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A greenhouse provides a means of changing the environment around plants to improve their growth. Some greenhouses are also an integral part of a house and yard design. Greenhouses chosen for their appearance are often more expensive than simple plant-growing structures.

Greenhouses are used in several ways. Some are used year round while others are used only to extend the plant growing season in the spring and fall. In some climates a greenhouse is needed during the summer season to make it possible to grow crops such as tomatoes that will not produce well outdoors. This is especially true in many areas of Wyoming.

GENERAL CONSIDERATIONS

One of the first decisions to make is whether to build a greenhouse as a free-standing separate unit, attach it to an existing structure, or make it a part of a new building. Attached greenhouses usually have lower construction and heating costs and easier access, but the plants receive less light. An attached greenhouse should face south but may require up to 50 percent more cooling capacity in that direction. East, west, and north, in that order, are less desirable. Available building characteristics may limit the choices for locating an attached greenhouse.

A free-standing greenhouse can be located away from existing buildings. Plants in a free-standing greenhouse receive light from all directions. These greenhouses are more expensive to build and heat, and extra expense is required to run water and electrical lines to

them. Any greenhouse must be located in a well-drained spot that is not heavily shaded. Nearby deciduous trees which drop their leaves in the fall can partially shade a greenhouse and may reduce summer ventilation and cooling requirements.

A greenhouse can be any size, but about 200 square feet (18.4 m^2) is the smallest that should be considered. Smaller greenhouses are proportionately more expensive to build and operate. Most owners find their greenhouses become crowded quickly.

STRUCTURES

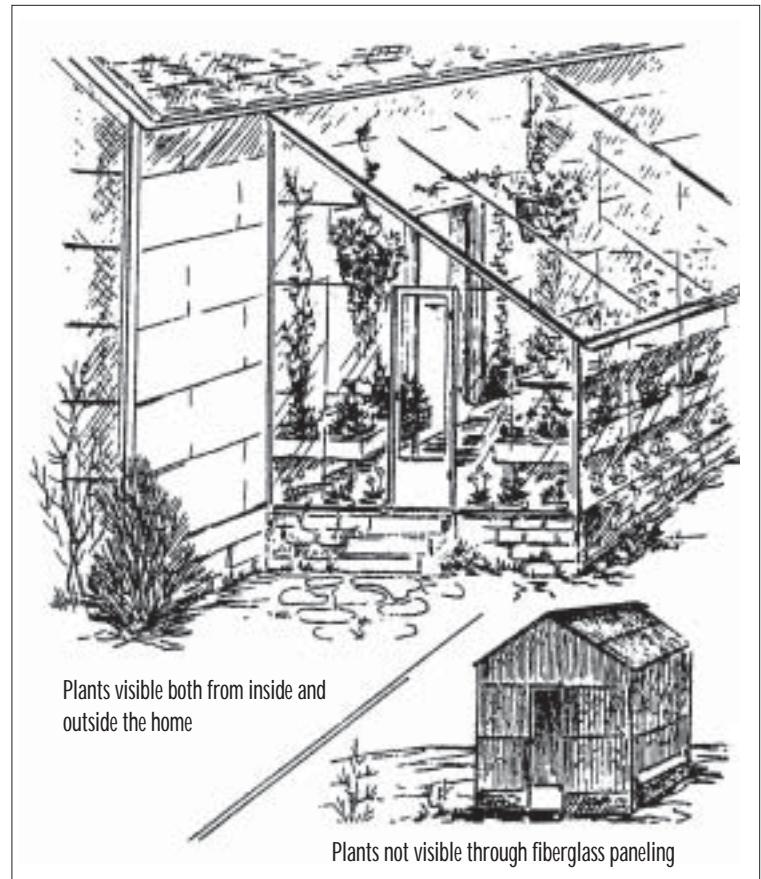
Greenhouse costs vary widely depending on the size of the structure and the covering material. Glass-covered, metal-framed greenhouses are usually the most expensive. Other covers such as fiberglass, acrylic, or polycarbonate are intermediate, and polyethylene-covered, wood-framed structures are the least expensive. Heating and ventilating equipment will cost about the same regardless of the structure, especially with small greenhouses. Solar greenhouses are possible but require special engineering. An excellent example is the completely solar greenhouse at the Cheyenne Botanic Gardens.

