WASHINGTON STATE ENERGY OFFICE
WASHINGTON ENERGY EXTENSION SERVICE

SOLAR GREENHOUSES

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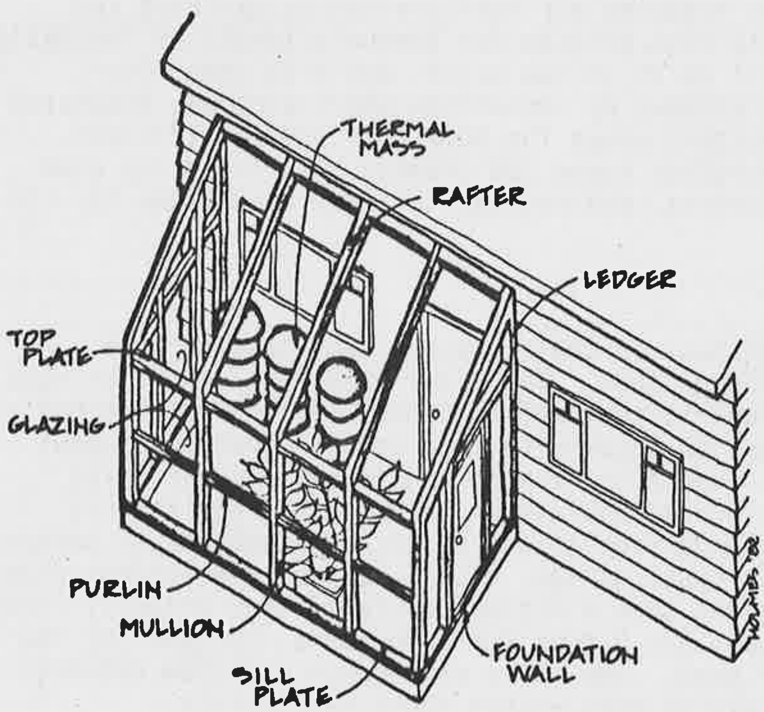
Printed by Seattle City Light

EY0750
March 1982

One of the most popular passive solar designs for both new and existing homes is the solar greenhouse. Sometimes referred to as a sunspace, solarium, or atrium, the solar greenhouse resembles in appearance the traditional greenhouse structure. The solar greenhouse differs, however, from the traditional greenhouse in design and orientation. These design differences allow the solar greenhouse to rely exclusively on the sun to maintain warm temperatures during the winter months.

The solar greenhouse performs best when it faces within 30^o, east or west, of true south. A southern orientation maximizes the amount of solar radiation that enters the structure. East and west facing greenhouses will collect less wintertime solar energy than those that face south, but they can provide the home with an energy savings.



The solar greenhouse should be constructed to have low rates of heat loss. By providing for high levels of insulation and minimizing air leaks, you will help ensure good greenhouse performance.

Inside the greenhouse, heat storage material, referred to as thermal mass, should be located in areas exposed to direct sunlight to store excess heat during the sunny periods. Heat storage materials such as water or masonry act as a thermal flywheel by absorbing excess heat during the day and slowly radiating that heat into the greenhouse at night to maintain warm temperatures. The key principles of the solar greenhouse are, therefore, proper orientation for solar collection, low rates of heat loss, and heat storage (see figure 1).

THE ATTACHED SOLAR GREENHOUSE

When attached to the south side of the home, the solar greenhouse provides three potential benefits to the homeowner. First, the solar greenhouse can reduce the cost of heating the home. As the greenhouse collects energy on sunny days, the temperature increases inside the greenhouse. Some of that warm greenhouse air can be transferred to other areas of the home. In addition to these direct heating benefits, the solar greenhouse also serves as a buffer for the area of the home it encompasses. Therefore, even during the night and long periods of cloudy weather, the solar greenhouse reduces somewhat the rate of heat loss from the home. Second, the solar greenhouse can add attractive living space to the home. Homeowners can use the solar greenhouse as an area for dining, relaxation, and entertaining. The solar greenhouse therefore enhances the home's livability and increases the value of the home. Third, the solar greenhouse provides an area for indoor gardening. The warm environment of the greenhouse allows for extended growing seasons and the possiblity of growing warm weather crops that do not typically flourish in outdoor gardens in Western Washington.

