the seedlings reach the cotyledon stage, they can be transplanted at wider spacing into other containers. Another is to seed directly into the growing flats or containers. When peat pots are used, the transplanting is done by placing the pot directly into the bed. The third system is to seed directly into peat pellets or similar blocks. To transplant, the peat pellet is placed into the growing bed. For best results sow at least two seeds per pellet and, later, discard the weakest seedlings.

Provide sufficient lighting, at least 10 800 lx at the plant level, to ensure good seedling growth.

Better plants are usually grown when the night temperature is 5°C lower than the day temperature. The best temperatures for warm-season crops such as tomato and cucumber are 15°C at night and 24°C during the day. During cloudy weather the greenhouse temperature should be lowered by about 5°C during the day. Temperatures lower than recommended slow down growth, and higher ones result in soft, "leggy" plants.

To achieve optimum growth in tomato plants, subject them to cool temperatures, between 11 and 13°C, for 10 days to 3 weeks just after the seed leaves unfold until the two-leaf stage develops.

Tomatoes can be planted in a greenhouse bench in rows 44–48 cm apart, with a spacing of 30–32 cm between plants. European cucumbers require a minimum width of 150 cm between rows and plants must be spaced 40 cm apart within the rows.

When transplanting tomato seedlings, place some of the stem below the soil surface (Fig. 44); the cotyledons (seed leaves) should also be buried. Spindly plants can be planted at an angle in the soil.

Remove the suckers from tomato plants when they are about 2–3 cm long. As the plant matures and the fruit is harvested from the lower trusses, remove also the lower leaves that have yellowed and died. In cucumber, thin the multiple fruits that form in one axil to one.

Enrichment of the greenhouse air with CO_2 improves productivity considerably: 20–30% is adequate for tomato and lettuce and 40% for cucumber. Vegetable seedlings and bedding plants grow much more sturdily in an enriched atmosphere. Generally three to five times the normal level of 300 ppm of CO_2 is best. For a small greenhouse, with an area of 2.5 × 3.6 m for example, burning 70–80 mL of ethyl or methyl alcohol in a kerosene lamp produces 2000 ppm of CO_2 over a 24-hour period.

Tomatoes and cucumbers must be grown along twine hung on a support above. Secure the plant to the twine every 30 cm or so with clips, to give support to the fruit as it matures. Tomatoes grown in greenhouses need to be pollinated by hand. Vibrate the flower clusters at least every second day to ensure pollination. When young plants produce their first trusses, they should be pollinated every day.

European-type seedless cucumbers do not need pollination and, if pollinated, develop seeds and a bitter taste. Other cucumber varieties do require hand pollination (Fig. 45). Generally, greenhouse-type varieties are better adapted to yield under controlled environmental conditions.

Predetermined planting schedules establish the expected times for seeding, transplanting, and harvesting. Some schedules for tomatoes and cucumbers with lettuce interplanted are described below. Several other short-season crops can be substituted for lettuce, such as radishes, beets, and many of the common herbs.

A late-spring tomato crop can be combined with a fall lettuce crop by seeding tomato in late December, transplanting by the middle of February, and harvesting from May to July. In this scheme the fall lettuce is seeded in mid August, transplanted into greenhouse beds by 10 September, and harvested in the second week of October. A second crop of lettuce is seeded in late September, transplanted into beds during the second half of October, and harvested in mid December.

Alternatively, lettuce and tomato are seeded at the end of December and transplanted in the first half of February. Lettuce is then harvested from mid March, and

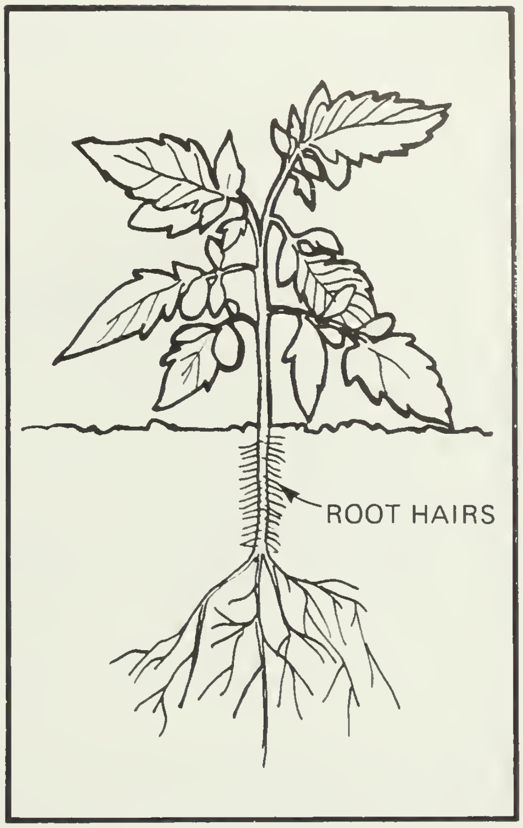


Fig. 44. When transplanting tomato seedlings, place part of the stem beneath the soil.

tomatoes starting in mid April. The lettuce can be seeded again in mid May. Tomatoes, for fall harvest, can be reseeded in early June. The second crop of lettuce is ready for harvest by the end of June. By mid July, the tomato plants for the fall crop and the lettuce should be transplanted. The final lettuce harvest then falls in the second part of August, with the last tomato harvest beginning in mid September.

Cucumbers and lettuce can be interplanted to yield three crops a year. Cucumbers and lettuce are first sown early in January and transplanted by mid February; the first lettuce is harvested beginning in March, and cucumber by the end of March and in April. The second crop is seeded in early May and transplanted into the beds by 10 June; lettuce can be harvested by 1 July and the cucumber harvest begins by the middle of the same month. For the third crop the seeds are sown early in August, transplanted into beds during the first part of September, and harvested from the middle of October.

Cucumbers and lettuce can also be sown at the end of December and transplanted by mid February, for a lettuce harvest in March and for a cucumber harvest