Greenhouse frames are built of metal or wood. Air-inflated greenhouses can be built in areas with high wind or heavy snowfall but require extra attention. The space between covering layers can be deflated to help the cover withstand wind loads. Wood-framed greenhouses are easy to build and are good choices when the owner is building the greenhouse. Use redwood or cedar if possible because these woods are resistant to decay. Otherwise, use pine treated with copper naphthalene. Avoid pressure-treated timber because it may contain arsenic.

COVERS

A greenhouse cover is usually glass, fiberglass, acrylic, polycarbonate, or polyethylene plastic. Glass is heavy, requires a strong frame, is expensive, and is also subject to breakage. It is usually considered more attractive and permanent. It is not recommended in areas prone to hail.

Fiberglass is widely used because it has good light transmission, little breakage, and requires less roof support. Only fiberglass made for greenhouses should be used. It should



last 10 years or so but will discolor and give less light transmission after several years. At higher elevations, fiberglass will discolor and degrade at an even faster rate due to high ultraviolet radiation levels. It may only last 3 to 5 years in some areas of Wyoming. Fiberglass is also highly flammable and may not meet local fire code regulations.

Acrylics are more durable, harder plastics. This type of cover should last 15 to 20 years. Double, single, and even triple-layer acrylic covers are available. Double-layer types are widely used to reduce heat loss during winter months.

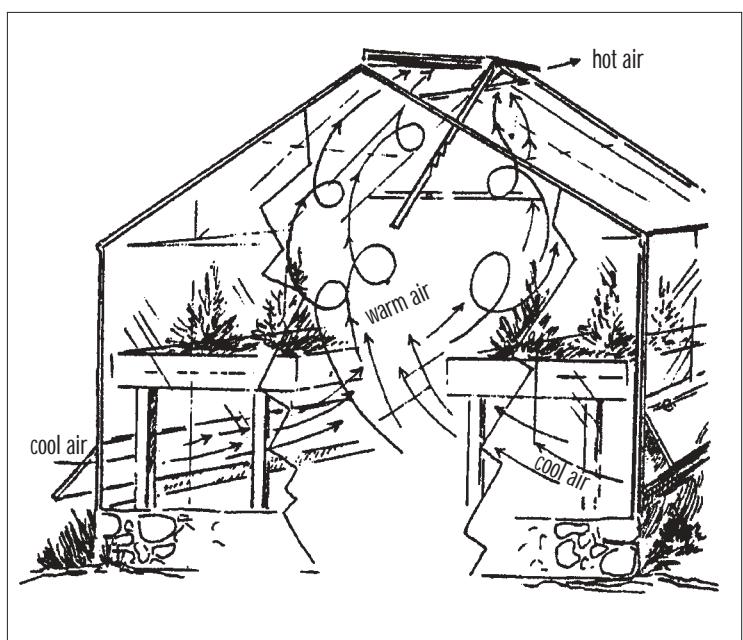
Polycarbonate coverings are very strong and are recommended in areas where hail can be a problem. However, polycarbonates are not hailproof and can be damaged if hailstones are large enough. Triple, double, and single-layer versions are available. Polycarbonate greenhouse covers should last 12 to 15 years or more.

Polyethylene plastic is economical, easy to put on, and gives good light transmission for plant growth. Ordinary polyethylene is broken down rapidly by ultraviolet light and must be replaced at least every year if not sooner. This is especially true at higher elevations. Special polyethylenes are now available that contain ultraviolet-inhibiting compounds. These may last one to two years. Polyethylene is not often used for year-round home greenhouses.