ROLE OF CONSERVATION

Any one of the three benefits described above can be sufficient reason to build a solar greenhouse. Those who are primarily concerned with creating a gardening space or adding living area to the home will probably be pleased with the qualities of the solar greenhouse. Those who are concerned about lowering the cost of home heating should be aware that the solar greenhouse should not be expected to heat the home completely. The impact of a solar greenhouse will be much greater in a well-weatherized and well-insulated home. It therefore makes sense to begin your solar project by taking adequate steps to reduce the rate of heat loss from the home itself. This typically includes reducing air infiltration by caulking and weatherstripping the home. You should also provide for adequate levels of insulation; a minimum of R-30 in the ceiling, R-11 to 19 in the walls, and R-19 underfloor. Finally, reducing the heat loss from windows by installing storm windows, insulated glass, and/or insulated shades or shutters makes the home more energy efficient. These basic weatherization and conservation steps can dramatically lower the cost of home heating, increase occupant comfort, and provide the best conditions for the operation of a solar greenhouse.

SOLAR GREENHOUSE ADDITIONS: ZONING

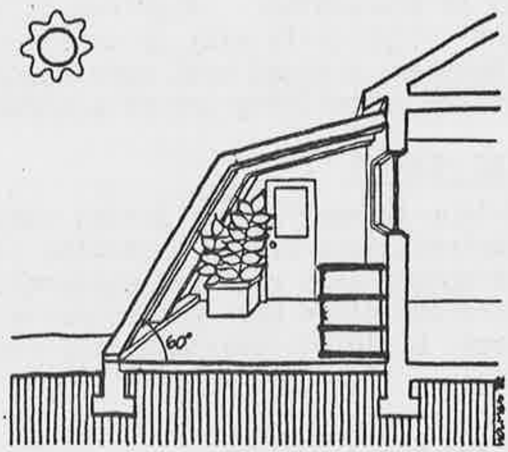
Those who choose to add a solar greenhouse to their present home need to take special considerations in planning the project. The solar greenhouse addition must conform to zoning regulations pertinent to your neighborhood. Zoning regulations can vary widely between jurisdictions, so check with your zoning department about regulations and the permit process. Generally, zoning considerations for solar greenhouse projects involve a lot coverage requirement and setback requirements. In many residential neighborhoods, zoning regulations permit a maximum of 35 percent lot coverage by all structures (i.e. house, garage, etc.). Zoning regulations also typically require that structures be set back a minimum distance from property lines. The requirements for most neighborhoods are 5 feet for side yards, 20 feet for the front yard, and 25 feet for the rear yard. The solar greenhouse addition requires a zoning permit and will typically have to work within these constraints.

SITING THE SOLAR GREENHOUSE

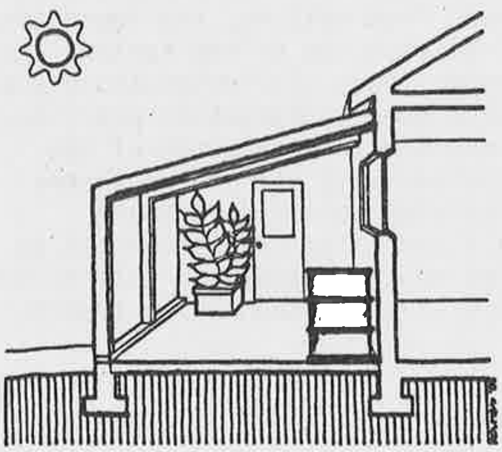
Deciding the exact location of the solar greenhouse involves a variety of factors. First, it is important to have adequate solar availability at the greenhouse site. A solar site survey can assist in that determination. Second, the solar greenhouse should be located to provide convenient access to the rest of the home's living space. Third, consideration should be given to what areas of the home could best use greenhouse heat. If the greenhouse is located adjacent to a living or dining room, greenhouse heat can be simply transferred from the greenhouse to the house. If the greenhouse is located adjacent to a spare bedroom or bathroom, a more sophisticated method of heat transfer, such as a fan and duct system, may have to be devised. Fourth, the greenhouse addition should be designed so that it can be closed off from the rest of the house. This allows the homeowner to thermally isolate the greenhouse in the summer and at those times that the greenhouse is colder than the inside of the home.

