Low-Cost Passive Solar Greenhouses: A Design and Construction Guide

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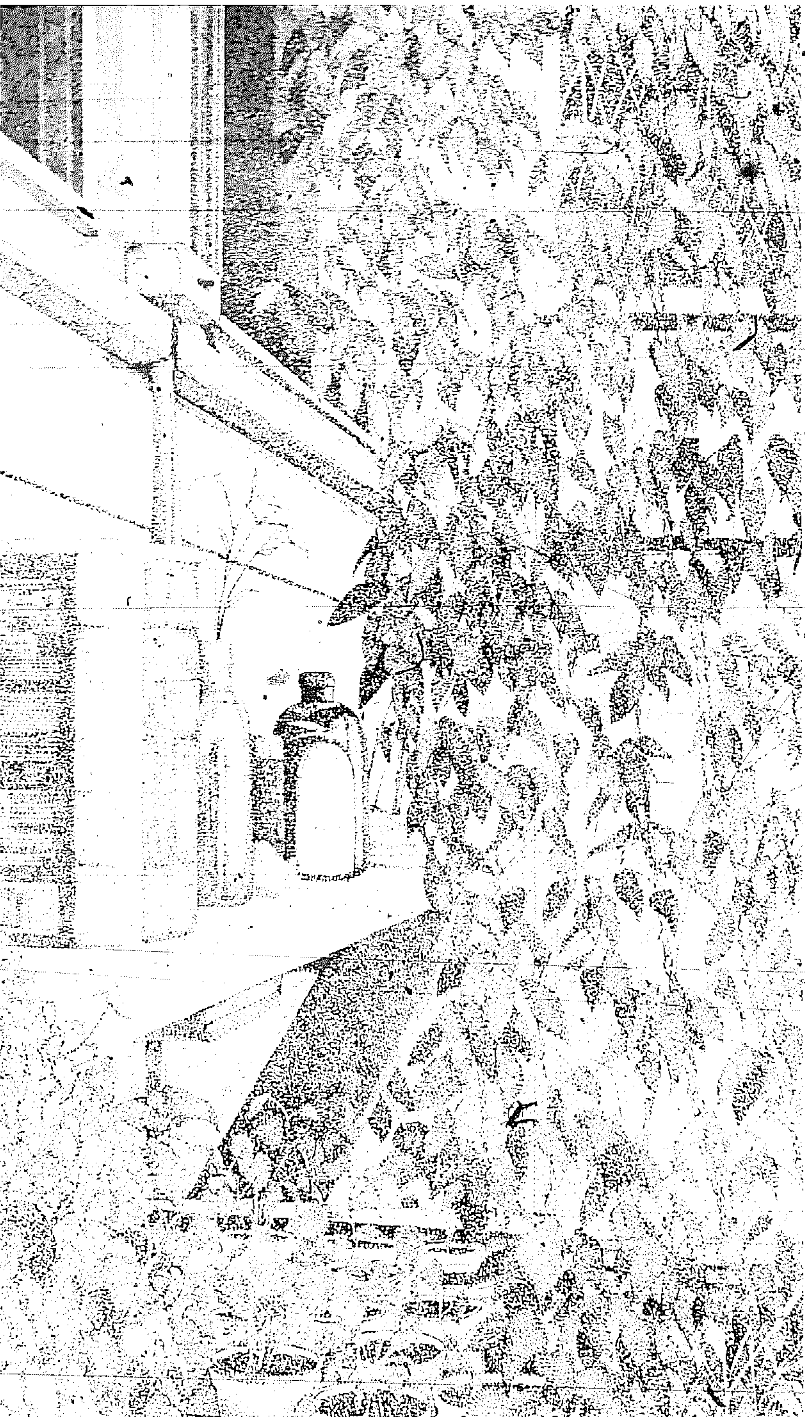

LOW-COST PASSIVE SOLAR GREENHOUSES

A Design and Construction Guide

SECOND EDITION, REVISED

by Ron Alward and Andy Shapiro

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INTRODUCTION

If you are interested in designing and building a passive solar greenhouse, this manual should help. It is a how-to technical guide for do-it-yourselfers that emphasizes durable, low-cost construction techniques.

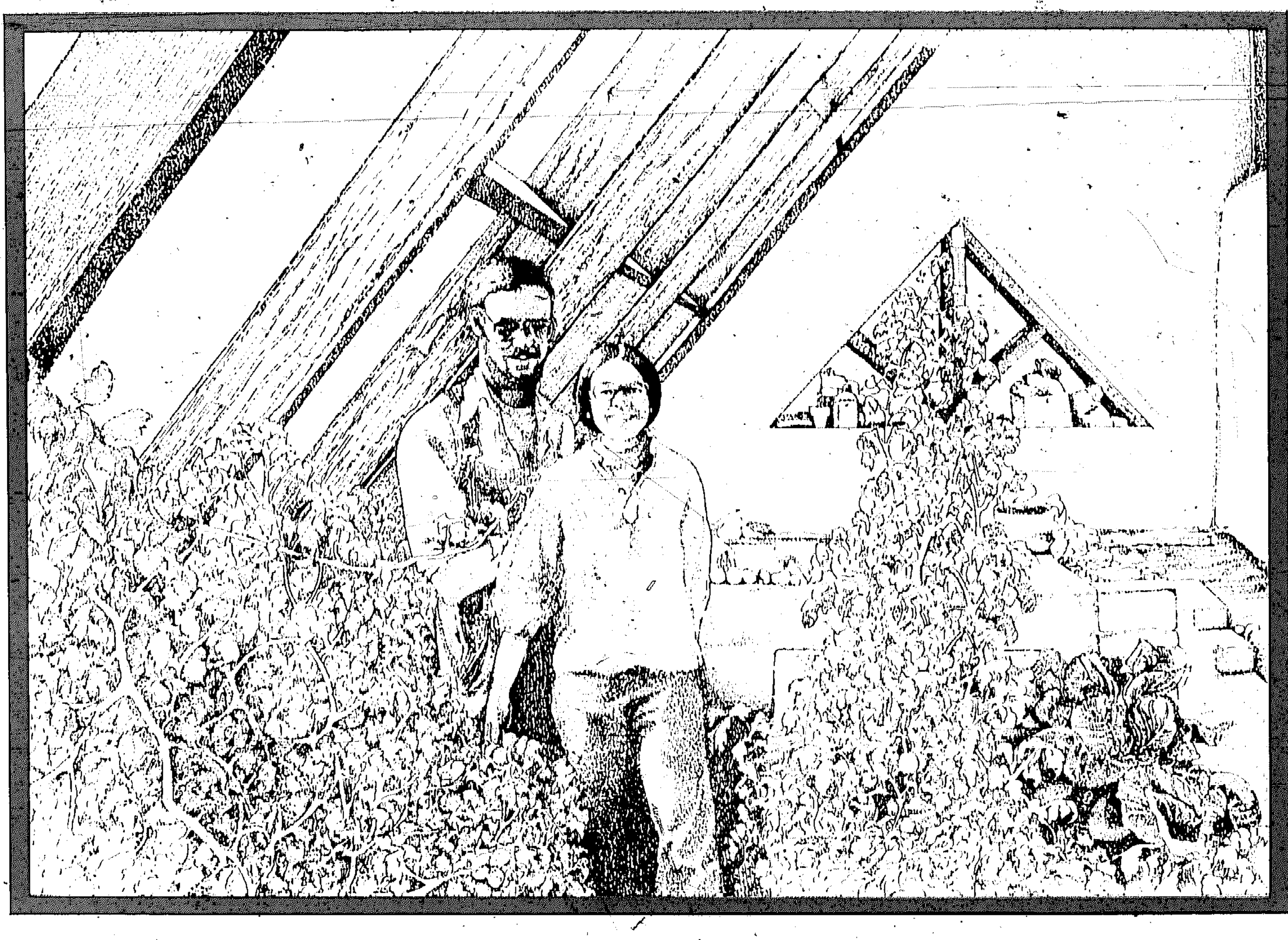
This **Guide** is not written for the novice builder. It should be treated as a supplement to existing literature on solar greenhouses and standard construction practice. Details that show how to mix concrete, build a stud wall or frame a door can be found elsewhere. This **Guide** details more specific construction techniques that accommodate the energy-efficiency and light transmission requirements of a passive solar greenhouse.

The authors assume that the readers understand what is meant by a "solar" greenhouse. Unlike a conventional greenhouse, a solar greenhouse uses glass or some other glazing primarily on the southern exposure. Most other surfaces—including the other walls, foundation and even part of the roof—are well-insulated to retain heat. Additionally, a solar greenhouse must contain heat-storing material—such as water in barrels or masonry—to store solar heat for nights and cloudy days. Heat bills for a solar greenhouse are much less because thermal storage, along with air-tight, energy conserving techniques greatly reduce the use of a backup heating system. What's more, a solar greenhouse can be designed to *supply* heat to an attached building—operating as a large solar collector.

The **Guide** is divided into four parts. Part I briefly reviews the needs, uses and economics of building and owning a passive solar greenhouse. Part II outlines the preliminary planning required in deciding the appropriate location, size and shape of a solar greenhouse. Part III discusses each component of a greenhouse, reviewing alternatives and detailing construction techniques for foundations, framings, glazings, venting systems, heat storage and various interior management parts. Part IV, the Resource Directory, provides a national list of solar greenhouse resource groups and individuals, a compilation of greenhouse supplies and components (referenced throughout the text), and an annotated bibliography of greenhouse references.

The **Guide** concentrates on low-cost building details that minimize material costs and maximize labor. Because the target audience is do-it-yourselfers, it is assumed that labor is more available than money. Also, the alternative designs and construction techniques sometimes differ from common practice. In such cases, builders are urged to modify the recommendations to satisfy their local conditions.

A solar greenhouse must be designed to complement its specific site as well as its builder's skills and resources. By presenting a number of alternatives, the **Guide** is intended to promote the design and construction of low-cost solar greenhouses that complement differing sites, building skills and available resources. Pending feedback from readers and builders, the **Guide** will be updated with each new printing.



Part 1

PERSONAL AND ECONOMIC CONSIDERATIONS

Chapter 1:

NEEDS, USES AND COMMITMENTS

Are you a homeowner hoping to reduce your heating costs? Would you like to have a room in your house where it is always warm and sunny? Are you a vegetable lover searching for a source of year-round fresh produce? Are you a frustrated gardener looking for a way to extend a short summer growing season?

It is important to ask yourself such questions, because you must determine *why* you want to build a solar greenhouse and whether a greenhouse is the best way to help satisfy your individual needs. Sound decision making and early planning can avoid false expectations. Building and maintaining a solar greenhouse requires a commitment—just how great a commitment depends on how the greenhouse is to be used. Time, personal energy, and money are three necessary resources, and you must determine how much of each you are *able* and *willing* to spend.

This chapter is designed to help you decide if a solar greenhouse is appropriate to your needs *before* you start building. First, we will discuss the main reasons for building a solar greenhouse and the needs it can fill. Secondly, we will present alternatives that can meet the same needs as a solar greenhouse. (Often, a less expensive and less time-consuming alternative can be more suitable.) Finally, for those who decide that a solar greenhouse is the right option, we will review general management skills needed for greenhouse use. For example, greenhouse gardening is somewhat different than outdoor growing. Likewise, a home-heating system that utilizes a solar greenhouse requires a good deal more attention than simply adjusting a thermostat.

THE MANY USES OF A SOLAR GREENHOUSE

While there are a number of good reasons to build a solar greenhouse, the two most practical justifications are to provide heat and to grow food. If attached to a heated building, a solar greenhouse can provide some heat on sunny days plus a large quantity of fresh vegetables throughout the year. Thus, heating bills and food costs can be reduced.

Supplemental solar heat can be utilized when a greenhouse is attached to the living space of your home. Often on sunny days, particularly in the spring and fall, the greenhouse will collect more heat than it can use immediately or store for later release. This excess heat, along with humidity and oxygen produced in the greenhouse, can be vented into the house via an open door or window, or through a vent. A well-designed, well-built attached solar greenhouse may cut heat bills by 10 to 30 percent, depending on the size of the house and the greenhouse, as well as other factors. The oxygen and humidity generally will make the house much more comfortable during the winter. To be most useful, this excess heat must be vented into an "active" part of the house (e.g., the living room or kitchen) rather than to a storage room or unused bedroom.

A solar greenhouse also can be used to produce food. On cold, sunny days, excess solar heat still can be vented into a home. However, a good deal of heat is required inside the greenhouse to support a suitable growing environment. More heat storage is placed inside the greenhouse and a back-up heating system is usually required for the coldest nights and cloudy days. (One convenient option is to reverse the vents and use house air to heat the greenhouse.) In any event, the small amounts of energy used to keep a well-designed and built greenhouse warm can pay fruitful dividends.

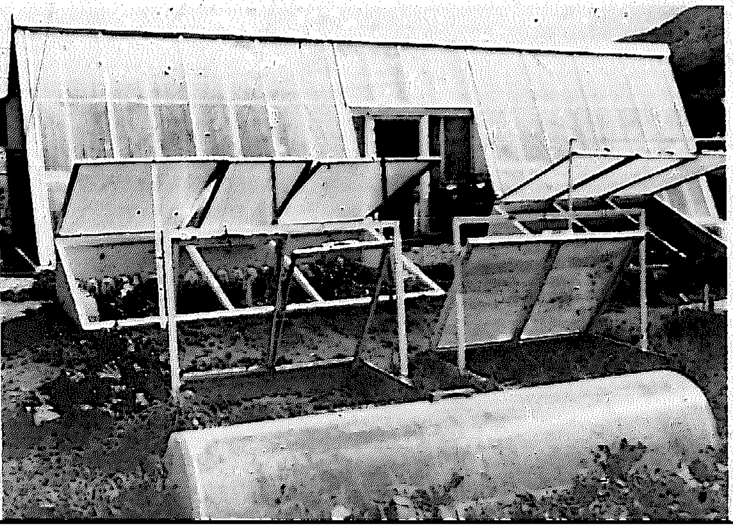
The nutritional benefits of fresh-grown produce are great. Vegetables can be raised to the peak of ripeness for immediate eating when nutrient values are highest. Careful planning of crops can permit you to enjoy fresh vegetables during most of the year. Further, you have control over the food growing process in your greenhouse—you control what, if any, chemicals are used. For example, careful managment can eliminate the need for pesticides and fertilizers. An added benefit is the luxury of growing and consuming certain out-of-season vegetables which are often too high-priced. Finally, if the greenhouse is not too expensive to build, and you are prepared to make the necessary commitments, *money* can be saved by growing your own food (see Chapter 2).

Additionally, there are various other benefits of a solar greenhouse. It provides an opportunity to extend outdoor growing seasons—a place to start seedlings in spring or to bring in plants from the garden as winter approaches. A small greenhouse can supply enough seedlings for several gardens. In fact, a small "pin money" operation is possible as starts or ornamental plants can be raised in the greenhouse for sale. (For the more ambitious, a profitable small business is feasible, given the right economic conditions—see the section on commercial greenhouses in Chapter 2 for more details.) And, during the coldest winter months when growing activities are curtailed, the greenhouse can be used solely as an air heater.