Many greenhouses are protected with a double-layer covering to reduce heating costs. Two layers will slightly reduce the amount of light that is admitted but will often cut heating costs by 40 percent. The two layers should be spaced 1 to 3 inches (2.5 to 7.6 cm) apart. Double layers of polyethylene can be separated by air inflation with a small squirrel-cage fan. Even plastic bubble wrap can be used to help insulate the inside of a greenhouse in winter. Glass or fiberglass greenhouses can be built with a spaced double covering. They may also have a polyethylene liner installed inside the outer layer, or a double polyethylene air-inflated cover can be put over the roof. Acrylics and polycarbonates are available in double and triple layers from manufacturers.

HEATING

Greenhouses are usually heated by hot air, hot water, or steam. Supplementary heat is sometimes provided by electric heaters. The heat source chosen should depend on the initial cost of the equipment and the cost of operation. Electric heat is less costly to install but usually very expensive to operate. Hot water or steam heating is expensive to install but has low operating costs. Home hot water heating systems can be extended to heat a greenhouse if the boiler has the capacity. Hot air heating, using gas or oil as fuel, is most widely used. Coal or wood can be used as a fuel, but each requires careful management.



Any combustion heater should be vented to the outdoors to avoid the accumulation of gases in the greenhouse that can damage plants in very low concentrations. There are newer unvented gas heaters available, however, that may circumvent this problem. Tightly constructed greenhouses must have a source of outside combustion air. A wall-mounted gas burner which draws combustion air from the outside and vents directly to the outside is satisfactory for most small greenhouses. The best heating is accomplished in the floor or below benches since hot air naturally rises.

The amount of heat a greenhouse will require must be known in order to provide adequate heating equipment. Heating equipment is rated in the number of BTUs that will be delivered per hour. The number of BTUs per hour necessary to maintain a greenhouse at the desired temperature can be calculated from the following formula:

Temperature difference x area x K (constant) = BTUs per hour where:

Temperature difference = the number of Fahrenheit degrees between the lowest acceptable temperature in the greenhouse and the minimum outdoor temperature.

Area = the exposed surface area of a greenhouse in square feet. This includes side walls, end walls, roof, and gable ends.

K (constant) = the heat-loss factor. For windy areas this is 1.4 for a single layer of polyethylene or fiberglass, 1.8 for a single layer of glass, and 1.0 for a double layer of plastic or glass. The factor would be about 0.2 less if the greenhouse were located in a non-windy area.