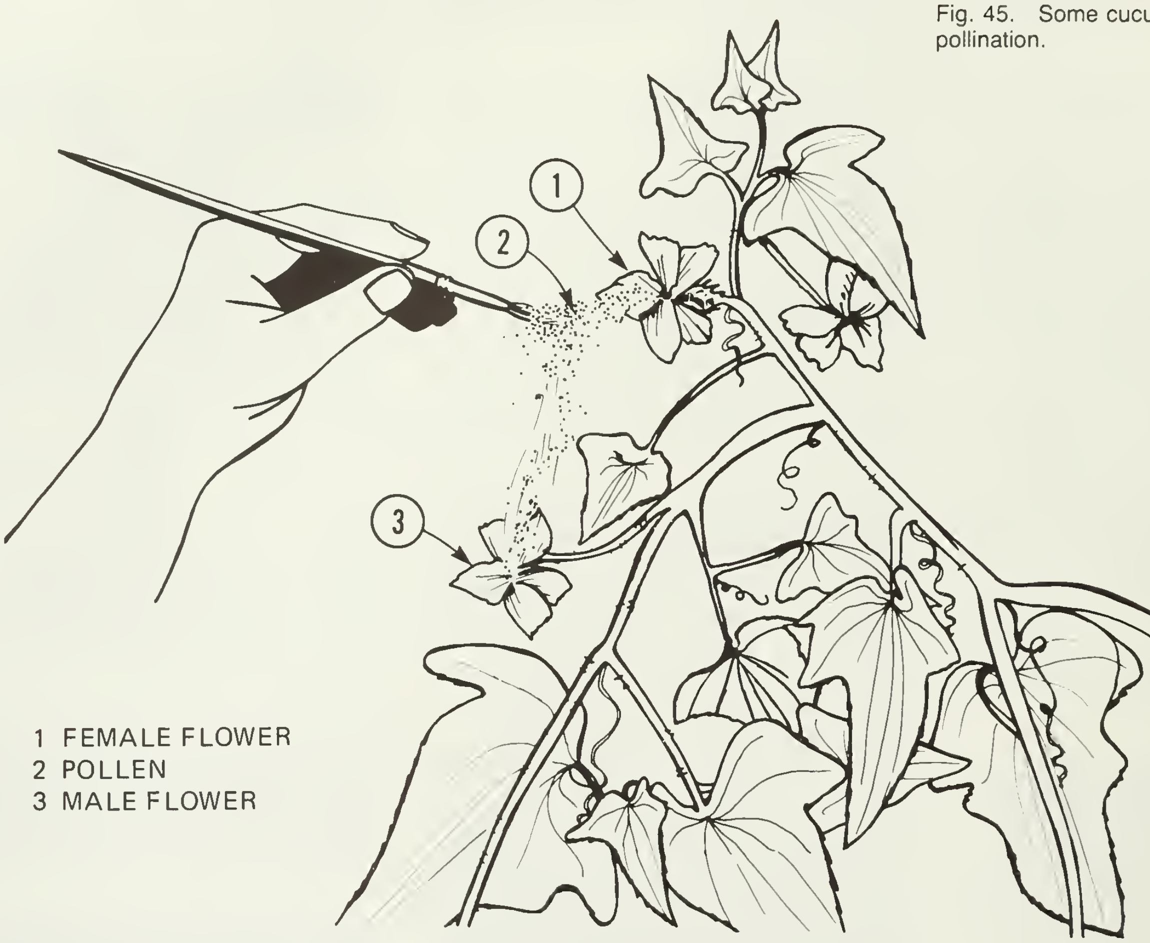


Fig. 45. Some cucumber varieties require hand pollination.

beginning at the same time. For the fall crop the seeds can be sown in the second part of June and transplanted by the end of July, for a lettuce harvest by mid September and a tomato harvest in October.

If possible, subject the tomato plants to a cold treatment, by keeping them at 11–12°C for 10 days to 3 weeks, the time required for the plants to develop from seed leaves to the two-leaf stage. Treated plants should give higher early and total yields.

Carrots

Carrots mature in a relatively short time (60–85 days) and successive plantings can generally be made. Because the soil in a greenhouse bench is of limited depth, grow only those varieties with short roots. Sow carrots less than 1 cm deep in rows. Keep the soil fairly moist until the seedlings emerge. Thin them to 2.5 cm apart and later to 5–7.5 cm. Carrot plantings should be made at intervals of about 3 weeks.

Kale and collards

These vegetables are related to the cabbage family. They can be cooked or used as salad greens. Kale grows about 60 cm high and matures in 2 months; collard grows to 90 cm and matures in 2.5 months. Both require fertile soil with a pH value near neutral. The plants grow fairly high and have heavy leaves, so they should be placed about 50–60 cm apart. The plants can be harvested whole or the leaves can be taken progressively from the bottom.

Radishes

Sow radishes every 10 days to ensure a continuous supply. They do not grow well at temperatures above 27°C. Sow the seeds directly into the soil on a bench, spacing them about 1–2 cm apart in a furrow 1.5 cm deep. Overcrowded plants develop poorly; therefore, thin them to 2.5–5.0 cm apart. Radishes require moist soil. Depending on the variety, radishes mature in about 20–30 days.

Beets

Both the above- and below-ground parts of beets can be eaten. Easy to grow, beets do best in soil that is not acid, at pH 6.0–7.5. Sow beets in rows about 30 cm apart and thin the seedlings to a distance of 5–7.5 cm. Beet roots mature in 55–70 days but the young, tender leaves may be harvested much earlier and used for salads. The root is best when about 5 cm in diameter; larger roots become fibrous.

Herbs

A hobby greenhouse can also be used to grow a pot or two of herbs, which are indispensable in the kitchen and rather easy to grow during the winter. Generally, herbs require light, freely draining potting soil, watered as needed. Only a few of the many usable herbs are mentioned here.

- Basil (*Ocimum basilicum*) is a tender annual usually sown in a greenhouse in early spring and transplanted into the garden. Alternatively, it can be sown outside and transplanted into pots in a greenhouse.

- Chives (*Allium schoenoprasum*) have leaves with a mild onion flavor. The plant is a hardy perennial established from seeds and propagated by division of clumps.

- Dill (*Anethum graveolens*) is propagated from seeds. For best flavor, use the leaves just as the flowers open.

- Mint (*Mentha* spp.) is a perennial propagated by division of roots.

- Parsley (*Petroselinum crispum*) is a biennial plant, which can also be grown as an annual from seeds sown in mid spring for summer cutting, and in mid summer for fall and winter harvest.

Popular ornamental greenhouse plants

Greenhouse conditions can be adjusted, especially with the use of supplemental lights, to grow a large number of plant species. Only those plants that have become popular over the years and are comparatively easy to grow are described here.

Begonias

Tuberous begonias (*Begonia × tuberhybrida*) can be grown from tuberous roots like dahlias. The tubers are started in damp peat moss at a minimum of 16°C. The flat surface of the tuber should be on the top, level with the surface. When the shoots appear, pot each tuber in a 10-cm pot in a potting mix containing a good proportion of peat. Replant as necessary and give liquid feeding monthly. To obtain deep colors, keep the greenhouse cool in the summer. Best blooms are obtained by allowing only one shoot to develop from each tuber. When the foliage begins to yellow, gradually reduce the watering until the pots are dry. Store the dry tubers in dry sand or perlite at 4–7°C. These begonias can also be used as summer bedding plants. The winter-flowering Lorraine cultivars are grown from cuttings taken in the spring for flowering the following November, at a temperature of approximately 10°C.

The small-flowered wax begonias (*B. × semperflorens-cultivorum* hybrids), used as bedding plants, are grown from seeds. For maximum flowering period, seeds should be sown in early January at a temperature of 18–24°C.

Regal begonias (*Begonia × rex-cultorum*) (Fig. 46) are rhizomatous plants noted for their richly colored and patterned foliage. White or pink flowers in spring are also attractive. Begonias grow best at light intensities of 32 000–43 000 lx and temperatures of 18–21°C at night and 27–30°C during the day. Fibrous begonias (*B. serratipetala*) require moderate growing temperatures. Humus should be added to the general soil mix. Low-level fertilizing is required for rhizomatous begonias and moderate-level fertilizing for the fibrous begonias.

Begonias are subject to stem rot (*Pythium*), powdery mildew, gray mold (*Botrytis*), and nematodes. Fungal or bacterial leaf spots can occur as a result of poor sanitation, poor ventilation, and high humidity. Propagation is achieved by seeds or by leaf or leaf-section cuttings.

Fig. 46. These begonias are noted for their foliage.

Calceolarias (*Calceolaria herbeohybrida*)

These plants produce pouch-like blooms in a wide range of colors and sizes (Fig. 47). The F_1 hybrids are particularly attractive. To grow as bedding plants, sow the seeds in March at 10–13°C. For Christmas and winter flowering sow the seeds in May or June. The seedlings can be transferred to flats. When the plants are large enough, they can be transplanted into pots of 10–15 cm. The plants can be grown through the winter at about 7°C. To prevent wilting caused by sudden temperature changes and strong sunlight, keep the plants shaded.