DESIGN OF THE SOLAR GREENHOUSE

When adding a greenhouse to an existing home, structural or physical considerations as well as aesthetic choices can dictate greenhouse appearance. Considerations such as the amount of space that is desired in the greenhouse, need for adequate headroom, how the greenhouse is attached to the home, and ground slope will influence its design. Often homeowners are concerned that the greenhouse match the appearance of the home. This can affect the roof slope of the greenhouse or the materials and color of the exterior finish.



Designing the greenhouse to maximize solar gain is a common concern for homeowners. In many instances, solar greenhouses have been constructed with the south wall angled at approximately 60^{o} to the horizontal in order to optimize the solar gain (see figure 2). Because of the latitude of the State of Washington, a surface sloped at this 60^{o} angle maximizes the area exposed to the low winter sun. Creating a 60^{o} angled south wall does decrease utility of interior greenhouse space, however, by lowering headroom in areas next to the south wall. Constructing the greenhouse with a vertical south wall does not significantly lower the solar collection efficiency of the greenhouse (see figure 3). Often, do-it-yourself greenhouse builders will find a vertical wall design easier to build and comparable in performance to greenhouses with a non-vertical south wall.



Overhead glazing in the solar greenhouse can also serve as an area for solar collection. The slope of the greenhouse roof will influence the amount of solar gain the greenhouse receives from overhead. Low angled greenhouse roofs (15^{o}-25^{o}) will not be very well positioned for maximum exposure to the low winter sun. More steeply pitched greenhous roofs of 30^{o} or more are better suited to capture the winter sun and can actually receive more energy than a vertical south wall. Also consider that the angle of the overhead glazing will influence solar gain from the summer sun, and can create a need for increased summertime ventilation.

FRAMING

The solar greenhouse can be constructed with a wood frame or an aluminum frame. There are advantages and disadvantages to each of these materials relating to cost, appearance, weatherability, and ease of construction. Wood frame constructed greenhouses are very popular with many homeowners. The greenhouse frame can be constructed with standard grade kiln dried 2 x 4 or 2 x 6 lumber. Many homeowners choose cedar or redwood for weatherability and appearance. The use of wood for framing the greenhouse has advantages in that the material is easy to work with, has distinctive aesthetic qualities, and can be fashioned into specialized greenhouse designs. It should be noted, however, that glazing a wood frame greenhouse can present some difficulties for the do-it-yourself builders.

The wood used in constructing the greenhouse should be treated with a wood preservative to ensure long life. Wood preservatives such as creosote or pentachloraphenol (referred to as "penta") should be avoided. These preservatives can be toxic to plants growing in the greenhouse. Preservatives such as copper or zinc napthanate are acceptable wood preservatives for greenhouse use.