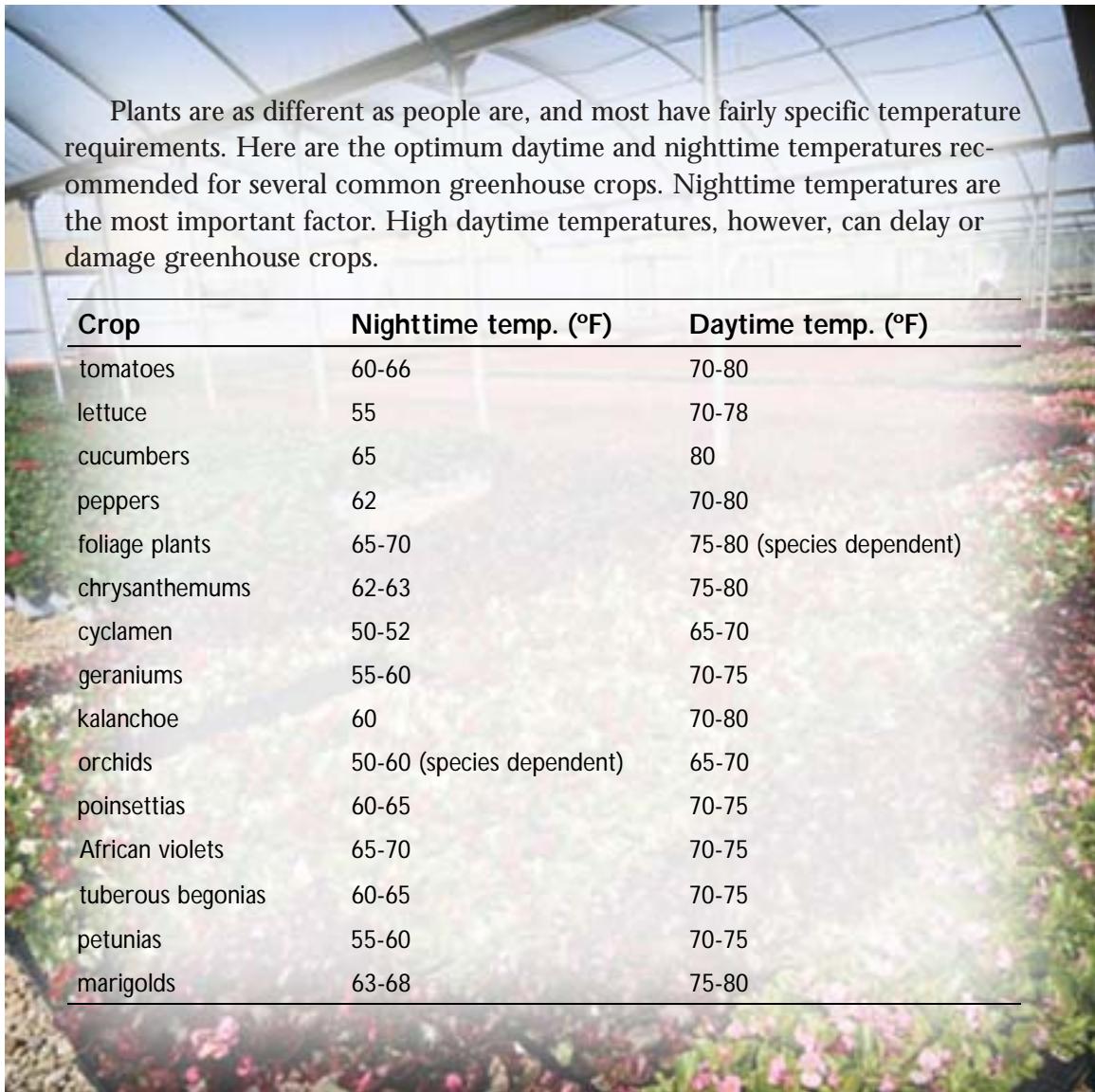
An example of greenhouse heat-loss calculation follows: Suppose there is a 10 x 20 foot single-layer glass greenhouse needing a minimum inside temperature of 50° F. Assume that

the lowest outside temperature is -25° F, and the surface area of walls, ends, and the roof equals 900 square feet. This would be multiplied by 75° F, which is the difference between +50 and -25° (900 x 75 = 67,500). The 67,500 is then multiplied times the factor 1.8 to give 121,500 BTUs per hour required for heating (900 square feet x 75° F x 1.8 = 121,500).

Given:

Outside Temp.	= Minus 25°F
Desired Inside Temp.	= 50°F
Area of House	= 900 sq. ft.
Constant (K)	= 1.8
50° + (-25°)	Difference = 75°F (or rise)
Temp. Area 75°F x 900 x 1.8	Needed = 121,500 BTU

If a greenhouse had a double-layer covering, the heat requirement would be 67,500 BTUs per hour (900 x 75 x 1.0 = 67,500). This would be about 45 percent less than the single-layer glass. Such a reduction would mean important savings in the cost of heating a greenhouse.



Plants are as different as people are, and most have fairly specific temperature requirements. Here are the optimum daytime and nighttime temperatures recommended for several common greenhouse crops. Nighttime temperatures are the most important factor. High daytime temperatures, however, can delay or damage greenhouse crops.