Cinerarias (*Senecio hybridus*)

These daisylike flowers can be grown in a cool greenhouse from December to June (Fig. 48). To grow cinerarias as a bedding plant, sow seeds in March at 10–13°C. For Christmas and winter flowering sow seeds in April or May. Most kinds of plants require 12.5–15 cm pots.

Fig. 47. F_1 hybrids of calceolaria are attractive.

Fig. 48. Cinerarias provide color in the winter months.

Fig. 49. Remove early buds on cyclamens to conserve their energy for their main blooming period starting in December.

Cyclamens

Cyclamen persicum or *C. indicum* (Fig. 49) can be grown from seeds planted from August to November. The seeds are large and can be sown individually, covered with a layer of moist peat 1 cm deep, and kept at 18°C. The seedlings should be pricked out and planted in 5-cm pots in a good potting mix and maintained at about 16–18°C. When the plants are growing vigorously they can be transplanted to 12.5-cm pots and the temperature lowered to about 13°C. Plants grown outdoors should be brought into the greenhouse in September when the temperature drops to 10°C. Remove early buds to conserve the plants' strength for their main blooming period from December on.

Regal geraniums (*Pelargonium domesticum*)

An important greenhouse plant, Regals (Fig. 50) can be bought or propagated from cuttings from existing plants from early spring to July and August. The tips should be pinched to promote bushy growth. Geraniums need moist soil throughout their growing period. Regal geraniums need some shade when they are grown under glass, but generally they require high light conditions.

Carnations (*Dianthus caryophyllus*)

Carnations (Fig. 51) require cool temperatures, so some shading may become necessary in summer. Carnations are started from rooted stem-tip cuttings planted in the early spring. To get uniformly good cuttings you need to devote an area just for this purpose. If you cannot spare the space, purchase cuttings from a reliable source. Rooted cuttings can be moved to pots by 1 April and from there to the bench bed by 1 June. A good soil mix contains three parts soil and one part peat or well-rotted manure. After 3–4 weeks in the bench, pinch the plants to encourage branching. By late summer, when pinching is discontinued, the plant may have as many as 10 shoots. Space the carnations about 18 × 20 cm apart in the bench. For 2-year crops, replant half of the area each year.

Fig. 50. Regal geraniums are an important greenhouse plant.

Fig. 51. Carnations bloom profusely in bright, warm weather.

The carnation blooms any time of the year, but flowering is much more rapid in bright, warm weather. When pinching is discontinued on the young plants in July, flower production starts in the fall and returns again in late spring.

Maintain temperatures in the carnation house at 10°C at night, 12–13°C on cloudy days, and 15–16°C on bright days. Too-warm temperatures produce weak stems and small flowers, and too-cool temperatures delay growth. With standard cultivars, only the terminal bud is allowed to flower and side buds are removed. For spray or miniature types, all buds are allowed to develop.

Cut the flower low on the stalk, to get the longest possible stem without harming the plant and the subsequent crop.

Red spider and aphids are the most common pests of carnations. Thrips can also be a problem, particularly in early summer.

Several diseases are common in carnations. Fusarium wilt, bacterial wilt, and *Rhizoctonia* stem rot can all produce symptoms that are similar. Rust develops only on moist carnation leaves and can be prevented by keeping the leaves dry. Greasy blotch and *Alternaria* leaf spots may also affect carnations.

In a split carnation, some of the petals extend through a split in the calyx, making an unsightly flower. Various causes for the problem have been suggested, but aside from varietal differences, large deviations in temperature may be the most important factor. Never allow more than about 10°C difference in temperature between day and night.

Chrysanthemums (*Chrysanthemum morifolium*)

One of the most popular plants for pots or cut flowers, chrysanthemums have been developed as a year-round crop (Fig. 52). Chrysanthemums are grown from rooted stem-tip cuttings. Depending on the variety, cuttings can be rooted in 2–3 weeks at

Fig. 52. Chrysanthemums can be a year round crop.

15°C in a rooting medium at 21°C. The best cuttings are obtained from specialist propagators.

Chrysanthemums can be grown on a bench as single-stem plants spaced about 10 × 15 cm apart or as pinched plants spaced at 15 × 20 cm. Give chrysanthemums long days for the first few weeks, to promote growth and increase the stem length. During summer, from May to August, the days are long naturally, but during the rest of the year supplementary light must be provided. When chrysanthemums are grown to about 30 cm high and then subjected to short days, they produce flower stems about 45 cm long. Chrysanthemums respond to the photoperiod, and flowering depends on the length of day and temperature. In the absence of short days flower buds do not develop or, if they do, they will be distorted. With some varieties, too cool a temperature may prevent bud formation or promote crown bud development.

This consistent response to day length allows you to predict the flowering date from the time the plants are subjected to short days. To promote formation of flower buds, place black cloth over the plants during the long days of summer.

Pot chrysanthemums are grown as either a single-stem or pinched plant. For a single-stem plant, put five to seven cuttings around the outside of a 15-cm pot. Allow only the main flower bud on each stem to develop, and remove all others. For a pinched plant, allow each cutting to produce several flowers. Then remove the tips 3 weeks after planting, to cause the plant to branch. Spray chrysanthemums are not disbudded and all side shoots are allowed to flower.

Chrysanthemums should be grown at 15°C at night and 15–21°C during the day, depending on whether it is cloudy or sunny. During the last weeks before flowering these temperatures can be decreased in an effort to increase the size of flower. Many varieties do not flower satisfactorily when grown at temperatures below 12–13°C or when kept at high temperatures.

Propagators of cuttings list the varieties by their response group and publish schedules giving dates for planting, pinching, lighting, shading, and flowering. This information makes it easier to plan for weekly flowering. Chrysanthemums like a growing medium that is loose and porous.

Fig. 53. Hydrangeas are grown mainly for Mother's Day and Easter.

A good mixture can be made by adding one part of peat or leaf mold to three parts of loam. Many pests attack chrysanthemums, among them aphids, cyclamen mites, leafhoppers, leafminers, tarnished plant bugs, thrips, spider mites, and whiteflies. *Ascochyta* blight, *Botrytis* rot, leaf spot, powdery mildew, root rot, and rust are common diseases encountered on chrysanthemums.

The height of cut chrysanthemums can be controlled with B-9® at 2500 ppm. Spray the top third of the foliage 2 days after disbudding or 4 weeks after they were placed in the shade. For pot plants, B-9® may be used as a spray at a concentration of 2500–5000 ppm when the shoots are 2–4 cm long; this treatment can be repeated 3 weeks later. A-Rest® at 2–8 ppm can be used as a soil drench when the root system is well developed.

Hydrangeas (*Hydrangea macrophylla*)

Grown mainly for Mother's Day and Easter, the plants can be started from cuttings taken from mature plants (Fig. 53) from February to May. Softwood cuttings are rooted in sand under mist. In 4 weeks the rooted cuttings can be planted in pots of 12–15 cm in a mixture containing two parts peat and one part loam. At 4 weeks after planting, the pots can be moved outside in a shady place. The new plants must be kept watered and fertilized until late September, by which time the flower buds are formed. Keep the plants at 10°C for at least 6 weeks before forcing them into bloom. For bloom at Easter, remove the plants from storage at the end of December and keep them at 15°C. Apply fertilizer and plenty of water at this time.

The color of hydrangeas can be controlled: pink varieties retain the color only if the soil pH is nearly neutral, at pH 6.5–7.0. When the pH is 6.0 or less the flowers are blue. To produce blue flowers, supply the plants with a solution of aluminum sulfate (500 g per 20 L of water).

On hydrangeas aphids and spider mites are the main insect pests and *Botrytis* blight, powdery mildew, and root rot are the diseases encountered.