The oxygen and humidity generated in a greenhouse environment have health benefits as well, particularly in areas where the winter humidity tends to be low. What's more, the carbon dioxide generated by residents of the house is a benefit to greenhouse plants.

Finally, a sun-space, or solarium, is a useful addition to almost any home, and a solar greenhouse can be used as such—a place to sit in the sun, using the solar heat quite directly to warm your body. If you pattern your living habits

A greenhouse or cold frames: Which suits your needs?



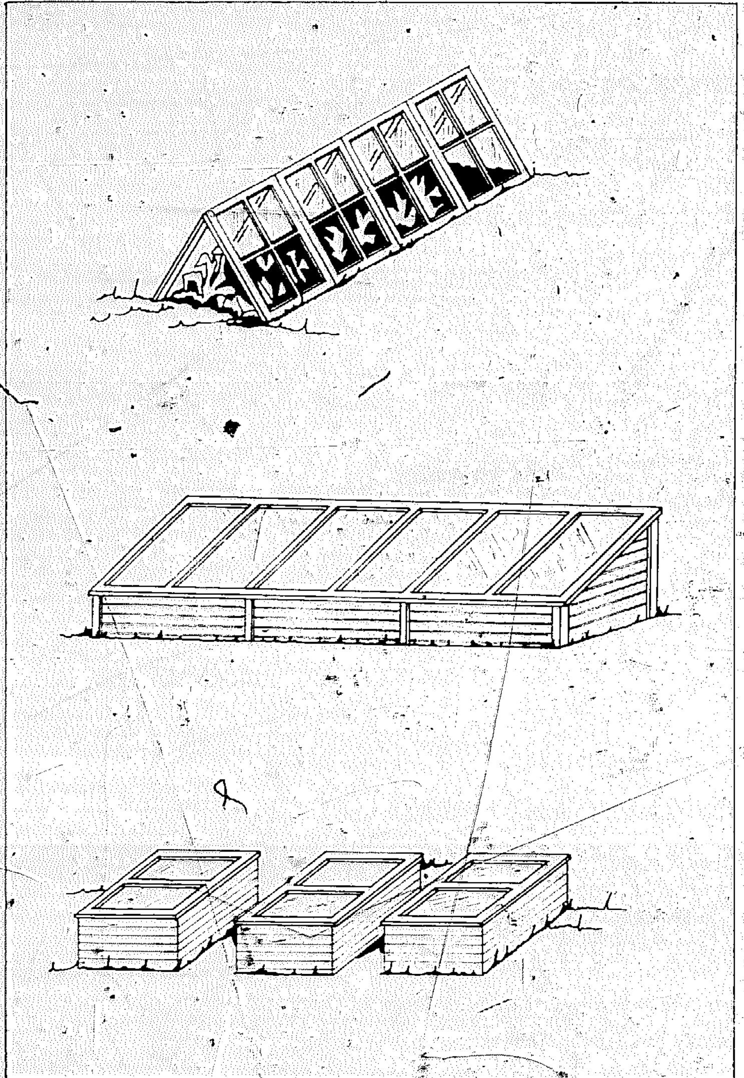


FIGURE 1.1 Old windows used as cold frames

to spend a lot of time in the greenhouse/solarium, the rest of the house often can be set at a cooler temperature, thereby saving heat (rather like sitting by the fireplace). Of course, if you are wealthy you need no greater justification to build a solar greenhouse than the attractive esthetics of having a green-filled room adjacent to your living space.

WHAT ARE THE ALTERNATIVES?

Before a decision is made to build a greenhouse, it is imperative that each prospective builder carefully examine alternatives, some of which can often be less expensive and less trouble than a greenhouse. To reduce home heating bills, the best alternative to a solar greenhouse is home weatherization. The money invested in insulation, double-glazing windows, caulking and general tightening-up of the house will be repaid much more quickly in fuel savings than will money spend for any type of solar heating. Then, once your house is well-insulated, you could consider a simple solar air-heater to supplement your home's heat. A properly sited, sized and installed solar air heater with no heat storage can supply up to 15 percent of your heating needs. (Plans for such a unit are available from the Domestic Technology Institute, Total Environmental Action, and others—see Resource List.)

As for fresh food production, a fully utilized outdoor garden is a good option. Explore all possibilities of available garden space. If you live in a city, an empty lot on a quiet street could be used for a community garden. Also, think about extending several months with cold frames or hot boxes (Figures 1.1, 1.2, 1.3). Planting crops that can tolerate cold weather also adds to the productivity of outdoor gardens. (Designs for inexpensive cold frames include the Solar Survival plans—see Resource List.)

If you have a cool cellar space or access to a root cellar, vegetables such as cabbage, carrots, onions and other root crops can be grown in your summer garden and stored for winter use. Many vegetables preserve well, if stored properly. While not quite as nutritious as fresh-picked produce, stored vegetables can be as nutritious as store-bought produce, and much cheaper.

Another food production alternative is to grow salad greens in a planter box indoors in a cool room with special growing lights. Planters can be moved outside when the weather permits. Some people have satisfied all their winter salad needs this way. (A good book on the subject is **Raise Vegetables, Fruits and Herbs Without A Garden**, by Doc and Katy Abraham, Countryside Books, 1974.) Seedlings can be started under indoor lights as well, for later transfer to the garden. Sprouts, grown in jars in the kitchen, also can supply part of your fresh vegetable needs.

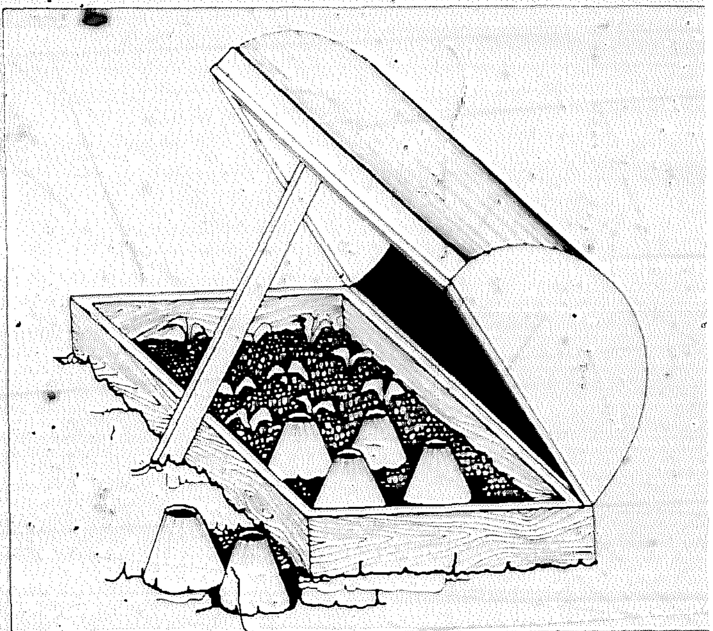


FIGURE 1.3 Solar pod with cloches

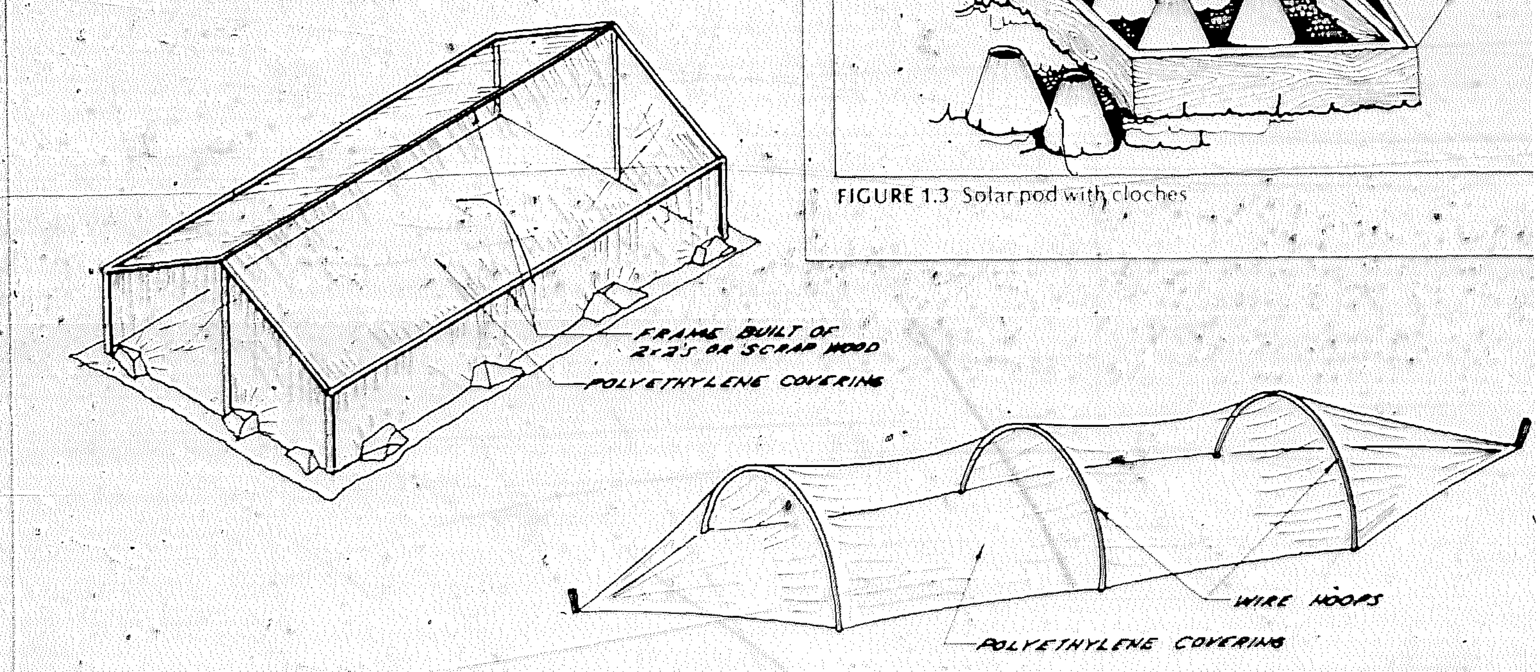


FIGURE 1.2 Polyethylene covered cold frames

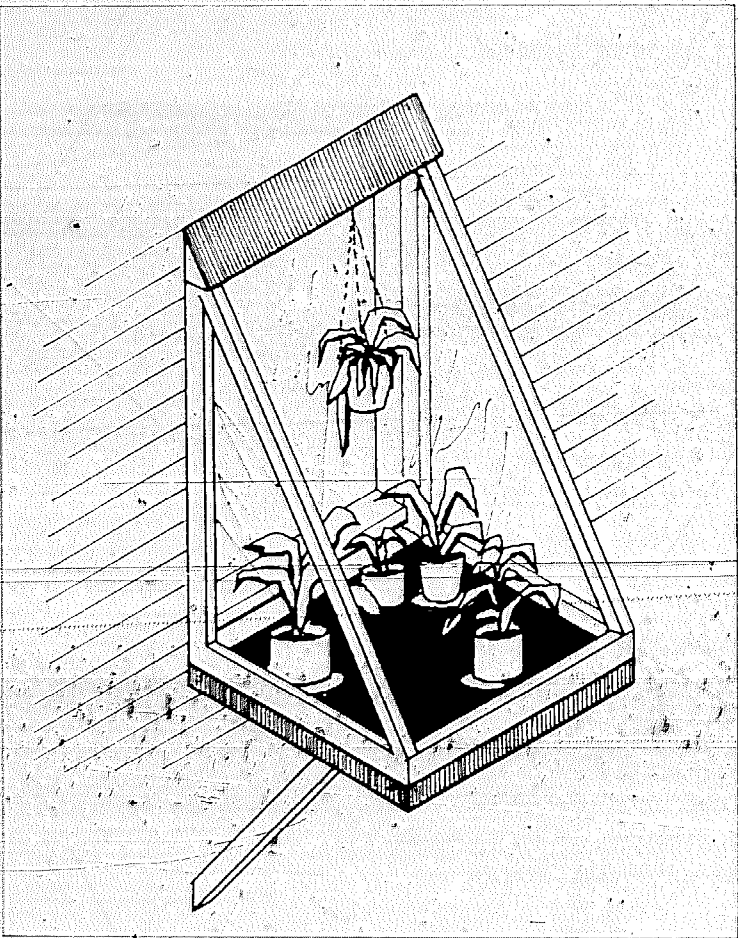


FIGURE 1.4 Window greenhouse

Another possibility is a window-greenhouse (Figure 1.4). Enough space is usually available for small salad or herb production or for starting seedlings. A window-greenhouse may supply enough growing space for people intent on spending just a little time gardening. (Refer to **Windowsill Ecology**, by William H. Jordan, Jr., Rodale Press, 1977.)

It is important to determine your commitment to home food production. It is a time-consuming, labor-intensive experience. You may find out that the alternatives to a solar greenhouse can provide sufficient food production opportunities to meet your needs. In any case, you will find that it is the gardener *working* in the greenhouse who greatly influences food production.

Of course, if you want a sunny, indoor living space where you can also grow vegetables year-round and produce heat for your house, a solar greenhouse is your best alternative. But a solar greenhouse represents a substantial investment of money, materials and time to build, maintain and operate. If some of the alternatives presented here are possible for you, it may be wise to try them before you decide that a greenhouse is what you need.

FOOD PRODUCING SOLAR GREENHOUSE

Owning and successfully using a solar greenhouse is somewhat like being a parent. To remain healthy, the living plants in a greenhouse require constant attention. They have to be watered, fertilized, weeded, thinned, transplanted, inspected and treated for insect infestation and disease, harvested and replanted. In all likelihood, if you are a successful outdoor gardener or if you are intent on learning about horticulture you can become a successful greenhouse gardener.

Using the greenhouse year-round as a tool for food production will require considerable greenhouse management skills. The main difference between greenhouse and outdoor gardening is control over the growing environment. Various factors that are left to nature in an outdoor garden must be controlled carefully by the greenhouse operator.

First of all, the greenhouse environment has to be maintained within certain limits of temperature and humidity, requiring attention to heating, cooling and ventilation systems. Extremes must be avoided. Under high temperatures and humidities, which are typical inside a greenhouse, plants are stressed and become susceptible to disease, insect infestation, and mold.

Carbon dioxide levels also must be maintained. Carbon dioxide and sunlight are two primary ingredients in the photosynthetic process, and for best growth, plants require a steady supply of both. In the air-tight environment in a well-built solar greenhouse, there is very little natural exchange of air to replenish carbon dioxide levels. Although less of a problem during the summer when vents and doors are left open, natural air flows are restricted greatly during colder weather to conserve heat. Thus, the greenhouse user must ensure that some ventilating takes place to replenish carbon dioxide supplies.