Crop	Nighttime temp. (°F)	Daytime temp. (°F)
tomatoes	60-66	70-80
lettuce	55	70-78
cucumbers	65	80
peppers	62	70-80
foliage plants	65-70	75-80 (species dependent)
chrysanthemums	62-63	75-80
cyclamen	50-52	65-70
geraniums	55-60	70-75
kalanchoe	60	70-80
orchids	50-60 (species dependent)	65-70
poinsettias	60-65	70-75
African violets	65-70	70-75
tuberous begonias	60-65	70-75
petunias	55-60	70-75
marigolds	63-68	75-80

VENTILATION AND COOLING

Heating a greenhouse is fairly simple, but cooling one is much harder. Also, the smaller the structure is, the more difficult it is to cool or heat. Greenhouses need ventilation with fresh air to reduce the build-up of heat in summer and also on sunny winter days as the air cools the area by its movement. Ventilation is also used to reduce excess humidity in a greenhouse and to bring in fresh supplies of carbon dioxide. The simplest system is a full-length ventilator 1 to 2 feet (30-60 cm) wide along the length of the roof ridge combined with air inlets in the side or end walls. Inlets are hinged to operate by hand as needed. This system needs continuous checking and readjusting during the day because temperature extremes can occur. Thermostatic controls are available to open and close these vents automatically.

Another system uses exhaust fans and inlet louvers on opposite sides of a greenhouse to move the stale humid air out and allow fresh air to enter. Exhaust fans large enough to replace all the air in a greenhouse every 1 to 1½ minutes will provide summer cooling. These fans keep the inside temperature from getting more than about 10 degrees (6° C) higher than outside, depending on the relative humidity of the outdoor air. It is much easier to cool a greenhouse in a climate with low relative humidity. Adding a wet wall of pads opposite the fans will increase cooling even more. This is valuable in areas with hot summer weather, low relative humidity, and for plants requiring cool temperatures. Summer shading is usually necessary in Wyoming because of its high solar radiation levels. Greenhouse shading paint can be applied to the cover at the beginning of the summer and should be washed off as fall approaches. Various types of screens can also be mounted inside or outside a greenhouse to provide shade.

Greenhouse cooling requirements are calculated based on square feet of floor area. Usually, about a 7° F (4° C) difference between inside air temperature and outside air temperature is reasonable, with the inside being warmer. An air exchange rate of about 8 cubic feet per meter is sufficient to keep this temperature difference. So, for example, if a greenhouse is 10 x 20 feet, it would have 200 square feet of floor area. This greenhouse would require a fan or combination of fans that could handle 200 x 8 or 1,600 cubic feet per meter to cool adequately.