The growth retardant B-9®, at 2500–5000 ppm, can be used as a spray to control height of the plants. Apply the treatment 3 weeks after transplanting; it induces earlier flowering but may cause some marginal leaf burn.

Roses

Rosa spp. (Fig. 54) can be planted in the spring for flower production beginning in the summer and continuing until the plants are cut back the following summer. The plants are usually kept in the bench for 4 years in continuous flower production, except during the cut-back periods.

Roses can be propagated by budding or grafting or by rooted cuttings. Budding is a job for a specialist and is done mostly in locations with a favorable climate, such as California and Texas. *Rosa manetti* is usually used as the rootstock. Although budded plants can be most readily obtained in late December, they can be stored at 1–2°C until spring.

Rooting stem cuttings can be a satisfactory method for propagating roses. For rooted cuttings planted directly, place the cuttings into rooting medium about 5 weeks before the desired planting date. The cuttings should consist of a section of stem with two leaves and should be rooted in a misted bed in which the air temperature is 15°C and the rooting medium is maintained at 21°C. Perlite, coarse sand, or a mixture of perlite and sand can be used as the rooting medium.

Because roses remain in the same soil for about 4 years, the soil should be well prepared. Roses grow in a wide range of soil but do best in a rich clay loam with plenty of organic matter and with a mulch of peatmoss or manure applied on the surface. Apply fertilizer with the first thorough watering after planting; roses need a continuous supply of nitrogen in the early stages of growth to produce large, heavy stems. Add superphosphate and calcium fertilizers to the soil before planting the roses; potassium nitrate and ammonium nitrate are supplied by the regular liquid fertilizer. Apply iron if deficiency symptoms appear.

A rose should develop several heavy shoots from the base of the plant. Allow the heavy shoots to grow to the young-bud stage, and then pinch them back to a five-leaflet leaf. Pinch the weaker shoots above the five-leaflet leaf as it begins to unfold. Pinching in this way increases the heaviness of the shoots that develop.

Maintain the temperature in the rose house at 15°C at night and 17–21°C during the day, depending on sunshine. Growth and flowering are faster in warm temperatures. Rose plants need to be cut back each year. The recommendations for the pinching and development of new shoots in the cut-back plant are then the same as for a new plant.

Two types of roses are grown; the large-flowered ones are the hybrid tea roses. Side shoots do not develop readily on these roses, but if they appear they should be removed, leaving only one flower per stem. Floribunda or Sweetheart roses form side shoots that are allowed to flower as a spray.

Fig. 54. Floribunda roses are allowed to flower as a spray.

Fig. 55. Poinsettias require short days to flower.

The most persistent pests on roses are spider mites, which first occur on the underside of the lower leaves. Thrips are another pest, which can cause distortion of the flower buds, cupping of petals, and streaks on the flowers. Aphids are found occasionally on stem tips and leaves.

Powdery mildew is the most common disease in the greenhouse, but black spot and *Botrytis* rot are also encountered.

Poinsettias (*Euphorbia pulcherimma*)

These Christmas favorites (Fig. 55) are short-day plants propagated from cuttings taken in late summer. Tip cuttings about 10 cm long can be rooted in about 3 weeks at a bench temperature of 15–21°C. Poinsettias root well in either coarse sand or perlite. If the cuttings cannot be rooted under mist, keep them heavily shaded.

The rooted cuttings can be planted in pots of 5 or 7.5 cm and later replanted three or five to a pan (flat pot) or 15-cm pot. A good growing medium is three parts

Fig. 56. Dieffenbachias are grown for their distinctive foliage.

Fig. 57. Dracaenas are another large plant with attractive foliage.

soil to two parts peatmoss with some superphosphate added. Poinsettias are susceptible to diseases of the root and stem, which are promoted by overwatering. It is often better to buy rooted cuttings from a reputable dealer than to bother with propagation at home.

Poinsettias require short days to flower. Take great care not to expose the plants to light accidentally during the dark period. Poinsettia pans with three or four flowers are the most popular. The plants can be pinched to produce two or more flowers on each stem; pinch the woody tissue about 15 August, and the nonwoody tissue about 1 September. Poinsettias need a continuous supply of fertilizer. When superphosphate has been used in the potting soil, apply fertilizer such as 25-9-25 every week at a rate of 1250 g / 350–400 L of water.

Whiteflies are the most common pest on poinsettias; they should be controlled in the early stages of cultivation because insecticides used later may damage the flowers.

Root and stem rots caused by *Rhizoctonia*, *Pythium*, or *Thielaviopsis* are considered the most important diseases of poinsettias. The propagation bench, soil, pots, and other equipment need to be thoroughly sterilized. *Thielaviopsis* develops more easily at 15°C; therefore take care to avoid drops in temperature. Both *Rhizoctonia* and *Pythium* become established more easily in constantly wet soils, so control watering carefully. These two diseases can be controlled by preventive soil drenches with fungicide shortly after the plants are potted. Excessive, undesirable elongation of plants can be controlled by use of growth retardants, like B-9® at 5000–7500 ppm, sprayed onto the foliage when shoots are approximately 5 cm long; A-Rest® at 2–8 ppm, applied as a drench at pinching time to 4 weeks later, or 8–12 weeks before finishing; and Cycocel® at 1500–3000 ppm, applied as a spray or drench when shoots are 2–4 cm long (spraying twice with the lower concentration is more effective). The plants require rather heavy feeding and should be given a complete fertilizer like 7-7-7 every week or 10 days. Slightly acid media (pH 6–7) are best for poinsettias.

Dieffenbachias (*Dieffenbachia maculata* 'Baraquiniana', 'Jenmannii', and 'Memoria')

Distinguished by glossy, bright green leaves often marbled or spotted with ivory (Fig. 56), these plants require moderate light at 32 000–48 000 lx and grow well in 63–73% shade. The optimum temperature for growth is 18–21°C at night and 17–30°C during the day. Keep the plants evenly moist but not soggy wet, and fertilize them regularly. Although insects are not a serious problem, plants are subject to attack by aphids and spider mites. Crowding, high temperature, and humidity favor infection by bacterial and fungal leaf spots; poor drainage or wet soil can result in crown rot or bacterial stem rot. Propagation is achieved by air layering, root suckers, or cane sections buried in sand.

Dracaenas

Dracaena spp., sometimes known as corn plant, gold-dust dracaena, or red-margined dracaena, are shrubby or treelike plants with bold foliage (Fig. 57). *D. marginata* requires high light intensity, about 54 000 lx; other dracaenas require moder-

Fig. 58. The weeping fig has a lovely pendulous habit.

Fig. 59. The rubber plant has rugged foliage.

Fig. 60. The umbrella tree is useful as a room decoration.

ate light, about 38 000 lx. They grow best in high humidity but they tolerate dry air when the foliage is misted regularly. Keep the growing medium moist but not soggy wet and apply 20-20-20 fertilizer about once a month. This species does best in warm temperatures, namely 18–20°C at night and 27–30°C during the day, but it tolerates 16°C at night and can survive at 10°C for short periods. The main pests are mealy bugs and scale insects. Poor aeration, high temperature, and humidity favor fungal and bacterial leaf spots.

Dracaenas are fluoride-sensitive: leaf tips and edges turn brown, or brown patches appear on leaf blades. The plants are sensitive to atmospheric fluoride as well as to soil fluoride. To avoid fluoride damage, maintain the pH of the soil at 5.5–6.8, avoid superphosphate fertilizers, use water with low fluoride content, and avoid growing media containing perlite. Propagation is achieved by air layering or by rooting stem sections or cuttings.