There are other differences between greenhouse and outdoor gardening. It never rains indoors, eliminating the luxury of natural watering. Plants are entirely dependent on the greenhouse operator for the right amount of water. Another task left to nature outdoors is pest predation. Guarded against the hardships of living among natural predators and in cooler, outdoor temperatures, pests thrive and propagate inside a greenhouse; once established, they are difficult to eliminate. Using chemical pest controls in an enclosed space often is dangerous to human and plant life. Therefore, natural predators should be introduced to the greenhouse by the operator. Maintaining the right pest/predator balance can be difficult; it is a skill usually acquired through experience.

Also, it is essential that the greenhouse grower be able to use a very limited growing area effectively. For example, plants must be arranged so that tall ones never shade significantly low ones at crucial stages in their development. The urban gardener may have some experience with limited spaces, but the grower used to an expansive backyard or an open lot must learn the mechanics of greenhouse plot planning.

Joe White uses every available space to raise herbs in his New Hampshire greenhouse.

TASK / SKILL	OPERATE WATERING SYSTEM	INSTALL, REMOVE, RAISE OR LOWER VENTS AND INSULATION SYSTEM	MINOR CARPENTRY WORK: PLANTER TRAYS, REPAIRS, ETC.	MAINTAIN MECHANICAL, ELECTRICAL AND PLUMBING SYSTEMS	READ THERMOMETER AND RECORD DATE	PHYSICAL ABILITY TO SHOVEL SOIL AND PUSH A WHEELBARROW	READ AND USE REFERENCE BOOKS ON SUBJECT	GENERAL HOUSEHOLD MAINTENANCE	REFER TO EXPERT IN THE FIELD	COMMON SENSE	TIME, CARE AND DEVOTION
PLANTING			☀			☀	☀			☀	☀
EFFECTIVE USE OF SPACE							☀			☀	☀
HEATING AND TEMPERATURE CONTROL		☀		☀	☀		☀	☀	☀	☀	☀
COOLING AND AIR FLOW CONTROL		☀		☀			☀	☀	☀	☀	☀
CARBON DIOXIDE REPLENISHMENT		☀					☀		☀	☀	
WATERING AND HUMIDITY CONTROL	☀						☀	☀		☀	☀
PEST AND WEED CONTROL							☀	☀	☀		☀
DISEASE CONTROL							☀		☀		☀
HARVESTING						☀				☀	☀
GOOD VIBES										☀	☀

TABLE 1.1 Management tasks and skills

HEAT PRODUCING SOLAR GREENHOUSE

Traditional home heating systems are fairly automatic and few tasks are required other than adjusting the thermostat or occasionally cleaning air filters. But a heating system utilizing a solar greenhouse necessitates a greater degree of involvement on the owner's part.

Basically, the solar system depends on the movement of air from the greenhouse into the house, and vice versa, to transfer heat. The user must understand how to manipulate air flows so that heat is furnished to the home when it is available. Opening and closing vents connecting the greenhouse with the living space are the critical tasks. When air inside the greenhouse is heated by the morning sun, upper vents should be opened. Warm air flows to the home, replacing cold house air which flows to the greenhouse through the lower vents, thus forming a natural convection loop. (See Figure 1.5.) The process continues until the sun sets. Then, all vents should be closed, preventing cold greenhouse air from moving to the warm house. The process requires understanding, and users must ensure that venting systems are working properly.

Insulating curtains or shutters also can be used at night to reduce heat loss. In the morning, when the curtains are opened, less sunshine will be needed to heat the inside of the greenhouse, and less time will be required before solar heat can be vented into the home. Likewise, if you use your greenhouse as a solarium, the space will be warmer and can be used earlier in the morning if glazing insulation is in place at night.

Thermal mass, another key feature of a solar greenhouse, also must be considered. As a space heater for the home, an attached solar greenhouse functions best when the solar heat is vented directly to the living space. Very little of the heat energy should go into storage within the greenhouse. If too much storage mass is exposed to the incoming solar radiation, too much solar heat will be absorbed, thus leaving very little surplus heat for venting to the living space. Of course, if you're growing food in the greenhouse, adequate temperatures must

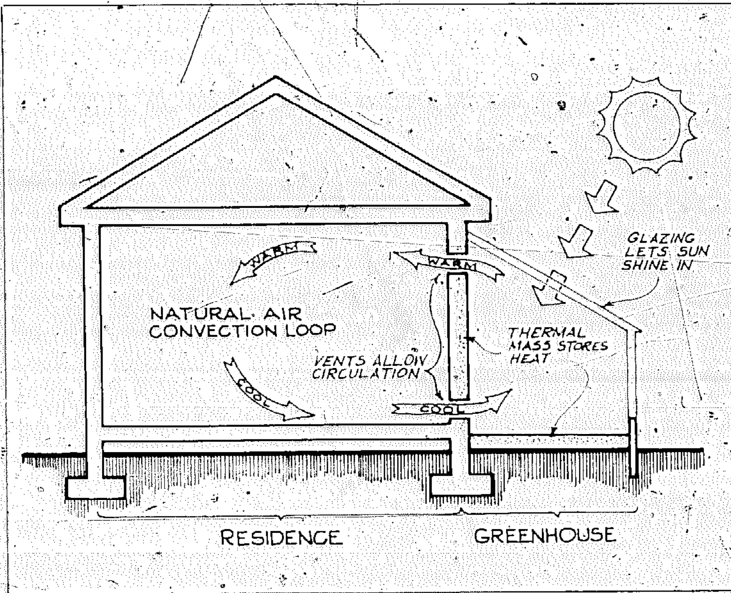


FIGURE 1.5 Natural convection loop

be maintained at all times. In this case, the balance between venting heat into the home and storing heat in the thermal mass becomes a bit more complex. (More on ventilation and proper thermal storage in Chapters 8 and 9, respectively).

WHAT IS YOUR COMMITMENT?

The point is not to make the tasks seem more difficult than they really are. Rather, you must understand that using a solar greenhouse requires daily management and ongoing effort. Actual time commitments will vary according to how the greenhouse is used.

For year-round food production, an average of one hour per day (split between morning and night) is probably needed to keep a family-sized greenhouse operating well. Season-extending greenhouses do not require this work during mid-winter. On the other hand, if the greenhouse is used solely as a solarium, opening and shutting vents may be your only tasks.

The basic operating tasks have been outlined briefly. If the required time commitments conform well to your present daily routine (work and leisure), maintaining a solar greenhouse should not be a problem. Conversely, if adjustments in your lifestyle will be needed, you must determine the relative value of building a solar greenhouse. For example, if you travel quite a bit, or if you and your family frequently leave home on weekends, the daily chores of using a solar greenhouse may be a burden. Of course, if no food or plants are growing, you can always keep the greenhouse closed. Some tasks (e.g., venting, watering, etc.) can be automated.

A solar greenhouse can be a useful addition to your home. The main question is whether *you*, as the owner and/or builder, are prepared to use it.

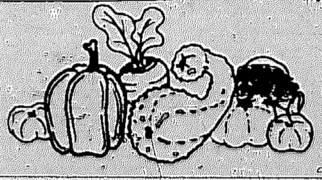
Linda Nelson, admiring her fresh broccoli, knows that it takes time, money and a good deal of work to earn the benefits from her Wisconsin greenhouse.

SKILLS NEEDED TO BUILD A SOLAR GREENHOUSE

Basic drawing ability, organizational know-how and fairly simple construction craftsmanship are the skills needed to design and build a solar greenhouse. Even with minimal experience, you should be able to handle the entire process if you are prepared to learn what you don't know and get help from others when necessary.

You will need drawing skills to sketch your plans, particularly if plans are needed to obtain a building permit. Your plans need not be exact, but should be accurate enough to estimate materials requirements. Drawings should include: a plot plan, showing the location and size of the greenhouse; a foundation plan, showing a cross-section through the foundation; and a floor plan, showing the size and spans of framing and rafters, and all door and window openings. If your drawings leave you with uncertainty about specific details (or the overall design), visit a solar greenhouse near you. Consult with the designer and the operator on what works well and what doesn't. Note how design problems were solved.

Managing your time efficiently also is important. You must recognize that the organization of tasks is a critical factor in the overall success of your project. For example, dealing with shippers and retailers on materials can be confusing unless you are prepared for shipping delays, prepayments, etc. Likewise, working with professional or volunteer help can be frustrating unless specific direc-



tions are made clear. If you are working with a group, you must coordinate everyone's time and always have the necessary tools and materials on hand. These jobs are not difficult if you plan ahead and try to consider every possible detail.

As for construction, the important thing is to stay within your capabilities. Do what you can do well, and learn what you don't. If you are unfamiliar with basic building techniques, get some help from a good carpenter, preferably one with solar greenhouse construction experience. The Resource List of designers and builders (Part IV) includes many people and groups with greenhouse experience. Locate someone in your area, or write to the closest contact and find out if they know of someone nearby. If you need help only with construction, perhaps you can get help from a local carpenter who is willing to try something new.

Some skills are required if you use a concrete foundation, specifically in building good concrete forms, installing a reinforcing bar, and pouring the concrete. Concrete block foundations are simpler, particularly if surface-bonding mortar is used (one trade-name for this relatively new, glass-fiber reinforced mortar is Block Bond; see the Resource List for information sources). Post and railroad-tie foundations are even easier.

General woodworking skills are required to frame the building. If a fairly skilled carpenter is working on your greenhouse, there should be no problem with framing, sheathing, insulating and roofing. However, building and installing glazing, doors and vents that don't leak air or water takes a good bit of skill. It is very important to build energy efficient structures as tight as possible. Pay attention to details such as corners where walls and roof meet, weatherstripping of doors and vents, and connections of greenhouse walls to foundations and to the main house. Be sure that air can't get through. Caulk doubtful-looking cracks. Good finish work improves the appearance and durability of the greenhouse. Review the construction drawings details in Part III and decide whether you will need help.

It may be convenient to have at least one light, one electrical outlet and a hose connection in the greenhouse. These are all fairly simple installations, requiring minimal plumbing and electrical knowledge. If the wiring is a problem, you might consider running an exterior quality extension cord into the greenhouse.

The important thing in building a greenhouse yourself is to combine your own skills with professional advice and assistance whenever necessary. Take your time and don't underestimate the tasks involved. On the other hand, don't be intimidated by the work. You may know more than you think you do.

Chapter 2:
ECONOMICS: Every Case Is Different

There are two primary economic questions regarding a passive solar greenhouse: How much does it cost to build? And, how much money can be saved through its use? The first question usually can be answered before you start to build. The answer to question two is a bit more ambiguous.

Your choices among a number of available options will dictate construction costs. Each component, from the foundation to the glazing, requires a separate costing decision. In most cases, though, the amount of money invested will be what you can afford. On the other hand, money saved from a greenhouse is a function of use, and is more difficult to project. The true value of the investment is directly related to an owner's personal commitment to utilize the greenhouse efficiently. The payback economics of owning a solar greenhouse are based on specific cases rather than general formulas. Each greenhouse generates a different set of figures regarding construction costs, home energy savings and food production, not to mention the unquantifiable esthetic benefits, such as promoting the gardening hobby, using renewable energy, or growing organic food. Owner/builders must determine their own set of economics estimates and make decisions accordingly.

In this chapter, we will give some basic guidelines to help builders make sound decisions on construction costs. Additionally, guidelines will be set forth to help you determine an estimated payback on your investment. You should get some idea of what to expect from your greenhouse from examples presented here. But, again, such an estimation is conditional upon actual use and no standard model is universally valid. Be wise and carefully plan your investment. Find out, before you build, how much you will need to spend, and determine as best you can how much you will save. The process can take time, but the planning will be well worth the effort, and may eliminate some unpleasant surprises.

FIGURING EXPENSES: A NECESSARY TASK!

The first thing to do is figure out an overall estimate. Using the sizing suggestions presented in Chapter 4, you should be able to estimate how large your greenhouse must be to be useful. Then, using the Rough Cost Chart (Table 2.1), figure out a total cost. If this cost is still within your budget, you should proceed with a more detailed estimate.

A tentative but relatively complete design is required. (Go through the design process in Parts II and III, and/or obtain a set of plans—see the Resource List.) Start with a set of drawings that includes the foundation, framing, glazing, wall and roof sheathing, and details such as vents, doors, and a fan. Drawings must be fairly accurate so that you can list all required materials. Then the costing process begins.

Investigate a variety of sources to find out how much each item will cost. Be cautious and obtain more than one estimate for each item. Table 2.1 lists four ranges of greenhouse construction costs. As you can see, costs will vary a great deal, depending on your building decisions. Labor can be the single most costly part of the project. Building the greenhouse yourself will keep costs to a minimum. However, materials and design factors also will weigh heavily in total expenses. Be resourceful—thrifty scavenging for recycled materails can reduce materials cost considerably. For example, obtaining unused storm windows from a neighbor's garage may be your best bet for glazing surfaces, and recycling wood from an old building scheduled for demolition can be worthwhile.

Depending upon your purchasing decisions and design constraints, construction costs per square foot of floor space can range from almost nothing (owner-built using all recycled materials) to $30 (using union labor and all new, top quality materials). Attached greenhouses tend to be less expensive than freestanding ones since the common north wall already exists. Automatic features, such as thermostatically controlled heating and venting systems, will increase costs. Using less expensive materials to make the greenhouse affordable is an option, although replacement costs for less durable materials should be anticipated.

	Cost/sq. ft. of Greenhouse floor area**	Labor	Materials	Glazing	Controls (i.e. venting)	Foundation
CASE 1	$1.00 – $3.00	Owner-built; no labor expenses	All Recycled	Polyethylene (a lighter weight plastic)	Manual	Railroad ties
CASE 2	$3.00 – $10.00	Owner-built; no labor expenses	All New	Good quality, fiber-reinforced plastic (outer glazing); polyethylene inner glazing	Manual	Concrete
CASE 3	$7.00 – $14.00	Professional	Same as Case 2	Same as Case 2	Same as Case 2	Same as Case 2
CASE 4	$15.00 – $30.00	Professional	Case 2	Highest quality glazing	Automatic	Case 2

TABLE 2.1 Rough cost estimates for a medium-sized attached solar greenhouse

* Costs do not include planting beds, soil, lights, back-up heaters, or other items needed to use in greenhouse for food production.

** 1979 prices subject to inflation – note that building materials prices tend to inflate faster than the general rate of inflation.

NOTE: This manual is intended to help design and build a durable greenhouse that can last indefinitely with proper maintenance. Where short-lifespan materials—such as plastic glazing—are suggested in subsequent chapters, their installation is designed for easy replacement with longer-life materials.