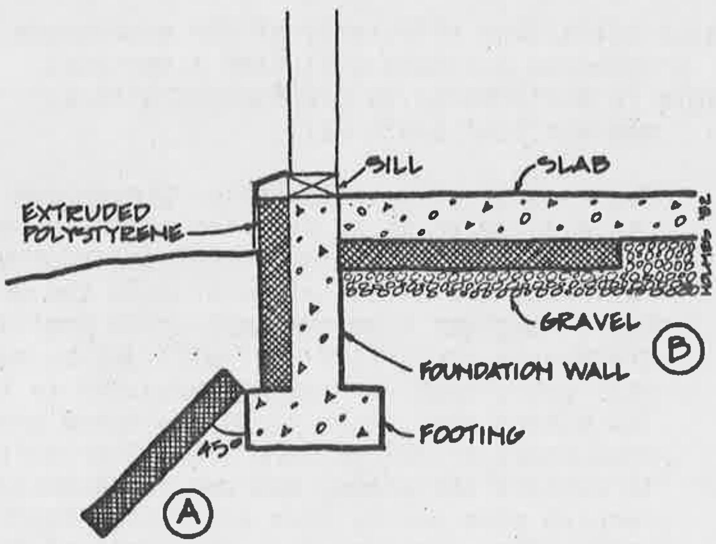
Aluminum frame greenhouses are often comparable in cost to wood frames and are generally maintenance free. Aluminum purchased with an anodized coating will maintain a bright finish while unanodized aluminum tends to dull somewhat as it oxidizes when exposed to the weather. Aluminum is a popular choice for pre-fabricated greenhouse kits and is typically easy to construct and glaze for do-it-yourselfers. Aluminum does, however, conduct heat more readily than does wood and generally has less flexibility in building one-of-a-kind greenhouse structures.

BUILDING PERMITS

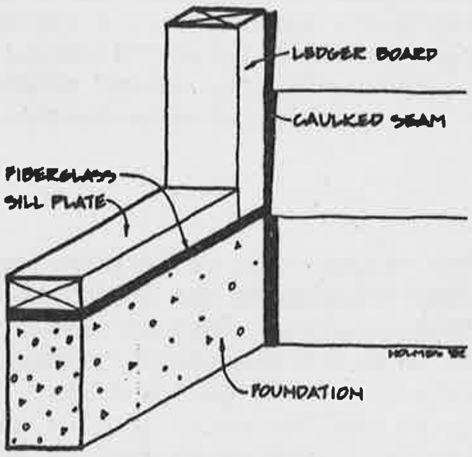
In addition to meeting all zoning requirements, a building permit is required in most jurisdictions before beginning construction on a solar greenhouse. In the State of Washington, this requires conformity with the Uniform Building Code. Local jurisdictions often have additional specialized requirements. You should check with your local building department for information on codes and how to obtain a building permit.

FOUNDATION AND STRUCTURE

An important element in the construction of the solar greenhouse is the foundation. One of the most common types of foundation is a concrete foundation shaped as an inverted "T" (see figure 4). The base of the foundation, called the footing, serves as a pad that stabilizes the structure in the soil. To protect wood members from rotting, the foundation wall sits on top of the footing and rises at least six inches above grade. It is a good construction practice to insulate the perimeter of the foundation with one or two inches of extruded polystyrene board insulation. The insulation can be placed on the foundation wall before backfilling the foundation trench.



Heat loss from the greenhouse can be reduced further by adding additional extruded polystyrene insulation in one of two locations. One method is to place insulation at a 45° angle to the footing extending to a depth of 1½ to 2 feet below grade (see A in figure 4). Placing the extruded polystyrene at a 45° angle ensures that the soil beneath the footing remains undisturbed. This insulation method tends to stabilize soil temperature below the slab and thus reduce heat loss. An alternative method of insulation places extruded polystyrene between the slab and foundation wall extending at least two feet under the slab around its perimeter (see B in figure 4). The extruded polystyrene, in contrast to expanded polystyrene, is moisture resistant and thus has a long life when used below grade. The insulation that extends above grade should be protected from the effects of ultraviolet light and the surrounding elements. An alternative to the concrete foundation is one constructed of specially treated wood that is rated for foundation use. It too should be insulated around the perimeter with extruded polystyrene.