Weeping figs (*Ficus benjamina*)

This evergreen tree or shrub has a pendulous habit that increases with maturity (Fig. 58). Leaves are slender, deep green, glistening, and slightly wavy or twisted.

Rubber plants (*Ficus elastica*)

Grown for its rugged foliage, this plant has bronze leaves that become glossy green with ivory streaks (Fig. 59). It re-

Fig. 61. Croton is an evergreen shrub.

quires average to high humidity, an optimum temperature of 18–21°C at night and 17–30°C during the day, and a high level of fertilizer. It is subject to attack from scale insects, mealy bugs, and thrips. Poor ventilation, high temperature, and humidity favor infection by *Cercospora* leaf spots.

Fig. 62. Like other philodendrons, the split-leaf type prefers indirect light.

Umbrella trees (*Schefflera, Brassaia actinophylla*)

These graceful, fast-growing plants are useful as a room decoration (Fig. 60). Leaves are long stalked, with six to eight glossy green leaflets 10–25 cm long. For optimum growth this plant requires a fairly high light intensity of up to 54 000 lx. It grows best at higher temperatures, 18–21°C at night and 27–30°C during the day. It requires average humidity but tolerates some degree of dryness. The plants should not be overfertilized. Spider mites, scale insects, and mealy bugs may become problems. In warm, moist conditions leaf spot diseases may be a problem. This plant can be propagated by cuttings, by air-layering, or from seeds.

Crotons (*Codiaeum variegatum*)

These evergreen shrubs have glossy leaves in shades of cream, yellow, and red (Fig. 61). The plants grow best at high light intensity (75 000 lx) and high temperatures (nights 18–21°C, days 27–30°C). However, crotons can tolerate night temperatures of 10–16°C. Plants should be watered heavily, allowed to dry, then watered heavily again. Crotons require a high level of fertilizing. Scale insects, mealy bugs, and mites are the common pests of crotons. Poor aeration, high humidity, and high temperature favor infection with stem and root rots. Drafts and low light intensity may cause leaves to become yellow and drop. This plant can be propagated by root cuttings.

Philodendrons

The heart-leaf type, *Philodendron scandens* subsp. *oxycardium*, is a vine with heart-shaped, glossy, leathery leaves 5–10 cm long. *Philodendron selloum*, the tree type, is self-supporting to 120 cm, with dark green, deeply cut leaves 30–45 cm long. The split-leaf philodendron, *Monstera deliciosa* (Fig. 62), is a robust tropical vine with perforated, glossy, leathery leaves 20–30 cm long.

Light conditions for these plants should be kept moderate (32 000 lx). The minimum temperature for growth is 13–16°C, but the plants grow best at higher temperatures. They are especially susceptible to mealy bug attack. Inadequate aeration and high humidity may favor infection by bacterial and fungal leaf spots as well as by bacterial leaf rot. They can be propagated by tip cuttings, root stem-joint cuttings, or air-layer tips of old plants.

Peperomias (*Peperomia caperata*)

These small, trailing succulents (Fig. 63) have attractive foliage and are mostly used in baskets. They require low to moderate light (22 000–32 000 lx) and warm temperatures (nights 18–21°C and days 27–30°C). Fertilizer requirements are very low. Poor ventilation and high humidity favor infection by stem and root rot and by *Cercospora* leaf spot. The plants can be propagated by division or cuttings.

Cacti and other succulents

Plants storing water in their tissues are called succulents. Cacti, the largest group of succulents, store water in their stems. Because of their desert origins, most cacti thrive in bright sunlight (Fig. 64). They rarely grow in regions where the rainfall is

Fig. 63. Peperomias are used mostly in hanging baskets.

Fig. 64. Cacti thrive in bright sunlight.

more than 25 cm a year. Some cacti, however, are native to moist climates.

Cacti should be watered during the growing period whenever the soil is dry. When dormant they do not need water, or just enough to keep the soil from drying out completely. A moist, very porous potting mixture is essential for success. A good growing mixture may be composed of eight parts soil, eight parts perlite, two parts dehydrated cow manure, and one part bone meal.

Cacti and succulents require high light intensity (54 000–65 000 lx), except for Christmas, Easter, and orchid cacti, which require moderate light (22 000–43 000 lx). Temperature requirements for cacti and succulents are moderate (nights 16–18°C and days 18–24°C). Water the plants well and allow the soil's upper layer to dry out before rewatering.

Christmas, Easter, and orchid cacti require warm temperatures (nights 18–21°C, days 27–30°C) and grow best in moist soil. Keep applications of fertilizer at a moderate level. Flower buds develop in short days at reduced temperatures when the soil is allowed to dry between watering. Short days are required for flowering; 4 weeks of 8-hour days, or natural fall–winter daylength. Reduce the temperature to 10–13°C at night. Leach the soil first to reduce fertilizer levels and allow it to dry between watering. Do not use fertilizer until the buds appear. When the flower buds swell, normal watering can be resumed and the temperature increased. Apply fertilizer at half rates until the flowers open. Even when flowering cacti are grown under poor light conditions, they sometimes produce flowers.

Cacti are subject to attack by mealy bugs, spider mites, and scale insects. Inadequate sterilization of pots, soil, and benches can result in infections by *Botrytis*, *Phytophthora*, *Pythium*, and *Fusarium*.

To grow cacti from stem cuttings, remove a section of the stem, whether globular, columnar, straplike, or segmented, by cutting it straight across. Place the cuttings in a warm, dry place for about 3 days to allow the wound to dry. Once the end is dry, put the section in a pot containing potting mix or sand deep enough to keep it in an upright position. Keep the potting mix slightly moist. The stem cutting should root in 1–3 weeks. Other cacti can be propagated from offsets and offshoots.

Sometimes cacti can be propagated from seed, either home-grown or purchased. Sow the seeds on the surface and leave them uncovered. Put the pot in a plastic bag or cover it with a glass plate to keep the soil from drying out. Maintain the temperature at 21–27°C.

Cacti can also be propagated by grafting if the plants do not grow easily from seeds, cuttings, or offsets.

Ferns

The large number of ferns available for cultivation include *Adiantum*, maidenhair ferns; *Asplenium*, spleenworts; *Asplenium nidus*, bird's-nest fern; *Blechnum*, rib ferns; *Davallia*, squirrel-foot ferns; *Nephrolepis exaltata*, Boston fern; *Pellaea rotundifolia*, button fern; and *Pteris*, table ferns. Ferns (Fig. 65) require relatively low light intensity (22 000 lx). The optimum temperature for growth is 18–21°C during the night and 27–30°C during the day, but many ferns tolerate minimum temperatures of 10–16°C. Ferns do best in high humidity and moist soil with a high humus content. An exception is the holly fern, *Cyrtomium falcatum*, which requires a fairly dry soil. Some

Fig. 65. Ferns require low light for best growth.

Fig. 66. *Cycas* is only one of the several palms available for cultivation.

ferns (*Adiantum*) grow best in calcium-rich soils. Use fertilizer sparingly. Ferns are subject to attack by scale insects, mealy bugs, aphids, and whiteflies. Poor sterilization of pots, soil, and benches can result in infections by *Botrytis* or *Rhizoctonia*. Leaflet tips and margins may dry and turn brown in low humidity or where the root system is damaged by either high salt content in the soil or waterlogging. Ferns can be propagated by division of old plants or by planting spores.

Palms

The many species of palms available require moderate light intensity (32 000–43 000 lx) and warm growing temperatures (nights 16–21°C and days 24–30°C). *Rhapis* and *Cycas* (Fig. 66) prefer more moderate temperatures. For *Cycas*, water heavily, allow the soil surface to dry, then water heavily again. For other palms, keep the soil uniformly moist but not soggy. Use fertilizers at a moderate level. Palms are subject to attack by spider mites. They can be propagated from seed.