EXACT COSTING

Prepare a separate cost sheet for each major component of the greenhouse: foundation, framing, glazing, sheathing, and details. Table 2.2 is a sample cost sheet for foundations. Note the detail in preparing the sheet—nothing is left to chance, memory or a "that won't cost much" attitude. Costs mount quickly. Labor is excluded from the example. If you don't plan to dig the foundation yourself, be sure to count excavation expenses. Also, in the example, the value of recycled materials is apparent—the lumber for concrete forms, the stakes and some scrap wire were obtained for free. Use the cost sheet as a notebook, and list supplies next to each item. When you check costs, check and note delivery times as well. Don't be left waiting for important materials when you're ready for construction. Glazing materials, for example, can take weeks to arrive after ordering and prepayment.

A framing cost sheet should include lumber (standard grade or better), nails (all galvanized) of various sizes, lag-bolts and other hardware such as joist hangers or angle braces, and, if you don't use pre-treated sill lumber, copper napthanate preservative.

On the glazing cost sheet, again be sure to include any hardware that goes with the type of glazing you will use, such as gasketed nails or stainless steel screws. For fiber-reinforced plastic glazing, silicone or some other caulking is needed. Flashing material also is required. Of course, don't forget

Material	Quantity	Cost Per Unit & Supplier	Cost
1. Excavation		none (manual; self)	
2. Concrete	35 cubic ft.	Bill's Sand and Gravel	
a. gravel	30 cubic ft.	$11/yd.	$ 12.22
b. sand	10 cubic ft.	$11.50/yd.	4.25
c. cement	5 bags	$4.95/bag	24.75
3. Lumber for concrete forms	as needed	none; scrap wood	
4. Rental of Cement Mixer	1 day	$10.50/day, U-Rental, Inc.	10.50
5. 8" Anchor Bolts	10	$.75, Al's Hardware	7.50
6. 2" Styrofoam, blue structural	16 each 4'x8'x2" sheets	$10.50, Joe's Supplies (two weeks delivery time)	168.00
7. Flashing for insulation			
8. Reinforcing bar			
9. Wire	as needed	none, (scrap)	
10. Stakes	as needed	none, (scrap)	
		Total	$

TABLE 2.2 Sample cost sheet for foundations

the glazing material for both the outer and inner surfaces if double glazing is used.

On the sheathing cost sheet, include interior and exterior sheathing, insulation, polyethylene for vapor barriers, roofing materials, flashing, interior and exterior primer and paints, exterior finish sheathing, hardware, such as finish nails or sheathing nails, and caulk.

As for details—doors, opening windows, vents, fans, heaters, watering systems, planting beds or benches, plumbing and electrical—prepare a separate cost sheet for each. For doors and vents, you must include hinges, latches, weatherstripping, springs, openers or closers, screen and screen doors. For fans and heaters, don't forget mounting hardware, electrical wire or extension cords, and if necessary, the cost of adding another circuit to your home wiring. For a free-standing greenhouse, you must include the cost of getting power to the greenhouse and wiring for fans and lights. Finally, for plumbing, you may want to include the cost of installing a hose spigot inside the greenhouse. If a more elaborate watering system is planned, be sure to consider all the necessary hardware.

After preparing detailed cost sheets for each item, you must calculate a comprehensive cost estimate. Add up the totals from each sheet. Be positively sure that you have priced everything, including tools you will need to buy or rent. For example, brushes will be needed to apply wood preservative; caulking guns are required; and special cutting tools for some glazing materials are essential. Shipping costs must be considered if certain materials are purchased from far away.

Another factor to watch is quantity. Be sure that your costs reflect the quanitities of material you must buy, and not the quantitites you intend to use. For example, if you plan to use 190 sq. ft. of glazing material and the materials comes in 200 sq. ft. rolls, your cost is for 200 sq. ft.

A final step is to have an informed observer, preferably an experienced builder, review your cost sheets and calculations. You may easily have overlooked something. Don't be disappointed if your cost estimates are somewhat off—accurate construction costing takes years of experience. For example, if time lags between pricing and purchasing, cost increases must be anticipated. A ten percent increase for each three months of delay is a safe projection. Check with suppliers on large items for anticipated cost increases. If you are building the greenhouse yourself, add 20 percent to the final total to cover unforseen expenses.

After completing this process, you should have a pretty accurate idea of materials costs. If you plan to hire a builder, you should be able to get a good estimate on labor costs from a local contractor based on your drawings and cost sheets. (Whenever possible, obtain a firm bid for the job.) Other costs that may result from your greenhouse addition are increased property taxes and insurance premiums.

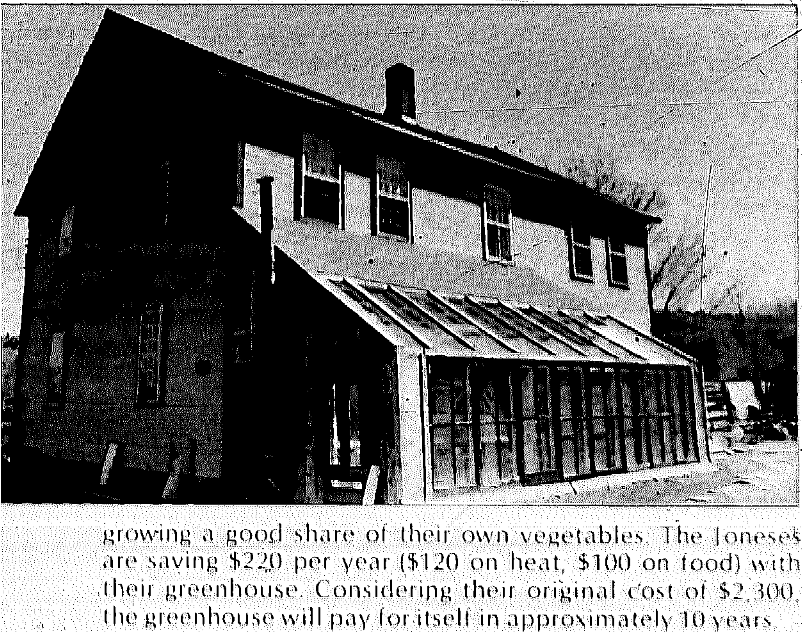
HOW MUCH WILL A GREENHOUSE SAVE?

Once you have determined how much it will cost to build the greenhouse, the logical next step is to determine whether such an investment will be worthwhile. The benefits of owning a greenhouse—food, heat, sunspace, growing season extender, etc.—were outlined in Chapter 1. Unfortunately, however, there are no "savings sheets" that can detail the approximate savings that can be obtained from each specific use. The amount of money you will save with a greenhouse is entirely dependent on how well it is designed and built, as well as how it is used.

Below are four examples which serve to illustrate the variables in figuring payback.

The Jones family builds a 250 sq. ft. greenhouse attached to their 1800 sq. ft. home. They spend $2,000 on construction, and an additional $300 for gardening supplies. They use the greenhouse for both food production and heat, and enjoy managing the necessary operations. With the greenhouse their heat bills, which were $600 per year, have decreased approximately 20 percent—a savings of $120 in the first year. During that time, they estimate a savings of nearly $100 by

In S. Acworth, N.H., the Phoenix Nest Earth Arts Center spent $1,200 for materials and 640 hours of labor to attach this pit greenhouse to their old farmhouse. The Center still burned 7-½ cords of wood but the backup oil stove was put in mothballs and 500 gallons of fuel were saved.



growing a good share of their own vegetables. The Joneses are saving $220 per year ($120 on heat, $100 on food) with their greenhouse. Considering their original cost of $2,300, the greenhouse will pay for itself in approximately 10 years.

The Smith family builds a 160 sq. ft. greenhouse on their 1200 sq. ft. home for $1,600. Very little food is grown in the greenhouse because supplemental heat is it's primary function. The greenhouse also acts as a vestibule to the front door. The house thermostat is near the front entrance. In the past, whenever the door was opened, the incoming cold air would start the furnace via the thermostat. The Smiths save 30 percent on a $700 yearly heat bill because of the greenhouse's energy conserving features. By saving $210 per year on fuel bills, the Smiths' greenhouse will pay for itself in approximately eight years.

The Johnson family builds the same size greenhouse as the Smiths—160 sq. ft. for $1,600. However, they use it exclusively for food production. With large amounts of thermal mass, most of the solar heat collected in the greenhouse is stored there to maintain a suitable growing environment for the crops. The Johnsons haven't really kept track of the monetary benefits of their food production, but grandfather is spending lots of time gardening happily and they are eating well.

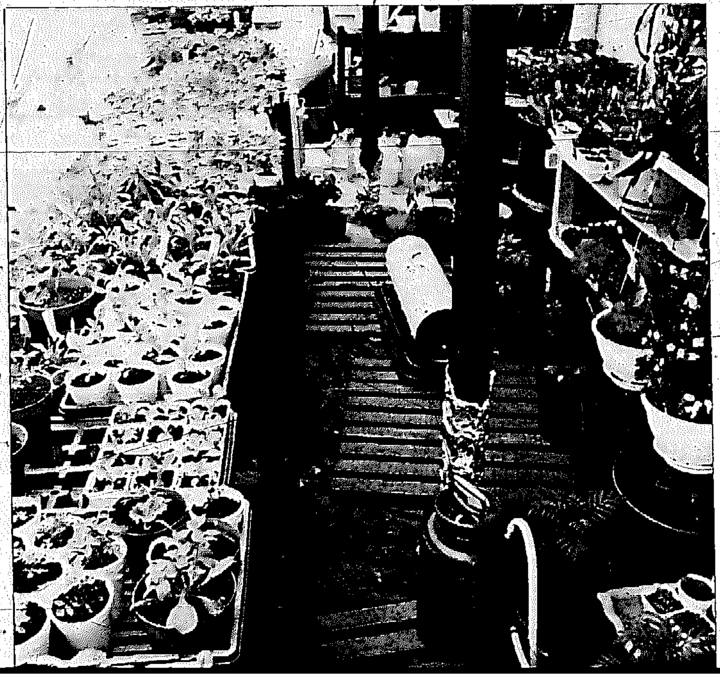
The O'Rileys spent $300 for a small 8' × 12' greenhouse. They kept costs low by using a variety of recycled materials and building the greenhouse themselves. The first spring, the O'Rileys sold enough seedlings grown in the greenhouse to pay for the whole thing. In addition, a little food was grown in the greenhouse by fall and some heat was supplied to the attached house during winter. For the O'Rileys the payback was immediate.

These four examples are hypothetical cases, but nonetheless are realistic. The economic numbers do not account for the rising costs of food and fuel which would lead to more favorable payback calculations. As fuel prices rise, a greenhouse's heat-producing capabilities increase in value; likewise, as food costs go up, so does the value of home food production. What's more, tax credits are available for solar installations and solar greenhouses increase property values. The Joneses, for example, could receive $1,300 in state and federal tax credits on their $2,000 attached greenhouse. Meanwhile, they increased the resale value of their home by approximately $1,500. Thus, their payback period is reduced considerably.

Some observers find it somewhat illogical to worry about monetary payback in the first place. After all, they say, people don't calculate the payback economics before purchasing a television, washer, or hot water heater. Buyers simply assess the value of such items relative to personal needs and satisfactions, and make purchasing decisions based on such values. Similarly, the decision to build a solar greenhouse could be based on the value and utility of the projected benefits—food, heat, extended growing season—and not on how soon the investment will pay for itself.

With a solar greenhouse, the return on your investment isn't based solely on how much money, but also on how much time and effort you invest. A high-priced greenhouse can reap few rewards if used improperly. On the other hand, a low-cost, owner-built greenhouse used to its maximum efficiency can pay for itself in a hurry.

Mary Pea in Kingston, R.I., makes use of space in her small, attached greenhouse to produce enough seedlings to supply most of her neighbors with garden starts.

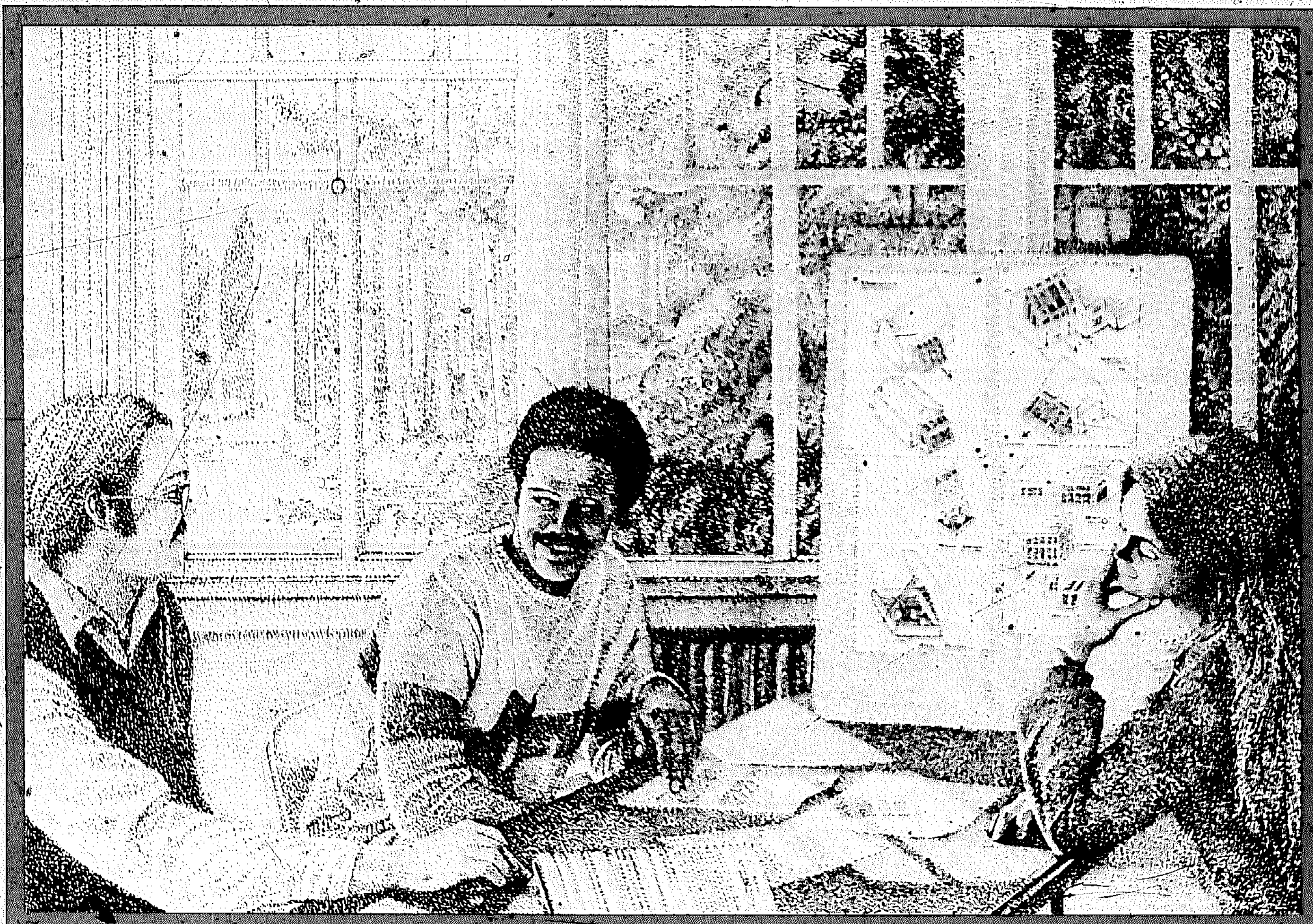


A MONEY-MAKING GREENHOUSE?