The construction of the solar greenhouse itself should emphasize making the structure as energy efficient as possible. Wood frame walls should be insulated and infiltration should be kept to a minimum. Two areas of considerable heat loss in a greenhouse occur at the sill plate and the ledgers. The sill plate rests on top of the foundation wall and should be sealed by placing a fiberglass insulation strip between the foundation wall and the sill plate (see figure 5). The ledger boards are placed on the home's south wall and are the structural connection between the house and the greenhouse. Air infiltration can be reduced by caulking the seam between the house and the ledgers (see figure 5).

The structural integrity of the solar greenhouse structure must be maintained to resist the forces of snow loads and wind loads. Structural members must be sized sufficiently to handle these loads. The spacing of structural materials will depend on the qualities of the glazing or covering material used. Adequate bracing and strong joints are necessary to ensure that the structure withstands all stresses.

GLAZING

There are a number of options in selecting the type of glazing material for the solar greenhouse. Glass, acrylics, polycarbonates, fiberglass, and thin films such as polyethylene or polyvinyl cloride have all been used as greenhouse glazing. Choosing a glazing material for the greenhouse requires consideration of a number of factors. The glazing material should allow at least 70 percent of the sunlight that strikes it to pass through to the interior of the structure. Also, some glazing materials are better than others at retarding the flow of heat from the inside of the greenhouse back to the outside environment. Other considerations include weatherability, breakage, abrasion resistance, ultraviolet light degradation, and the effects of thermal expansion. The ease with which the glazing material can be affixed to the structure is also important to consider. Finally, appearance and cost will influence your choice of glazing material.

In both Western and Eastern Washington, the solar greenhouse will generally perform better if it is double glazed. While the extra layer of glazing does decrease somewhat the solar transmission, this loss is more than compensated by the additional insulating value of a double-glazed window unit. Frequently, homeowners who choose glass as a glazing material consider using factory second patio glass door units as greenhouse glazing. Unobtrusive defects in the glass reduce drastically the cost of the glass and the units are available from many glass suppliers as a sealed double-glazed unit. Those who choose to single glaze the solar greenhouse will probably experience cooler greenhouse temperatures during the winter months as well as heavy condensation on the glazing, but still have acceptable performance the other seasons of the year.

THERMAL MASS

The use of thermal mass in the solar greenhouse reduces the temperature swing between day and night. On a sunny winter day, the solar greenhouse can absorb more solar radiation than needed to maintain comfortable temperatures. Thermal mass, such as water or masonry, can store this excess heat to moderate greenhouse temperatures during cool nighttime hours. Water can be contained in 55 gallon drums, 4'-8' fiberglass water storage columns, or a variety of smaller water bottles and containers. If the container is opaque, it is wise to paint it a dark earth tone to heighten its absorptivity of sunlight. Masonry storage can be used in the solar greenhouse in a variety of ways as well. Concrete or brick floors represent one popular approach. Many homeowners choose to give concrete floors a more finished look by adding tile over the concrete slab. Greenhouse walls can also be constructed of masonry for use as heat storage. For thermal mass to function properly, it should be located within the solar greenhouse and be exposed to direct sunlight at least part of the day.

When deciding how much thermal mass should be placed in the solar greenhouse, it is important to know what the greenhouse's primary use will be. If the greenhouse is primarily a collector for solar heat for the home, less thermal mass should be used. Rule of thumb guides suggest using one to four gallons of water per square foot of south-facing greenhouse glazing. If a concrete slab floor is used, it need not be thicker than four inches. Concrete slabs of greater thickness seem to be no more efficient in their heat storage properties. One square foot of concrete, four inches thick, has the equivalent heat storage potential of one gallon of water.

HEAT TRANSFER

One of the most important considerations for the solar greenhouse is the method of heat transfer. How efficiently greenhouse heat is transferred into the home affects the overall performance of the solar greenhouse.