Forced bulbs

For forcing (Fig. 67), choose bulbs that are intact and disease-free. They need not be top size, but the tips should not be damaged nor the outer skin torn. Avoid bulbs that look skinned. Expose the bulbs to a period at low temperature after they have been planted and then to a higher temperature as they reach the flowering period. Controlling these conditions allows a grower to determine when flowering will start.

Most bulbs can be grown in soil, compost, or peat and vermiculite. Be sure to maintain a uniform amount of moisture. Never allow the planting material to become waterlogged or to dry out. Fertilizing is not as crucial because bulbs store enough reserve to bring them to flowering. If soil is used, a mix of equal parts of loam, coarse sand, and peat gives good results. Many special mixtures also are available.

When planting, place the bulbs close to each other, but not touching, in a half-filled container. Cover the bulbs so that the tips are just at the soil surface. Plant crocus corms so that they are just covered by the soil. Label the pots and water the soil carefully. A good root system must develop before the bulbs are subjected to higher temperatures. Most bulbs need about 2 months storage, but this time varies with the kind of bulb. Put the pots in a dark storage space at a temperature of 5–10°C, or put them outdoors under sand and leaves in a trench 45–60 cm deep until needed. All pots stored above ground should be inspected for need of water.

When the bulb shoots are about 2 cm in length after a storage of 10–13 weeks or more, the forcing process can be started. Put the potted bulbs in a light, cool room at a temperature of about 10°C. Cover the emerging shoots for the first day. They will gradually turn green and grow vigorously but should not be moved to a warmer place at 15.5°C until the leaves are well developed. At this stage the pots must be watered more frequently. Afterwards, the pots should be located where they receive more light, but do not put them in direct sunlight.

- Hyacinths should be ready to move for forcing after mid January and bloom in 3 weeks.

Fig. 67. Forced bulbs make an attractive display in spring.

- Tulips can be forced after the end of January and bloom in about 4 weeks. Use any of the varieties listed in catalogs as single earlies.

- Daffodils can be forced after the end of January. Bulbs kept at a temperature of about 13°C develop long stems and long-lasting flowers.

- Paper-white narcissus do not need a low-temperature rest period and can be planted at a warm temperature. They bloom in about 6 weeks.

- Crocuses and grape hyacinths can be moved for forcing after the end of January and forced at a temperature of 10–15°C.

Bulbs that have been forced cannot be used again for this purpose but can be saved for outdoor planting. To allow the bulbs to mature, water and fertilize the plants until the foliage yellows, then allow the soil to dry out. The bulbs should be removed, cleaned, and stored in a dry, cool place until planting time. Nonhardy bulbs like *Narcissus tazetta* 'Paperwhite' do not survive cold and cannot be used for outdoor planting.

Bulb plants are subject to several diseases, but they are usually not encountered in home greenhouses.

A low level of fertilization, using soluble 20-20-20 fertilizer in a 15-cm pot, is 0.4 g; a moderate level is 0.8 g; and a high level is 1.2 g. The corresponding values for a 25-cm pot are 1.2, 2.4, and 3.6 g.

Insects and diseases

Insects

Many kinds of insects are found in greenhouses, but only a few occur in numbers great enough to cause damage to the plants. Good cultural practices, designed to discourage infestation and keep numbers of insects as low as possible, are the best control. Plants kept for long periods of time are the main source of undesirable reinfestation. Take care to remove old leaves and entire plants that are showing chronic signs of unthriftiness. Cut plants back to only a few leaves or branches after flowering and allow them to produce fresh foliage. Remove dead leaves and flowers immediately, because they can harbor both insects and disease organisms. Avoid overcrowding to ensure adequate aeration, prevent a build-up of humidity, and make plants easier to get at. Many insects and diseases thrive under conditions of low light. A few of the more troublesome insects are described below.

Whiteflies (Fig. 68) are one of the most common insects in the greenhouse. They are usually found on the undersides of the leaves where they feed through a piercing–sucking mouthpart. These insects cause a yellow stippling of the leaves and leave behind a sticky residue that must be washed off the fruits of plants such as tomatoes and cucumbers. They are particularly troublesome on chrysanthemums, fuchsias, petunias, poinsettias, salvias, tobacco, and tomatoes. Although adults can be readily killed, the eggs, pupae, and larvae are not susceptible to pesticides. Therefore repeated use of insecticides may be required for control. It is a persistent pest and has developed resistance to many chemical control agents.

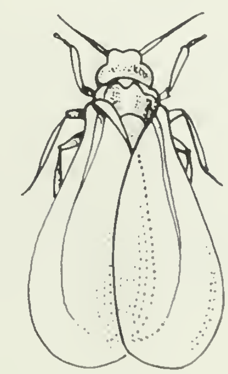


Fig. 68. Whiteflies are common insect pests.

Mites (Fig. 69) are wingless organisms related to spiders, with oval-shaped bodies and short legs. They have piercing–sucking mouthparts with which they suck sap from plant tissue. Their feeding gives leaves a dried, whitish appearance and causes new growth to be distorted. Cyclamen mites are very small, a fraction of a millimetre long when fully grown, and are difficult to see with unaided eyes. Cyclamen mites affect many species of plants, distorting leaves and flowers. Two-spotted mites have two dark spots on their bodies and are twice as large as the cyclamen mite. These mites are most prevalent on the undersides of leaves and in flowers, which eventually dessicate. Low relative humidity promotes development of this pest.

Mites also live on plant refuse and on the greenhouse framework and spread to tomatoes, lettuce, and almost all vegetables and flowers. Fumigation of the green-

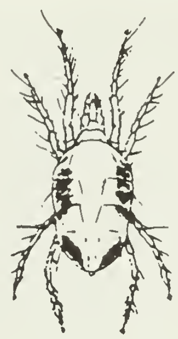


Fig. 69. Mites suck sap from plant tissues.

house is probably the most effective control but must be repeated to catch the active stage of the pests.

Aphids (Fig. 70) are small insects that feed on moist greenhouse vegetables and flowers. They suck the sap of the plants, causing leaves to become distorted and leaving a sticky residue called honeydew. They may also transmit plant viruses. When the population of aphids becomes too great, chemical insecticides are needed to control them.

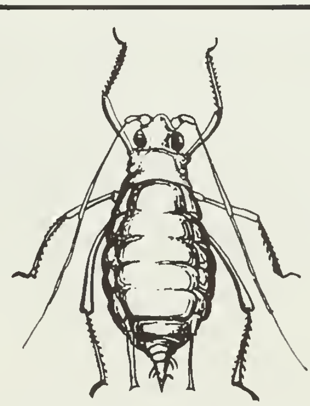


Fig. 70. Aphids leave a sticky residue called honeydew.

Mealybugs are small, white wax-covered insects (Fig. 71) that affect many indoor plants, leaving masses of a white cottonlike substance at leaf nodes. Mealybugs are one of the most serious greenhouse pests, damaging the plants by removing the plant sap, promoting the growth of the black, sooty mold, and leaving waxy residues. Root-feeding mealybugs live on roots and cause wilting or yellowing of plants. Systemic insecticides give the most effective control of these pests.

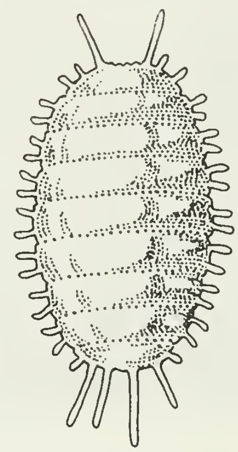


Fig. 71. Mealy bugs leave a cottonlike substance at leaf nodes.