Growing vegetables, flowers and garden "starts" for profit can be a rewarding experience, but not without the necessary effort. If you are interested in the idea, the first thing you should do is conduct a market survey. You must find out how much demand there is for the products you intend to provide. A list of potential customers should include your neighbors, small neighborhood food markets, and local florists. Find out what people would be looking for from a local supplier such as yourself. Find out what prices they would pay. Ask for suggestions and advice on kinds of crops to raise, seedlings to start, and flowers or ornamental plants to grow.

After determining the demand, turn your attention to supply. You must determine how much money and time will be required to meet the demand. The investment for seeds, soil, and other garden supplies should match closely your projected sales. You also need to consider how much your time is worth. The time factor will affect significantly the price of your goods. If you are intent on a full-fledged greenhouse business, your prices should reflect your labor as well as production costs. If you are starting the business primarily as a hobby, you may be seeking other satisfactions, and labor costs could be less.

If your primary projections look favorable, investigate the proposition more thoroughly, and analyze the various management concerns (e.g., advertising, distribution, store hours, insurance, etc.). Determine all the variables and then think seriously about making the investment. Remember, trying to sell products in a market that does not exist is very frustrating.



Part II

PRELIMINARY PLANNING

It is not our intent to tell you exactly how to build your greenhouse. Rather, we want to explain the major design considerations of a solar greenhouse and to advise you on the various construction options. Your job is to design and build a solar greenhouse to fit your needs. Our job is to assist you in selecting good techniques and systems, as well as to help you make sound design decisions.

A detailed, final plan for a greenhouse is not provided, because any single, complete design has limited applications. A solar greenhouse is site specific. Thus, many essential features of your greenhouse must be designed with your specific site in mind. For example, the amounts of insulation, glazing and thermal storage will vary according to where the greenhouse is located and its intended use. Likewise, size and shape, types of materials to use, bed arrangement, etc., depend upon available resources and individual preferences. In addition, your greenhouse should be a product of your personal involvement and choice rather than someone else's ideas. By becoming involved in all aspects of the project, from the design decisions to the construction tasks, you will better understand the functions of a greenhouse and its sub-systems. Likewise, you will be in a better position to maintain and operate your greenhouse efficiently.

No one has designed a "Model T" solar greenhouse that is suitable for every application. However, there are a number of good designs (with plans and drawings) available that may incorporate certain details and features appropriate to certain climatic zones and specific sites. If you need help putting together a design, obtain a set of plans and/or get help from an experienced solar greenhouse designer. Review the Resource List in Part IV and find out where to find such plans and people.

In Chapters 3 and 4, a number of preliminary design questions are addressed. What type of greenhouse best satisfies your needs: attached or freestanding? Do you have a suitable location for a greenhouse? What is a good size and shape? If you answer these questions thoughtfully, you will be ready to begin construction.

Chapter 3: LOCATION

The primary design consideration affecting solar greenhouses is *location.* No matter what size, shape or type of greenhouse you intend to build, you must have a suitable location. Of course, all design considerations are interrelated and must be complementary. But your location decision will significantly affect every other design factor. For example, you may choose a site that is sloping away from the house to the southwest. Thus, the greenhouse may require a slightly sunken foundation, glazing facing predominantly southwest with some east-glazing, and raised beds in the rear with lower beds in front.

A suitable location for a solar greenhouse depends upon many factors—most notably, sun access. A certain level of solar radiation is required for a solar greenhouse to function properly. "Micro-climate" factors that will affect greenhouse operation include site location, too; for example, windbreaks, surrounding buildings, and slope of the land can be used to shelter the greenhouse from harsh winter weather. Other location considerations include safety, pollution, drainage, and building codes. Consider every factor before you make a final decision. Once built, a greenhouse becomes a permanent feature of your property, and is difficult and costly to move.

SUN ACCESS

The primary site consideration is the availability of direct sunlight. You must understand the sun's path to determine the suitability of your greenhouse site. As shown in Figure 3.1, the sun rises in the east, follows an arc through the southern sky, and sets in the west. The sun travels a different path in winter than in summer, and subsequently, solar radiation falls on the earth's surfaces (and on your greenhouse) at different angles during each season.

If you intend to build an attached solar greenhouse, it must be constructed on the south side of the existing building. Any well-exposed wall area that faces from southeast will have adequate daily exposure to the sun and a southern sky. However, shading obstructions to the south will affect your site. Nearby buildings, trees and hills can block the southern sun and limit a greenhouse's efficiency. You must be sure there are as few obstructions as possible, particularly during winter months when maximum solar exposure is critical.

The sun does not rise as high in the sky during winter, and objects south of your site which do not cause shading problems in summer may completely or partially shade your greenhouse during winter. On the other hand, deciduous trees, which lose their leaves in winter, can partially shade your greenhouse in summer but cause less shading during cold winter months. Actually, summer shading (from deciduous trees) can be advantageous in some parts of the country by reducing the solar radiation passing through the glazing and thus moderating interior greenhouse temperatures. Also, remember that trees do grow, and small plantings that seem insignificant at construction time could shade your greenhouse completely in years to come.

To determine your optimum greenhouse location, it is wise to do a site survey. First, visually inspect your proposed site. Monitor the site at different times of the day to determine the sun's approximate path and whether any shading occurs. If this series of inspections shows a site that is generally sunny, use the procedure outlined below to do a more thorough site survey:

There are three basic steps to conducting a thorough site survey:

1) You must determine the direction of *true south;*

2) You must determine the height of the horizon at true south, and its height every 15° east and west of true south up to 120° (east and west); and

3) You must determine the height of all obstructions within 120° east and west of true south.

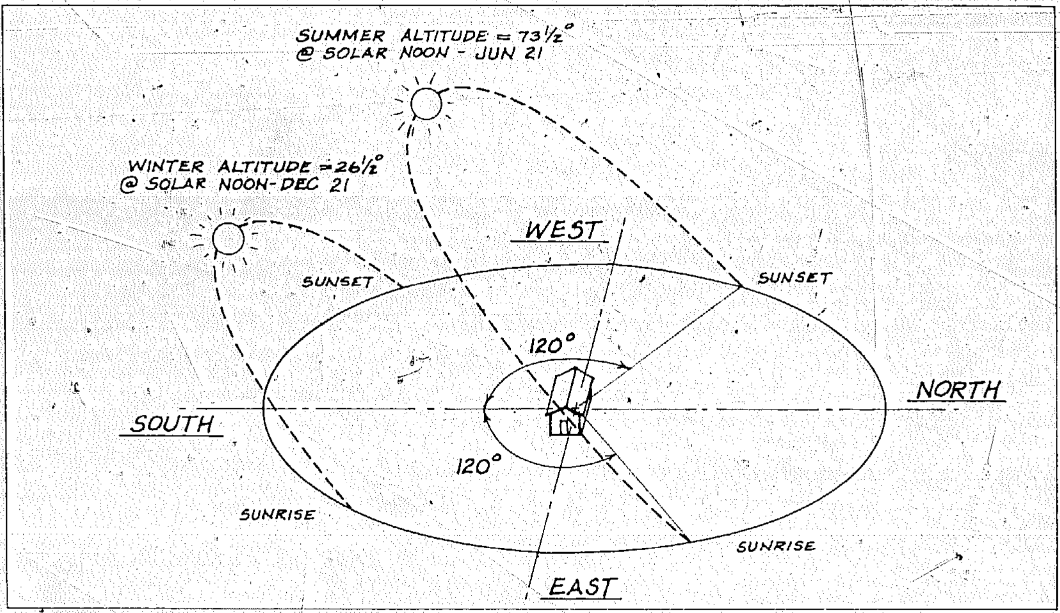
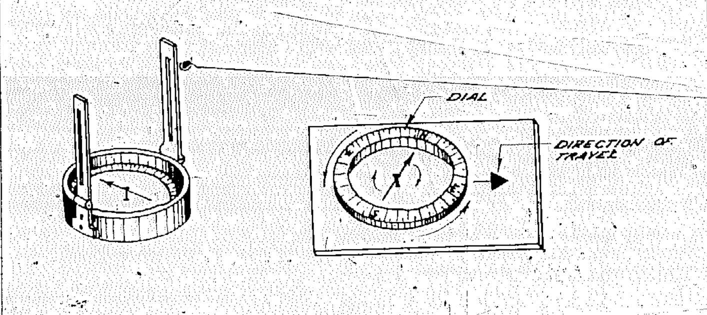


FIGURE 3.1 Sun's path at 40° north latitude

You will need certain tools and must understand certain terms to conduct these three steps. First, *a compass* (Figure 3.2) and *Chart A* (Figure 3.3) are needed to determine true south. Secondly, *a protractor with a plumb-bob* (Figure 3.4) is needed to determine the heights of the horizon and surrounding obstructions such as trees. Third, *a sun-path chart* for the latitude closest to the latitude of your site (Figure 3.5) is needed to show how the sun, the horizon and obstructions interrelate.

The sun-path chart shows the position of the sun in the sky at any time of day on representative days of the year. Along the bottom of the chart (Figure 3.5) are *azimuth angles*, which are measures of an object's angular position on the horizontal relative to true south (Figure 3.6). Along the side of the chart are *altitude angles*, which are angular measures of an object's position relative to a horizontal line of sight (Figure 3.7).



NOTE: In urban and suburban areas, the use of a compass to determine magnetic north and south may be unreliable. Underground piping, reinforcing steel in building, and overhead and underground wires all seriously affect compass indications. Even a jackknife in the operator's pocket can throw a compass off. Always, double check your compass indicator against a local map.

FIGURE 3.2 Using a compass to find true north

In a site survey, you must plot the altitude angle of the horizon (every 15° from true south) and all obstructions onto the sun-path chart.

In order to determine the direction of true south, you can use a compass and Chart A (Figure 3.3). First, using your compass, you determine the direction of magnetic north. Make sure there are not ferrous objects within the magnetic field of the compass needle (see note with Figure 3.2). Then, alter the compass reading the proper amount east or west at your location as indicated on Chart A. This direction is defined as *true north*. True south, then, is directly opposite (180°) from true north.

For example, suppose you live in Boulder, Colorado and plan to build a solar greenhouse onto your home. Using your compass, you determine the direction of magnetic north. Looking at Chart A (Figure 3.3), you find that the variation of magnetic north from true north is approximately 14° west for your specific location. Thus, true north is 14° west (clock-

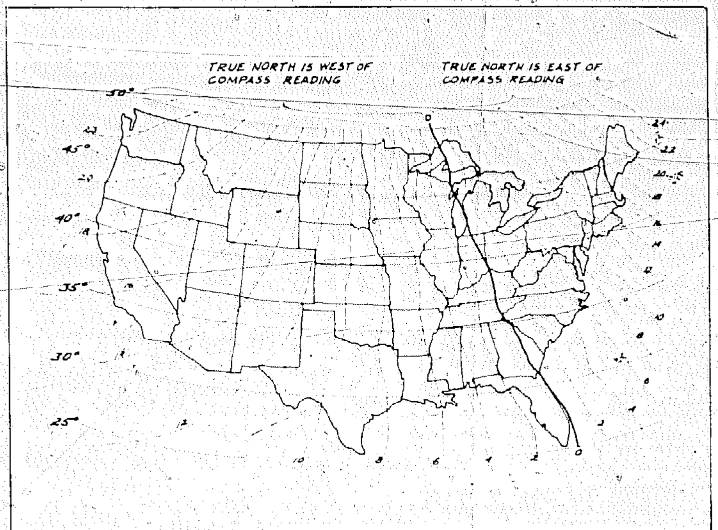


FIGURE 3.3 Chart A: Magnetic variation from true north (all U.S. locations)

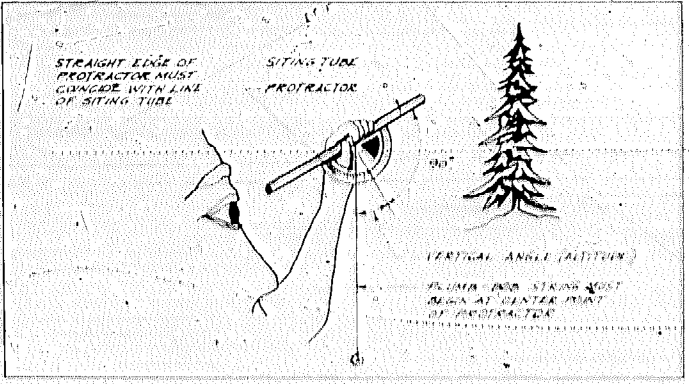


FIGURE 3.4 Using a protractor with a plumb-bob to determine altitude angle

NOTE: Positioning the pivot of the bob-string is vitally important. When the siting tube is horizontal, the string should hang perpendicular to the tube (at a 90° angle). The tube is used like a gunsight, aimed at the top of an obstruction or the horizon.