The simplest and least expensive method of heat transfer is natural convection. A greenhouse addition can be built over the home's existing doors or windows, which, when open allow warm greenhouse air to enter the house. Since natural convection air currents are not particularly strong, this method of heat transfer is generally somewhat inefficient. It is attractive, however, due to its simplicity and low cost. In a two-story greenhouse, convective heat transfer can be more practical as more forceful air currents can be generated thereby increasing the efficiency of heat transfer.

One method of increasing heat transfer efficiency is to use a fan to force warm air into the home. This method can be as simple as a manually controlled window fan, but many homeowners choose a more sophisticated system. Depending on the greenhouse design, window or wall mounted fans can be installed which operate automatically on temperature sensors. Variable speed controllers can be used to regulate fan speed. In some situations, a fan and duct system can be used to take greenhouse air and circulate it through the home's existing forced air heating system or a totally independent ductwork can be installed. When air ducts are used, greenhouse heat can be utilized in areas of the home other than those directly adjacent to the greenhouse.

The following two methods of heat transfer are less frequently used. In new home construction, a common masonry wall between the greenhouse and the home can provide a very effective method of heat transfer. The masonry wall absorbs solar radiation, which is conducted through the wall, and then radiates heat directly into the living space. Another method of heat transfer involves the use of a rock bin storage system. If the greenhouse is sufficiently large (that is, a glazed area of 15 to 20 percent of the floor space area of the home), a rock bin storage system can be well used and the costs will be justified. In a rock bin storage system, greenhouse air is fan forced through ducts into a well-insulated bin of 1" - 1½" rock. Heat is transferred from the air to the rocks, which is later reclaimed when needed in the home. Rock bin storage systems are typically not well suited for smaller greenhouses due to the $2,000 to $3,000 cost of the rock bin and the limited area of solar collection of a small greenhouse space.

SUMMERTIME OPERATION

Keeping the solar greenhouse cool during the summer months can be accomplished by shading the structure and providing adequate ventilation. Shading for the greenhouse can be provided by well-placed deciduous trees or by shading cloths that roll over the greenhouse glazing. The greenhouse should also have two vent areas of appropriate size to exhaust warm air out of the greenhouse. Each vent area should be sized to 10 to 15 percent of the floor area of the greenhouse. By opening vents, either manually or automatically, the greenhouse can be passively ventilated. Some greenhouse owners choose to add a properly sized fan to provide for mechanical ventilation. These fans are often sized as 4 to 5 cubic feet per minute for every square foot of south-facing greenhouse glazing.

COST AND PERFORMANCE

How much supplementary heat you receive from a solar greenhouse depends on its size, construction, and method of heat transfer. The solar greenhouse performance can range from a provider of modest amounts of daytime heat to a structure that provides as much as 50 percent of a well-insulated home's annual heat demand.

The cost of a solar greenhouse will depend on its size, materials used, and labor costs. An extremely basic greenhouse with inexpensive polyethylene or vinyl glazing and a framing system using scrap lumber can cost $4 to $5 per square foot. A more finished solar greenhouse with a quality wood or aluminum frame, with glass or plastic glazing will be more expensive. A greenhouse addition of this type, built by the owner, might cost between $15 to $25 per square foot of floor area. A similar scale project that is contractor-installed might cost between $30 to $40 per square foot. Typically, a contractor-installed greenhouse will have a nicer finished appearance with more amenities than do-it-yourself projects. An elaborate solar greenhouse of more specialized design or one with a sophisticated heat transfer system might range in cost between $45 to $80 per square foot.

SUGGESTED READING:

Clegg, Peter and D. Watkins. The Complete Greenhouse Book. Garden Way Publ. Co., Charlotte, VT.

Magee, Tim. A Solar Greenhouse Guide for the Pacific Northwest. Ecotope, Seattle, WA.

McCullagh, James. The Solar Greenhouse Book. Rodale Press, Emmaus, PA.

How to Build and Use Greenhouses. Ortho Books, San Francisco, CA.