Fungus gnats (Fig. 72) are becoming a serious problem because of the greater use of soilless mixes with a high proportion of organic matter. They feed on young roots of the plants and on the decaying organic matter. Soil drenches and granular insecticides give effective control.

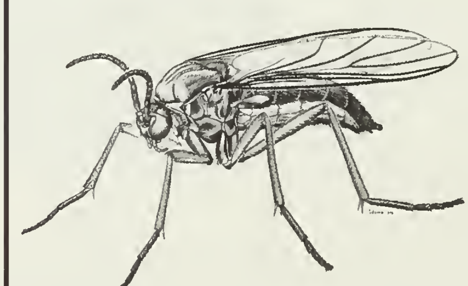


Fig. 72. Fungus gnats feed on decaying organic matter.

Scale insects (Fig. 73) are minute wingless insects, up to 3 mm in length, with piercing–sucking mouthparts and a waxy or scalelike covering over their bodies. Scales infest many ornamental plants including *Ficus*, fuchsias, ferns, palms, and ivy. Systemic insecticides usually control these pests.

Fig. 73. Scales infect many ornamentals.

Thrips (Fig. 74) are small insects, 15–30 mm long when fully developed, which feed on a broad range of plants. They are commonly found in buds, flowers, petals, and axils of leaves and between the scales of bulb plants. The insects remove the epidermal layer of a leaf or flower petal and suck the sap, leaving a streaked pattern. Thorough coverage of the plant with insecticides is required for control.

Fig. 74. Thrips leave a striped pattern.

Slugs (Fig. 75) are slimy, dark gray, soft-bodied animals that eat the foliage of most greenhouse plants. They are nocturnal and hide under cover during the day.

Snails (Fig. 76) are similar in appearance but have a shell cover. Control is obtained with baited pesticides.

Fig. 75. Slugs eat most greenhouse foliage.

Fig. 76. Except for their shells, snails are similar to slugs.

Earwigs (Fig. 77) are becoming an annoying pest in recent years. They eat irregular holes in leaves, giving them a tattered appearance. Clematis, dahlias, gladiolas, and other plants including many vegetable crops are affected. Several insecticides are available for control of these insects.

Fig. 77. Earwigs give leaves a tattered appearance.

Nematodes are pests that damage roots (Fig. 78) or leaves. Plants attacked by root nematodes become stunted and less productive. Soil fumigation can be used to control them. Foliar nematodes, those that attack the leaves, are quite prevalent on begonias, chrysanthemums, and strawberries.

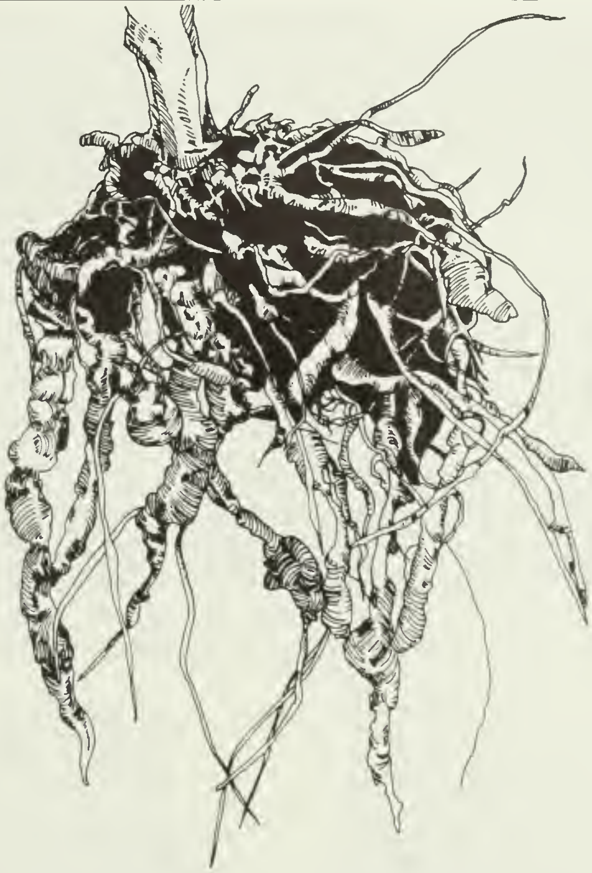


Fig. 78. Plants attacked by root nematodes become stunted.

Fig. 79. *Botrytis* grows on flowers, leaves, and stems of plants when humidity is high.

How diseases are spread

A great many diseases occur on plants in the greenhouse, so you must always remain alert to detect infections early. Diseases such as *Botrytis* mold or powdery mildew can spread so rapidly that a single infection can become an epidemic in 2 or 3 days. High humidity, poor aeration, and the presence of senescent foliage encourage the growth and spread of the fungi and bacteria that cause plant diseases. Diseases can also be spread by careless handling of plants. Virus diseases, for example, are transmitted in plant sap. Therefore handling healthy plants after touching diseased specimens can infect them with the same disease. Many fungi produce spores in great abundance. These can be blown about from plant to plant by air currents, carried on the watering can or hose, or spread from hands or clothing. Most bacterial diseases result in small droplets of bacteria oozing from the plants and adhering to the surface of foliage. The bacteria are usually moved from plant to plant by the gardener. Insects can also spread fungi and bacteria by carrying them on various parts of their bodies. Several virus diseases can as well be transmitted from infected to healthy plants by insects but, in many cases, the insect must pierce the leaf or stem surface in order to pick up the disease-producing entity from the sap. The infected insect must then puncture the leaf of a healthy plant to inoculate it with the virus. Some of the more common greenhouse diseases are described below.

Fig. 80. Powdery mildew is only one of several fungus diseases found in greenhouses.

Fig. 81. Damping-off of seedlings is usually caused by *Pythium* or *Rhizoctonia*.

Fungus diseases

Gray mold (*Botrytis* spp.) attacks bulbs, stems, leaves, and flowers of many ornamental and vegetable plants. The symptoms are a brown rotting and blighting of flowers and other affected tissue (Fig. 79). The spores are carried by air and germinate on moist plant surfaces.

Because spore germination requires high humidity and moisture, ensure that ventilation is adequate and avoid splashing water on the plants. Be sure to practice good sanitation procedures, such as the removal of old blossoms and leaves.

Early blight and leaf spot (*Alternaria* spp. and *Septoria* spp.) are common diseases of tomatoes. Early blight lesions are characterized by dark rings on a brown background. Leaf spot shows up as small black dots on the affected area. The oldest leaves are attacked first and these diseases may cause a defoliation of the lower part of the plant. Spores of these diseases are wind-borne or may be spashed onto leaves during watering. Proper ventilation and reduction of humidity help in controlling these diseases.

Powdery mildew (Fig. 80), caused by any one of many species of fungi, is characterized by the appearance of small, snowy white spots on the surface of leaves, stems, and flowers. On some plants, like roses, the young shoots may become completely covered with the whitish mildew growth and become distorted. The disease spreads by spores that are carried in air currents. Certain species of the powdery mildew fungi usually are specific to particular crops; for example, powdery mildew on chrysanthemums does not affect roses. Spores of the powdery mildew fungus may germinate at a lower humidity than that usually required for other plant diseases.

Rhizoctonia, *Pythium*, and *Thielaviopsis* are soil-borne fungi that attack a wide variety of plants. *Pythium*-infested roots usually turn black and wet and appear hollow and collapsed. Cool, wet, poorly drained soils promote this disease. Therefore avoid excessive watering. *Rhizoctonia* can infect leaves, stems, and roots of many plants. It does not cause as much rotting of roots as *Pythium*, but most amateur gardeners are not able to differentiate between the two.