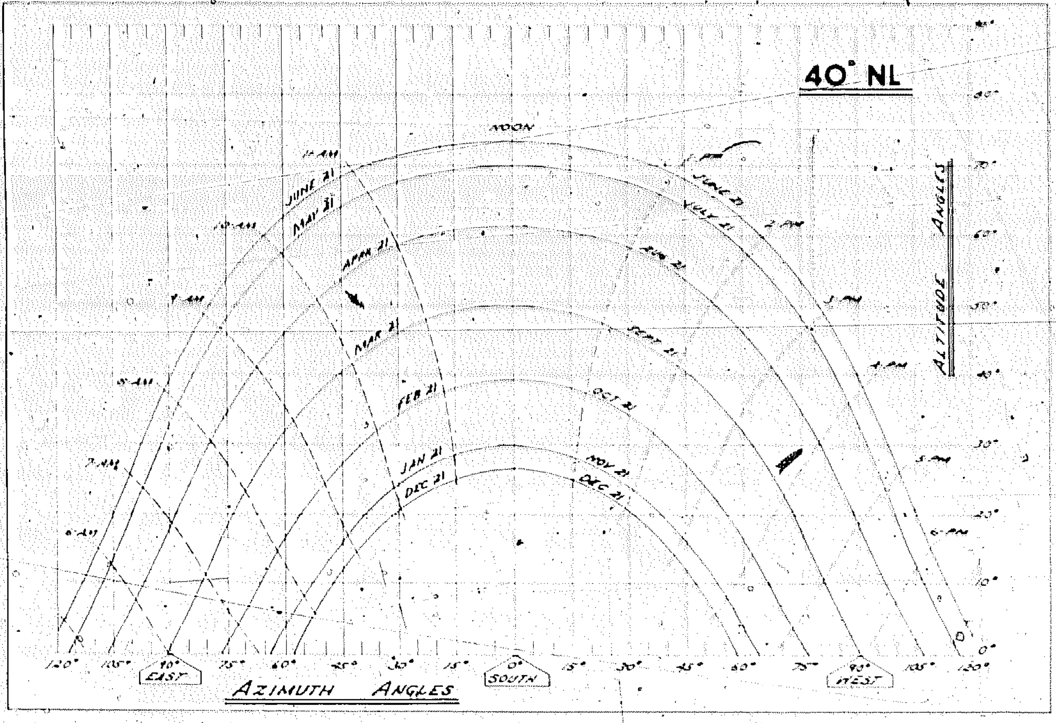


FIGURE 3.5 Sun path chart for 40° north latitude

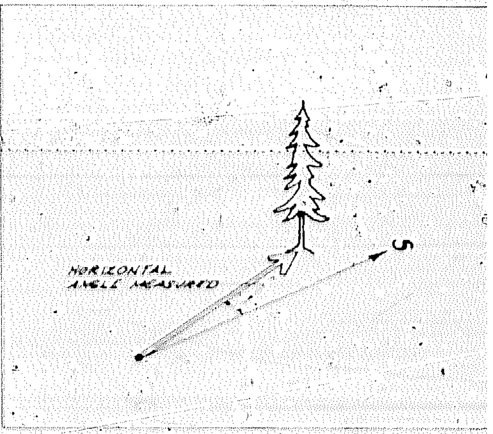


FIGURE 3.6 Azimuth angle

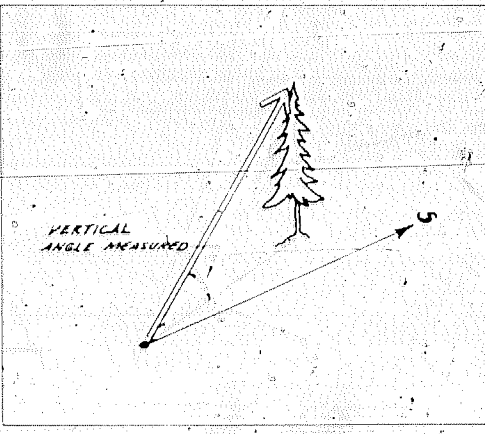


FIGURE 3.7 Altitude angle

wise) of the north reading on your compass. True south is directly opposite (180°) from true north. On the sample sun-chart (Figure 3.8), **point A** is horizontally true south of your proposed greenhouse location.

The next step is to determine the altitude angle of the horizon at true south. Align the protractor (by your eye) to the top of the horizon and have a friend read the angle indicated by the plumb-bob, record it on the sun-path chart (in the example, **point B**). Then using the compass (don't forget *to adjust for the deviation from true south) and the protrac*tor, plot the altitude angle of the horizon every 15° east and west of south (**points B1** through **B16**).

However, in the example a garage lies between 5° west and 80° west of true south, and the horizon is not visible. Using your compass, plot the approximate location of your garage on the sun-path chart. Points **B2 through B8**, then, are actually the adjusted altitude angles of the horizon given the presence of the garage. Likewise, all other obstructions must be plotted: the spruce trees between 15° and 45° E and between 70° W. and 90° W; and the maple tree between 55° E and 95° E (which should be plotted with a dotted line because deciduous trees aren't as much of an obstruction in winter when they lose their leaves).

With the horizon and all obstructions plottted on the sample chart (Figure 3.8), compare it to Figure 3.5. Now, you can determine when and how much the sun will be obstructed. The period between 9:00 a.m. and 3:00 p.m. is most critical: If this area is more than half obstructed during the months when you will be operating the greenhouse, you will not have enough sun. At the site in the example (Figure 3.8), the greenhouse would probably not have enough sun to function properly from November 21 through January 21. Although it *would probably work fine the rest of the year, the proposed* greenhouse should be moved (if possible) to receive more sun during the cold winter months, or you should plan on not using the greenhouse during these months.

Generally, if the greenhouse faces within 15° of south, the loss of solar radiation is minimal, and anywhere within 30° of true south is fairly acceptable. At 45° east or west of true south, though, 25 percent of the available solar energy will never be collected, and is effectively lost. Facing east of south is more desirable than west of south, as the sun will begin to warm the greenhouse earlier in the morning. It is important *to get heat and light into the greenhouse as early as possible* to replenish depleted heat storage and protect against freezing. By late afternoon solar radiation is less critical because the thermal masses as well as greenhouse plants and surfaces have been warmed throughout the day. Also, prevailing winds tend to come from the west, so it is best to have that side partially protected. It is not wise, however, to have a solid southwest wall with a predominantly southeast-facing structure because too little light will enter the greenhouse to support photosynthesis.

In Appendix A, there are sun-path charts for 28° north latitude (NL), 32° NL, 36° NL, 44° NL, and 48° NL. Choose the one that is closest to your location and conduct a thorough sun survey for your own greenhouse site. For more information on sun access and site surveys, see Mazria's **Passive Solar Energy Book** or Bennett's **Sun Angles for Design** (referenced in the Bibliography).

MICRO-CLIMATE EFFECTS

Undoubtedly, regional climatic characteristics, such as annual snow and rainfall, average cloud cover and average seasonal temperatures, will influence the design of your greenhouse. Also, as your site survey has shown, your site latitude affects the amount of sunlight striking your greenhouse location. In addition to these factors is a set of "micro-climate" effects which will have a significant influence on greenhouse design and performance. The micro-climate is *the climate at your site only. It varies, sometimes significantly,* from the climate at the nearest weather station or even the other side of the house. It is a function of the site's proximity and location with respect to certain physical features. For example, the micro-climate surrounding your greenhouse

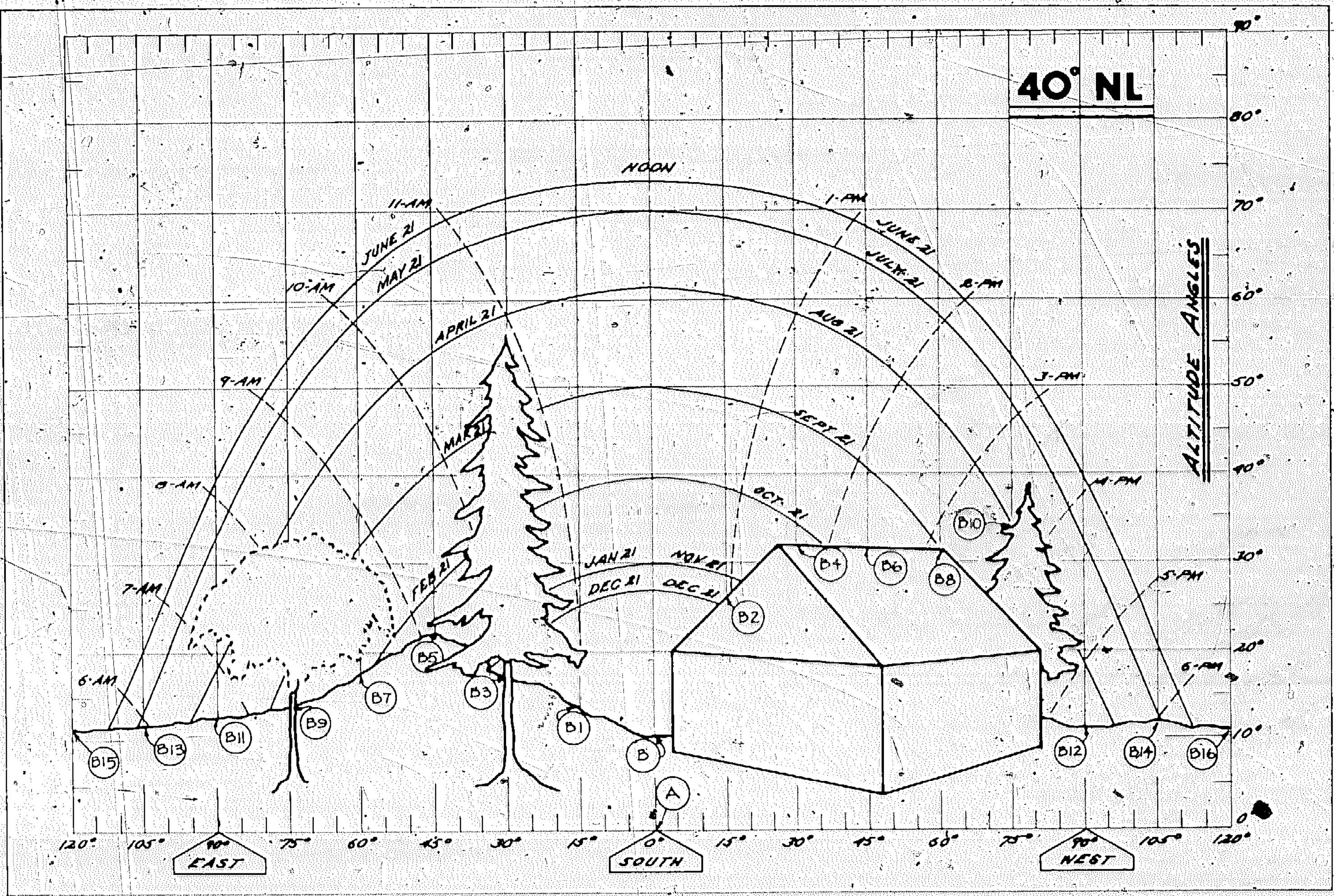


FIGURE 3.8 Sample sun path chart for 40° north latitude with plotted obstructions

relates to the surrounding buildings and natural vegetation, the slope of the land, the presence of lakes, oceans or other water bodies; and any prevailing winds or windbreaks that may exist. Some micro-climate effects can be beneficial, while others may pose problems. In determining the proper greenhouse location, you must consider and compensate for such effects.

Windbreaks can be very advantageous. The prevailing winter winds in most continental United States locations come from the west through the northwest. Also, trees or buildings to the windward side will lower the wind velocity reaching the greenhouse's exposed surfaces. Thus, a greenhouse that is sited just east to southeast of a windbreak and within the wind shadow of that windbreak can be less costly to heat. Decreased winds will decrease cold air infiltration and reduce heat loss from the greenhouse. In addition, air temperatures on the lee side of windbreaks are noticeably warmer than temperatures in the full wind stream. If the greenhouse is sited properly relative to natural or constructed windbreaks, its winter heating load can be reduced significantly.

However, not all nearby structures are suitable as windbreaks. Placing your greenhouse near tall buildings can be a real hazard. If you live in an urban area, you may have noticed the increased wind intensities adjacent to tall buildings. The taller the building, the more intense this wind effect seems to be. The reason is that the upper sections of a tall building intersect and split up higher windstreams. Some of this wind rises up and over the building; some of it is redirected around the sides; and some of it is directed downward and then around the sides near ground level. Ground level winds in such locations are often two and a half times greater than mainstream winds. These increased winds may cause damage to your greenhouse and, at the very least, will increase your winter heat needs.

On the other hand, your greenhouse need not be protected from *all* prevailing winds. In fact, you may want to locate your greenhouse so that it is exposed to summer winds to assist in ventilation and help reduce excessive temperature build-ups inside the greenhouse during summer months. Such a location may appear to conflict with the need for protection against winter winds. However, the dominant winter and summer winds usually blow from different directions. Summer winds tend to come from a more southwesterly direction. As a result, you can locate your greenhouse to take advantage of windbreaks in winter and wind channeling in summer. Check with your nearest meteorological office to determine the seasonal wind direction variations in your area. For a quick visual check on wind directions at your site, attach a five-foot piece of ribbon to an eight-foot pole sunk in the ground. Several of these "indicators" will help identify calm and windy spots at your proposed site.

Channeling summer winds onto your greenhouse may require too much effort. It could entail such tasks as planting trees or constructing buildings to the south of greenhouse in such a configuration that mainstream winds are intercepted, redirected and concentrated onto the side of your greenhouse. Nevertheless, you should choose your greenhouse site with some understanding of where the summer winds are likely to be stronger—that is, already channeled by existing buildings, natural features, or vegetation.

Attaching your greenhouse to the south side of an existing building automatically places it in an improved microclimate. Due to solar exposure, south sides of buildings are warmer and usually less windy during the winter than other sides of the same building. A similar effect is created by placing your greenhouse on south-facing slopes. Here again, the winter winds can be lower. The major effect appears to be that the ground surface is more nearly perpendicular to the sun's rays during the winter; therefore it absorbs more solar and sky radiation, thus raising its temperature. To see this effect, note on which hillsides thawing occurs sooner in the spring and freezing occurs late in the fall.

Nearby buildings, fences, vegetation and natural features such as large rocks or sudden ground-elevation changes can cause snow drifting in your proposed greenhouse location. This can be a problem, particularly if your area is windy and receives a lot of snow. Try to avoid sites where the snow is known to drift.

LEGAL NOTES

Suppose you live in a suburb outside a major city. After conducting a thorough site survey and considering all the other factors noted in this chapter, you've decided to build an attached solar greenhouse onto the front of your home. You've just finished the foundation when your neighbor comes over to inquire about your work. After explaining your project, the neighbor becomes irate. He/she claims there is a restrictive convenant in your subdivision preventing the construction of any such structure in the front yard. "We have to maintain visual conformity on this block," the neighbor explains. "It's important for resale values." Although you may object to your neighbor's lack of creativity on building design, he/she may have every legal right to stop you.

Before you start construction, a meeting with your local building inspector can be helpful, and in many places necessary (permits).

Before you decide where to locate your solar greenhouse, it is important that you understand all the accompanying legal considerations: **building codes, zoning regulations, land use controls, propery easements, insurance**, and even **"sunspace rights."** The major issue you will confront is uncertainty. The kinds of laws that affect construction generally are enforced by local governments, and no two local governments seem to think alike. Consequently, there are no universal guidelines that apply. Every greenhouse must conform to existing *local* regulations.

The number of different building codes across the country is incredible. Even more striking is the diversity in levels of enforcement. Some governments have stringent laws and enforce them with determination.

Building codes generally set standards for new construction, including residential and commercial structures, and additions to existing structures. They regulate such matters as **structural design** (size and location, loads and stress, foundations, exterior walls, floor systems), **fire protection** (fireproofing of materials, chimneys and fuels, firewalls), **mechanical and electrical systems** (heating equipment, plumbing, electrical wiring) and **issuance of building permits.**

In most municipalities, a building permit is required before construction. To obtain a permit, construction plans are submitted to the local building inspector who determines if they meet existing regulations. The degree of detail required for these plans may range from clear sketches to architectural or engineering drawings. A building permit usually costs very little, although in some jurisdictions this fee is based on the value of the construction. Other permits also may be required for plumbing and electrical installations.