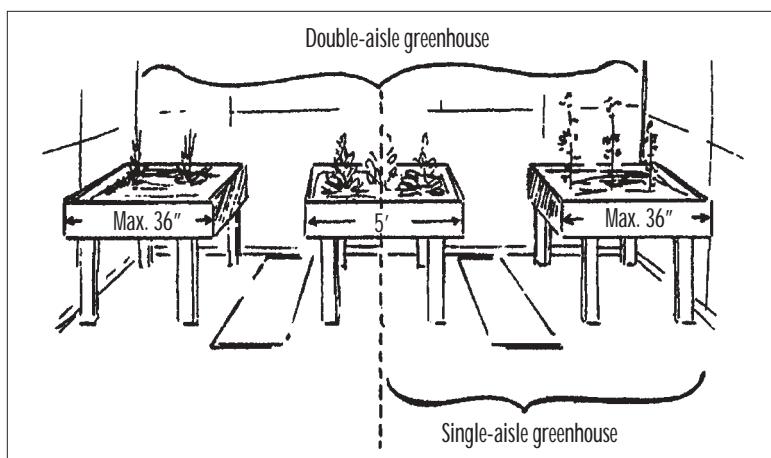
CONTROLS

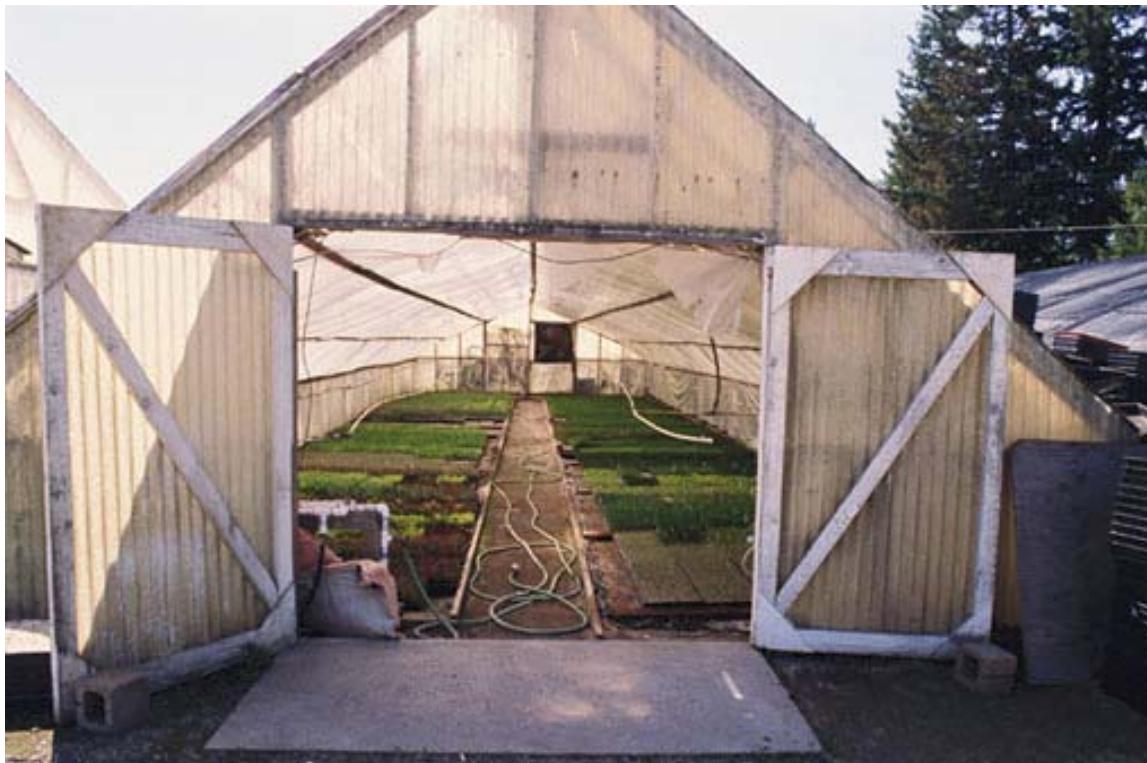
Most owners of small greenhouses find that automatic control devices are worthwhile. Thermostats, humidistats, time clocks, or computerized controls can be combined to give accurate management of temperature and humidity even when an owner cannot be present. Watering and lighting can also be controlled automatically. Control systems can be assembled by the owner, or they can be purchased as package units.

BENCHES AND ACCESSORY EQUIPMENT

Most greenhouse crops are grown in some type of container. These containers can be placed on the floor or on benches. Benches are not necessary, but they make working with the plants easier. Any bench should be made of sturdy, decay-resistant material such as cedar or redwood or rust-resistant metal.

Wood used for benches other than cedar or redwood, as well as all other greenhouse construction, should be treated with a wood preservative containing copper naphthalene for longer life. Benches made of metal work better. *Do not use creosote or pentachlorophenol-treated wood in or near a greenhouse because these materials produce fumes which can kill plants and can also be injurious to humans and pets.*





Plants can also be grown without benches on the floor of a greenhouse. Over the bare ground, put a layer of landscape fabric down and then an inch or two of gravel. This will allow adequate drainage and also provide aeration under containers.

Accessory equipment can include potting areas, storage for pots, growing media, fertilizers, and any watering or spray equipment needed. It is best to keep these in a separate area outside of a greenhouse in order to keep all usable space inside available for growing plants.

FOR FURTHER INFORMATION

Aldrich, Robert A. and John W. Bartok. 1994. *Greenhouse Engineering*. Storrs: University of Connecticut Natural Resource, Agriculture, and Engineering Service. NRAES-33.

Smith, Shane. 2000. *Greenhouse Gardener's Companion: Growing Food & Flowers in your Greenhouse or Sunspace*, Cheyenne Botanic Gardens.

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