Thielaviopsis causes a drier rot of roots but, again, the differences in symptoms produced by *Pythium*, *Rhizoctonia*, and *Thielaviopsis* are not great enough for the hobbyist to be able to differentiate.

The damping-off disease of seedlings is most frequently caused by *Rhizoctonia* or *Pythium*. Infection of the seedlings can occur before they emerge or after they appear above the soil (Fig. 81). To prevent damping-off diseases, use well-drained soil that is thoroughly pasteurized or sterile rooting media; clean thoroughly plants, benches, pots, and tools; and practise a generally sound sanitation program. Soil treatments with chemicals can also be helpful.

Verticillium is a fungus that invades the conducting tissues of plants and causes wilting. Quite often only one side of the plant is affected. The fungus persists in soil and the infection occurs through roots; in many cases the plants appear to be symptomless. However, cuttings from such plants may carry the fungus. Pasteurize the growing medium to control this disease.

Leaf mold of tomatoes, caused by the fungus *Cladosporium fulvum*, starts as gray spots on the lower side of the leaves and continues to develop until the entire leaf, top and bottom, becomes covered with an olive-colored mold. It can be controlled by good sanitation procedures and good ventilation.

Bacterial diseases

Bacteria are single-celled organisms that grow within the tissues of the plant, making the diseases difficult to control. The best control is achieved through prevention, as well as the early removal and careful disposal of infected plants. Crown gall on roses, geraniums, and chrysanthemums caused by *Agrobacterium tumefasciens*, bacterial leaf spot of geraniums caused by *Xanthomonas* spp., bacterial wilt of carnation caused by *Pseudomonas caryophylli*, and soft rot of cuttings and bulbs caused by *Erwinia* spp. are some of the most common bacterial diseases.

Fig. 82. Rose mosaic virus discolors the leaves, stunts the plant, and decreases flowering.

Virus diseases

Viruses are extremely small infective agents similar in size and chemistry to DNA, the genetic material within plant cells. They live within cells causing complex symptoms including stunting, dwarfing, leaf mottles, mosaics, and distortion of leaves, flowers, and fruit. Usually, the first symptoms appear on the leaves as mottles or mosaic patterns (Fig. 82). Flowers can be dwarfed, deformed, or even changed into leafy structures. Viruses can be spread by insects feeding on a healthy plant after feeding on an infected one, by grafting of infected plant parts, or by using infected plants as a source of cuttings. Sometimes viruses are spread simply by handling healthy plants after having contacted infected ones. Be sure to use pathogen-free propagating material and a good sanitation program to control these problems.

Several viruses attack tomatoes. Tobacco mosaic virus (TMV) is the most common, causing distortion of leaves, stunting of growth, and reduction in yield. It is spread by insects, hands, or tools. Besides good sanitation and control of insects, a nonsmoking rule helps to avoid infection, as this virus may be present in tobacco.

Physiological diseases

Undesirable greenhouse temperatures, faulty fertilizing and watering, build-up of soluble salts, and other nutritional problems may cause physiological disorders in plants.

- Tomato blossom end-rot appears as a brown, leathery tissue at the blossom end of the fruit. The direct cause is low supply of calcium; an indirect one is plant stress caused by low soil moisture, excess soluble salts, high rates of transpiration, or high soil moisture.

- Tomato fruit cracking is usually caused by a sudden change in moisture supply to the plants. Prevention is usually achieved by avoidance of high temperature and maintenance of uniform, medium moisture conditions.

- Blotchy ripening of tomatoes is associated with low light intensity, cool temperature, high soil moisture, high nitrogen, and low potassium.

- Sunscald of tomatoes can be avoided by preserving the leaves that offer protection to the fruit clusters and reducing the greenhouse temperature.

- Roughness and catfacing of tomatoes, a radial wrinkling of fruit shoulders, is caused by poor pollination, low temperature, and high relative humidity. These factors cause the flower parts to develop abnormally.

- Crooking of cucumbers, an excessive curvature, can be caused by a leaf or stem interfering with the growth of the young fruit. Adverse temperature, high soil moisture, and poor nutrition can also cause this disorder.

Physiological diseases occur in most plants that are under stress. Their symptoms take on many different forms, including leaf spots, scorching of leaf tips and margins, abnormal growth habits, defoliation, flower and fruit drop, and general deterioration.

Pesticides

The kinds of pesticides available to the amateur gardener, their formulation, and the recommended usage change with time. Handle and apply all pesticides in *strict* accordance with given directions. Follow exactly all instructions on correct handling, dosage for greenhouse or outdoor use, and timing of applications on edible crops. Note all precautions regarding toxicity.

Plant injury can be caused by pesticides. To minimize it, apply pesticides during the cooler parts of the day.

Many pesticides, even though carefully tested before registration for use, are toxic to humans and animals. Avoid careless handling or overuse of these chemicals. Good sanitation and proper cultural methods are the best means for control of insects and diseases. Chemical pesticides should be used only as a last resort.

Resource bibliography

Greenhouse construction

A guide to rock bed storage units. 1981.
Enermodal Engineering Ltd.
National Research Council of Canada, Solar Energy Project, Ottawa, Ont.

Canadian wood-frame house construction. Metric edition. 1981.
Canada Mortgage and Housing Corporation, National Office, Ottawa, Ont.

Handbook on insulating homes for energy conservation. 1980.
Canadian General Standards Board, Hull, Que.

Keeping the heat in. 1976.
Energy, Mines and Resources Canada.

Low-cost passive solar greenhouses. 1980.
Alward, R.; Shapiro, A.
National Center for Appropriate Technology, P.O. Box 3838, Butte, MT.

Solar greenhouses: underground. 1982.
Geery, D.
Tab Books, Inc., Blue Ridge Summit, PA.

The food and heat-producing solar greenhouse. 1976.
Fisher, R.; Yanda, B.
John Muir Publications, P.O. Box 613, Santa Fe., NM.

The solar greenhouse book. 1978.
McCullagh, J.C.
Rodale Press, Emmaus, PA.

The solarium workbook. 1981.
Hawes, D.; Lawand, T.; LeNormand, J.; Skelton, A.
National Research Council of Canada, Solar Energy Project, Ottawa, Ont.

Greenhouse management

Ball bedding book. 1977.
Ball, V.
Geo. J. Ball, Inc.

Diagnostic techniques for soils and crops. 1948.
The American Potash Institute, Washington, D.C.

Greenhouse grow-how. 1977.
Pierce, J.H.
Plants Alive Books, Seattle, WA.

Greenhouse operation and management. 2nd ed. 1981.
Nelson, P.V.
Reston Publ. Co. Inc., Reston, Virginia.

Greenhouse vegetable production in Ontario. 1976.
Tiessen, H.; Wiebe, J.; Fisher, C.
Ontario Ministry of Agriculture and Food, Toronto, Ont., Publ. 526.

Horticulture for profit and pleasure. 1969.
Hamilton, G.H., et al.
J.M. Dent and Sons Ltd. (Canada).

Hydroponic food production. 1978.
Resh, H.M.
Woodbridge Press Publ. Co., Santa Barbara, CA.

Pesticide recommendations for greenhouse ornamentals. 1981–1982.
Ontario Ministry of Agriculture and Food, Toronto, Ont., Publ. 381.

Reader's Digest illustrated guide to gardening in Canada. 1979.
Calkins, C.C., ed.
Reader's Digest Assoc. (Canada) Ltd.

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