If you need to obtain a building permit, be prepared for anything from an easy ride to difficult times. In all likelihood, your local building inspector will be a positive influence on the construction process. Inspectors can pinpoint certain problems with your proposed design. However, local building officials sometimes lack the expertise to judge unusual building structures, such as solar greenhouses. If they are unfamiliar with the structural design, even though it is good, your proposed greenhouse plan may be rejected. Sometimes merely the unfamiliar term "solar greenhouse" generates a code problem. Hence, it may be helpful to describe your planned greenhouse as a sunporch, thereby laying some common ground between the inspector and yourself. Also, before you make any official inquiries, talk to someone in your area who has had recent experience putting an addition onto a building. A good briefing from a well-informed neighbor can be very valuable. In any event, don't let the permit process stop you. Even if a building code may, in fact, prohibit your greenhouse construction, a variance from the code sometimes can be obtained to allow it.

Zoning laws also may affect your location decision. These regulations usually deal with such matters as: allowable uses for the zoned area (residential, commercial, industrial); building height (possibly a limitation for a rooftop greenhouse); setback requirements (the minimum open space that must be left between a structure and the property line); side clearance (the space between your building and the next); and maximum lot coverage. Such regulations generally are more rigidly enforced in urban and suburban environments than in less populated areas. Further, if you live in a subdivision or condominium development, examine any regulation (such as restrictive covenants) imposed by the developer or neighborhood residents.

Another legal consideration is **insurance**. Obtaining coverage for your solar greenhouse is not likely to be a problem. Your current homeowner's policy should cover an attached or detached greenhouse on the property. But proceed with caution. Check with your insurance company before starting to build, to ensure that the additional structure will be covered. A special rider to the policy may be necessary. Some urban dwellers may have trouble because, due to a lack of precedent, their insurance companies may have difficulty finding an insurance category for a greenhouse. Solar greenhouses have been insured variously as heating systems, attached but uninhabited space, and attached buildings, as well as greenhouses. Finally, if you plan to insure, make sure your greenhouse meets all safety and building codes. If it doesn't, your insurance company may have grounds to refuse your claim.

There is one other issue you must consider: **sun rights**. Suppose you have built your greenhouse onto your home and have enjoyed the benefits for two years. But then your neighbor to the south happens to move away. He sells his home to an inconsiderate soul who decides to surround his yard with blue spruce trees. It's obvious that, sooner or later, the trees will shade your greenhouse completely. Can you stop him? Not in most areas of the United States, where you have no legal right to unobstructed access to direct sunlight. In some localities, however, zoning regulations can prevent the construction of multi-story buildings, and property easements can be obtained to restrict a neighbor's love for tall evergreen trees. Also, some states and municipalities have passed laws that specifically protect sunspace rights for solar users. But, again, no universal laws apply. Before you build, check with your neighbors who could possibly interfere with your sunspace needs. Strike a deal, in writing and notarized, to prevent them from making your greenhouse obsolete. Perhaps you can work out a deal whereby you help plant your neighbor's trees in exchange for his agreement to plant a variety of trees that will not grow so tall (and may provide a better windbreak).

OTHER CONSIDERATIONS

Pollution and drainage considerations, as well as the general safety of your site, are three other important factors in your location decision.

Pollution, atmospheric or otherwise, is a problem when dust from nearby dirt roads or soot from chimneys collects on the greenhouse glazing. Unless washed off periodically, such accumulation reduces the amounts of solar and sky radiation that enter the greenhouse and contributes to the degradation of plastic glazings. Likewise, exhaust fumes from passing traffic and general city air pollution can deteriorate the quality of the air entering the greenhouse. Heavy metals (such as cadmium and lead) can build up in the soil and be absorbed by the plants. No definitive studies have been completed to determine the impact of heavy-metal contamination on greenhouse produce. However, the problem is regarded as serious by many greenhouse horticulturists and it would be wise to think twice before building a food-producing greenhouse near heavy automobile traffic or heavy urban air pollution.

Drainage considerations, generally, relate to the contour of the land, the groundwater table, and existing drainage mechanisms on adjacent buildings. Obviously, you should avoid sites where water normally sits on the ground for some time after a rain. Hollows or slight depressions should be avoided, although sloped land is all right as long as the slope is down and away from the greenhouse.

A shallow groundwater table can be a problem, particularly when building a pit or sunken greenhouse. Seepage or leakage of water into the greenhouse contributes to a damp environment that should be avoided. However, a greenhouse floor built at about the same level as the surface of the earth is not likely to cause any problems.

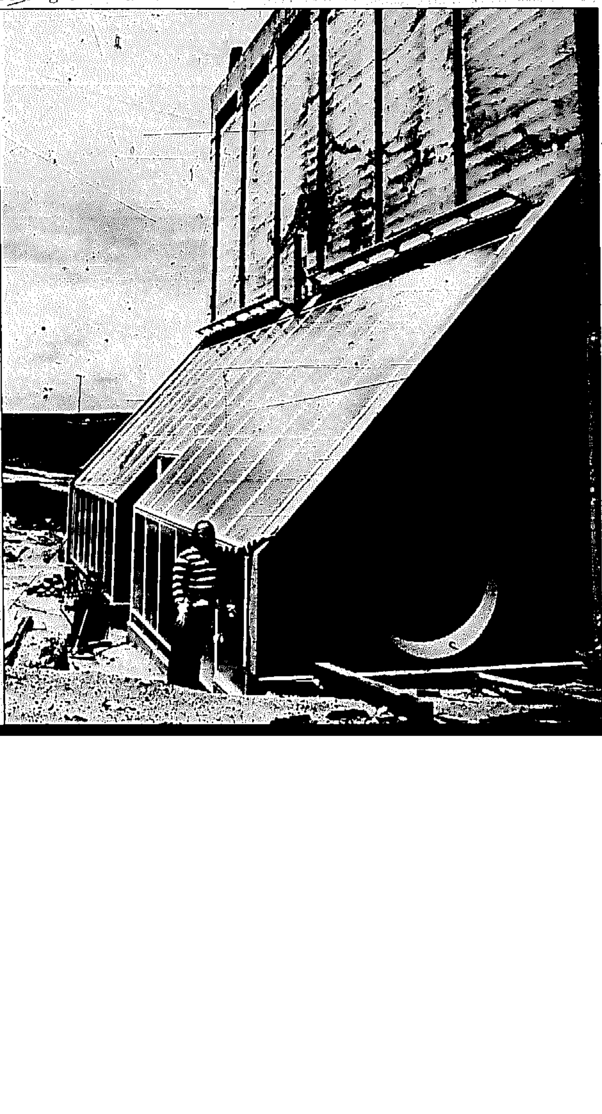
Also, watch where you place your greenhouse with respect to the rain gutter down-spouts from the house roof or other nearby buildings. Be sure that rain runoff is directed away from the greenhouse. If you are installing your greenhouse on a roof or porch, do not block existing drainage holes or slopes that carry water off these areas.

Finally, try to choose a greenhouse site where there is little likelihood of structural damage due to accidents, falling debris or vandalism. The glazing, especially, should be protected. Some of the potential hazards to avoid:

1) Falling ice or packed snow from overhead tree branches or roof sections.
2) Falling tree branches.
3) Rocks or other objects thrown by children (or adults) in a nearby street, park or playground.
4) Rocks spun up by tires on nearby driveways or roads.

If the only site you can find may be subject to such accidents or vandalism, consider the use of unbreakable plastics for the glazing. If vandalism is a particular problem in your neighborhood, you may want to place your greenhouse on a rooftop, porch, or some other out-of-the-way place. If the vandals are young children, consider getting the local kids to help build and/or operate the greenhouse. Their participation can help eliminate the cause of vandalism.

Bob Corbett's greenhouse in Butte, Montana uses the solid concrete walls of a 75-year-old ore bin for thermal mass. The large mining structure provides a unique location for an attached solar greenhouse.



Chapter 4:
SIZE AND SHAPE

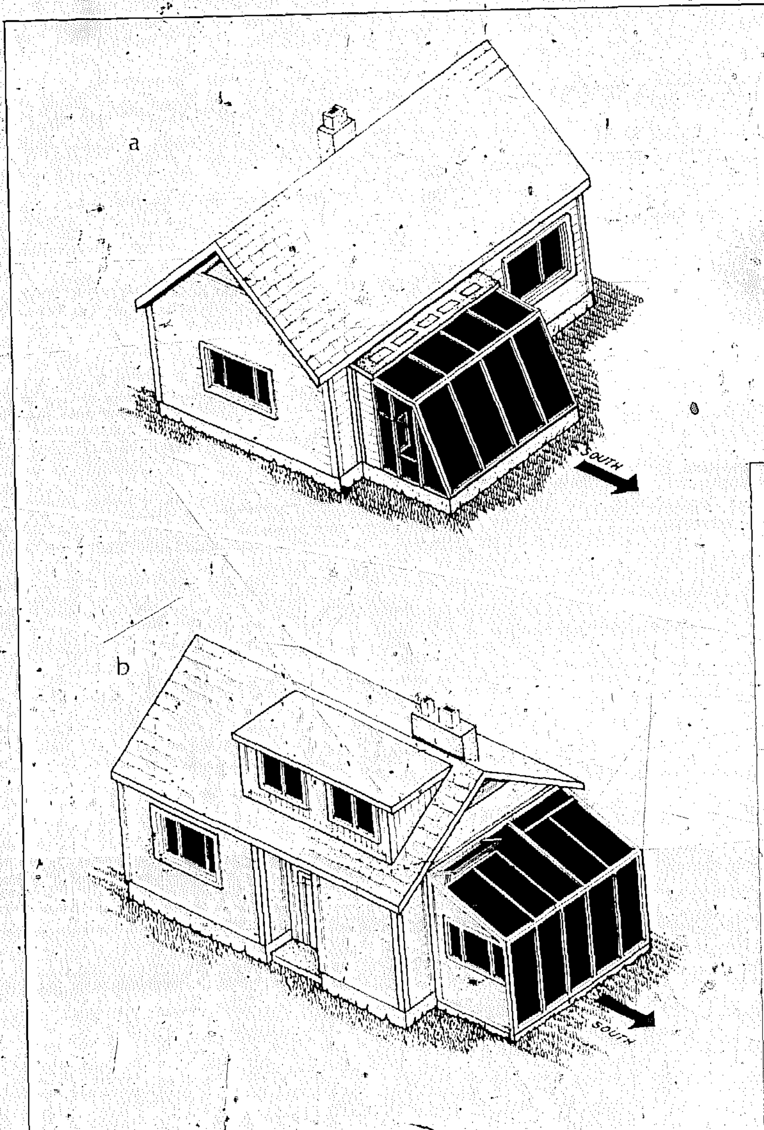
A solar greenhouse's performance depends upon the integration of all design factors. While location is probably the most important factor contributing to its overall efficiency, the type, size and shape of a greenhouse determine how well it suits your needs. All factors must complement all others. Your initial decision on location is related directly to your choice on what *type* greenhouse to build. Your decisions on location and type will affect the size and shape of your greenhouse. All factors depend upon your available space, resources, and intended use.

TYPE

There are several "types" of greenhouses, including attached, freestanding, rooftop, and pit greenhouses. Each type has its advantages and disadvantages. Often, it is more economical to build an attached greenhouse (Figure 4.1 and 4.2) rather than a freestanding structure. Add-on greenhouses are cheaper to construct, can provide heat (and insulation), and generally are a better return for moderate investments in time, energy and money since heat and food savings are combined.

Attached greenhouses are cheaper because there is no north wall to construct, and many times, the vents and access openings—windows and house doors—are already in place. Also, excess heat and humid air collected in the greenhouse can be vented to the interior living space. Meanwhile, there is less heat loss from the adjacent living space due to the greenhouse's insulating effect, and lower heating costs for the greenhouse since its north wall is already heated and insulated. Another advantage of an attached greenhouse is the easy and direct access from the house, which encourages greater winter use. Direct access from the warm house instead of an outside door also protects plants from shock caused by exposure to cold winter air.

On the other hand, in instances where an attached greenhouse is not feasible, a freestanding greenhouse is an excellent option. You may want a larger greenhouse than can be accommodated on the south wall of your house, or there may exist some legal issues (fire or building codes) that re-



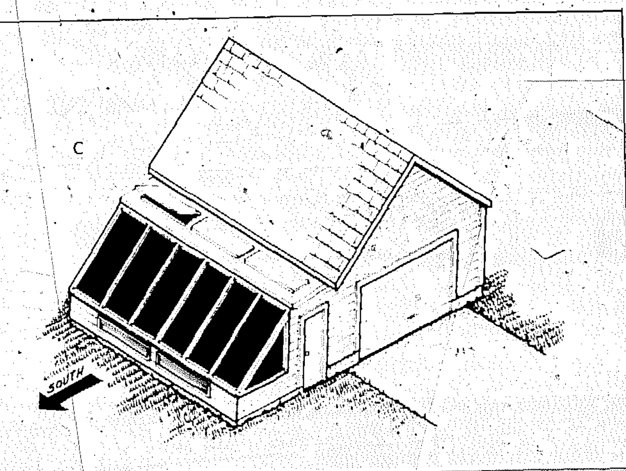


FIGURE 4.1 Three examples of attached greenhouses

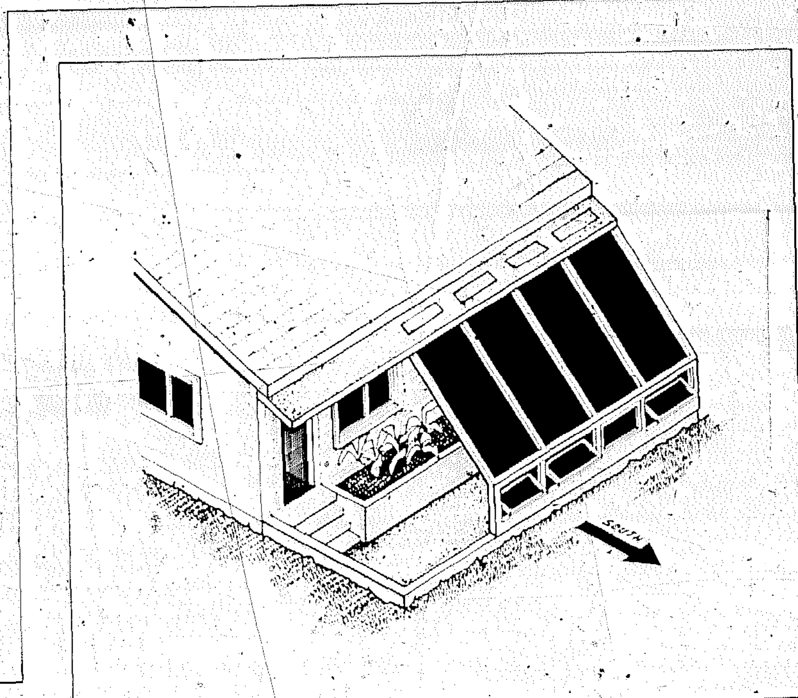


FIGURE 4.2 Attached "pit" greenhouse

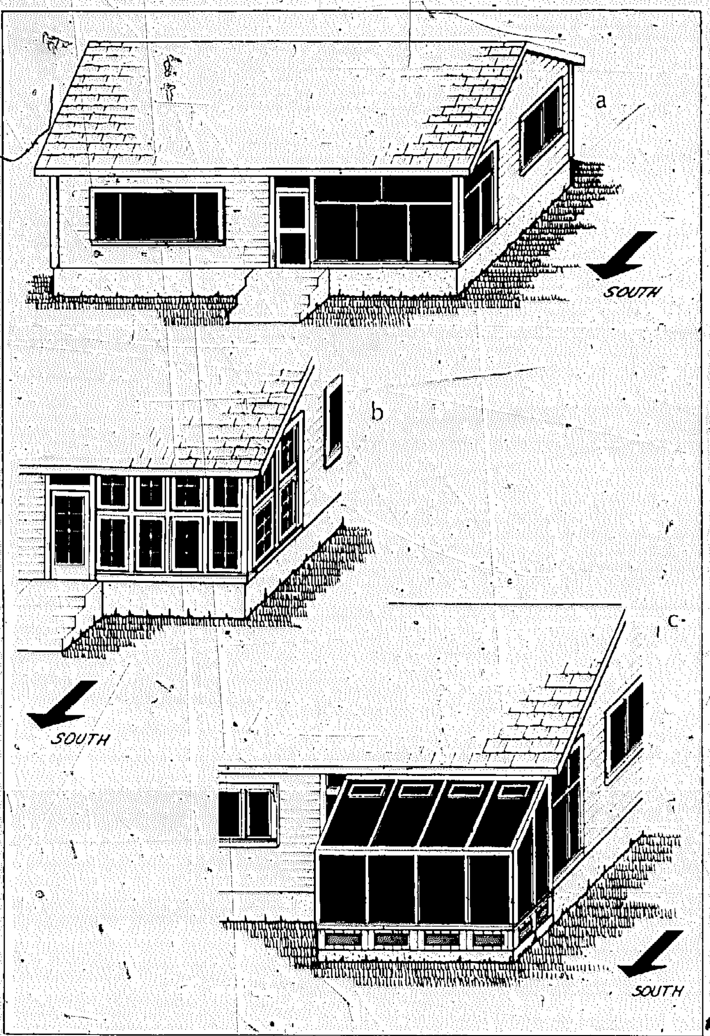


FIGURE 4.3 Three examples of a south-facing porch converted to a greenhouse: a.) using plastic glazing panels, b.) using recycled windows, c.) greenhouse extended from porch

quire separate structures. Whatever the reason, be it aesthetic, architectural, practical, or just plain personal, a freestanding greenhouse can be built to function efficiently.

An attached or freestanding solar greenhouse can be partially sunk into the ground in the manner of a "pit" greenhouse to take advantage of the insulation effect of soil (Figure 4.2); or it can be built down a south-facing slope in order to capitalize on the improved micro-climate effects and better exposure of the soil or floor area to the winter sun. South-facing porches also can be converted into solar greenhouse space (Figure 4.3).

If none of these options are available to you, a solar greenhouse could be built on flat roof areas, provided that the roof structure will support the extra load of the greenhouses, soil and people (Figure 4.4).

SHAPE

Determining the right **shape** of a solar greenhouse, initially, will necessitate your most-critical design decisions. Primary functions of a solar greenhouse are to capture heat; to provide a warm, protected environment for plant life; and to allow sufficient penetration of light energy to stimulate plant growth. But, often, these considerations come into conflict when designing greenhouses, especially in severe winter climates.

The amount of light, and thus heat, available from bright, direct sunlight is about 10 times that available from an overcast sky—so it makes sense to design for maximum direct sunlight in areas where there are a significant number of clear winter days and thus direct winter sun. But glazing oriented only for direct sun often does not admit enough total sunlight for photosynthesis on overcast days, or in the early hours of early summer days. Clearly the shape of a greenhouse plays a major role in balancing heat collection and light penetration. In addition, shape is a consideration in a number of other respects—available space, aesthetics, planting and working area needs, etc.

We'll go through some of the major considerations one by one, and then describe some approaches to solve the problems presented. Most of the comments relate directly to a food-producing solar greenhouse, because the main thrust of this manual is geared toward such uses. Some of the information presented, though, applies to structures used primarily as heat producers. Here, again, the important thing is to determine how you intend to use the greenhouse before you design it.

Radiation penetration for optimum heat collection. The winter sun is low in the sky, so its radiation must travel through more of the earth's atmosphere to reach an object on the ground than does radiation in the summer, when the sun is more directly overhead. Thus, the strength of the sun's rays is reduced in winter and radiation intensity at the earth's surface is relatively weak. To capture these weaker rays effectively, the greenhouse glazing must be installed at an angle nearly perpendicular to the sun's rays during the coldest months of the year, especially if you are planning to utilize the greenhouse during the winter. A perpendicular angle will allow maximum solar radiation to pass through the glazing without being reflected off.

Of course, the sun travels across the winter sky during the day from southeast to southwest, so the fixed glazing will not always be "nearly" perpendicular" to the sun's rays. We also know that maximum solar intensity usually occurs at solar noon, when the sun is highest in the sky and directly to the south. Further, the sun's highest position in the sky changes daily, decreasing to its lowest on December 21st and rising to its highest on June 21st. With all these variables you may well ask what the best angle of the south-facing glazing should be for maximum heat collection.

Experimental observation has shown, generally, that for optimum radiation penetration throughout most of the winter heating period, *the angle of the glazing should be the site latitude plus 10 to 15 degrees.* For example, if you live at 40° north latitude, and you plan to use the greenhouse during the winter, the south-facing glazing should be sloped somewhere between 50 and 55° from the horizontal. If the greenhouse is *not* going to be used in winter, the angle can be 5° to 10° less, or 45° to 50° in the example.

However, that angle, latitude plus 10 to 15 degrees (for

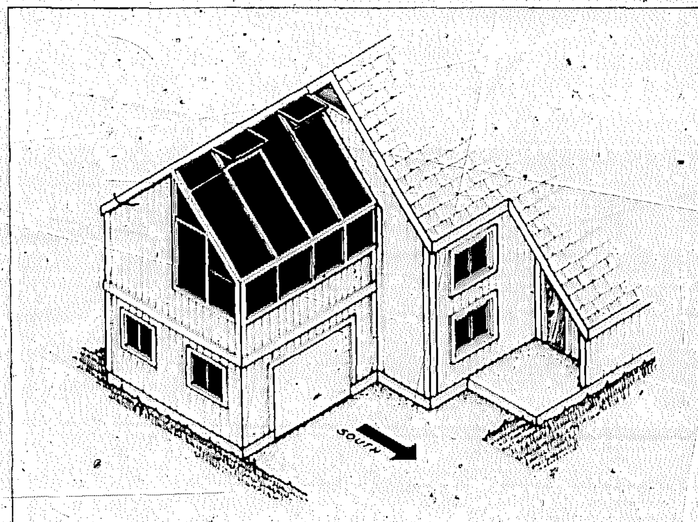


FIGURE 4.4 Rooftop greenhouse

year-round operation), is not absolute. The formula works well for areas receiving a high proportion of diffuse radiation to total radiation—that is, cloudy areas such as the New England states and the Pacific Northwest. But your climate and weather conditions may indicate a more favorable angle. Areas which receive a high proportion of very clear winter days should *increase* the slope by 5 to 10 degrees (latitude plus 15 to 25°). For many regions in the U.S., particularly northern locations above 45° latitude and sites with open snow-cover to the south, glazing slope can go up to vertical (that is, 90° from horizontal). Snow tends to reflect the sun's rays onto the glazing and, if the glazing is mounted vertically, a good part of the reflected radiation can enter the greenhouse, adding both extra light and extra heat to the interior. Inclined glazing surfaces less than 90° would tend to deflect more of this snow-reflected radiation off into the sky. (Check Chapter 7 for more glazing details.)

Radiation penetration for optimum light levels.

Many of the considerations mentioned for heat collection also apply to light entry into the greenhouse, because it is light radiation which strikes interior surfaces and is converted to heat. However, while heat generation is a major consideration during the colder months, optimum light penetration is a consideration year-round to promote the photosynthesis necessary for good plant growth. In fact, light (rather than heat) is often the limiting factor for greenhouse plant growth, particularly in areas with cloudy winters.

The sun is higher in the sky during late spring and summer. Thus, a steeply sloping, south-glazed surface designed to accommodate the low winter sun may not permit adequate light penetration to the back of the greenhouse during late spring and summer, or during overcast periods when diffuse light comes fairly uniformly from the whole sky. On the other hand, if the south glazing were mounted less steeply, say around 25 to 40 degrees from horizontal, the summer sun could reach back into the greenhouse quite some distance before shading occured, and entry of diffuse light would be adequate. But this angle would be at odds with direct winter sunlight and accompanying light and heat needs.

A compromise design.

One solution to this dilemma, for greenhouses designed for heat *and* food production, is to build a structure with two sloping south-glazed surfaces. The lower section, called a "kneewall," should be a steep-angle or vertical glazed wall (say, a 60° to 90° slope); the upper section, also glazed and sloping to the south, would be at a less steep angle (say, 20° to 45° from the horizontal). This less steep, upper glazed section would still permit snow to slide off (with help if the angle is below 30°) and allow better penetration of both diffuse radiation on cloudy days and direct summer sun. The steeper, lower glazed section would allow good entry of direct and snow-reflected winter sunlight. (If you do not plan to grow anything in the rear of your greenhouse in winter, and you live in an area with much direct winter sun (many clear days), you may choose to insulate the shallow angled, upper glazed section for the entire winter, removing the insulation for spring, summer and fall operation.)

Both single- and double-sloping attached solar greenhouses have their advantages and disadvantages. To provide good head room throughout a single-sloping structure, the greenhouse is going to have to be quite tall. But it is generally a simpler structure to build and lends itself to growing crops directly in the ground. The double-sloping attached solar greenhouse can provide adequate head-room for working in raised beds at the front of the greenhouse. Also, in heavy snow areas, the less-steep roof section must be strong enough to support the expected snow load—if the slope is less than 30° the snow may not slide off by itself (see Chapter 6, glazing support and roof construction sections).

East and West Glazing. Another way to increase light penetration for photosynthesis is to glaze the southern half of the east and west end walls, above the level of the planting beds. The entry of increased morning and afternoon light for photosynthesis will support better plant growth. Direct morning sunlight is particularly beneficial to plants for both light and warmth. If the greenhouse is oriented southeast, glaze a large portion of the southwest-facing end wall; if it is oriented southwest, glaze most of the southeast wall.

Solid Portions of the South Roof. If you are building an attached greenhouse in a climate with long, hot summers, you should insulate a portion of the south-sloping roof to protect the main house from overheating in summer (unless you intend to remove the glazing from the greenhouse in the summer; see Chapter 7, double-glazed plastic panels). The solid portion should be wide enough to shade the main house wall during the mid-portion of the day. For small (less than 10 feet in the north-south dimension) attached greenhouses with fairly shallow roof pitches, the insulated section will be about half of the roof, or three to-four feet horizontally out from the house.

In Figure 4.5 are some possible shapes for attached greenhouses. The examples are by no means an inventory of all possible schemes, but rather a guide to a few sensible choices.

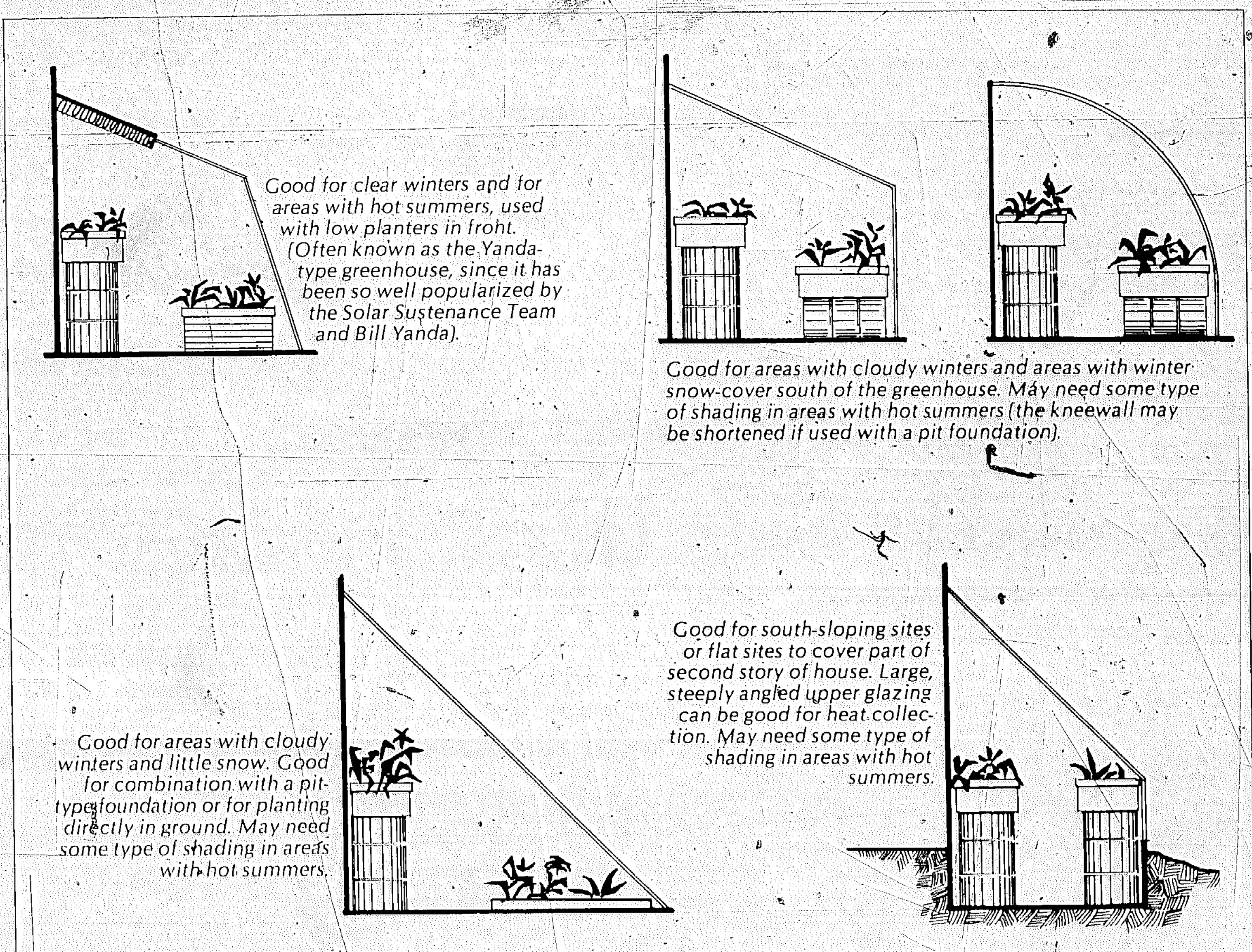
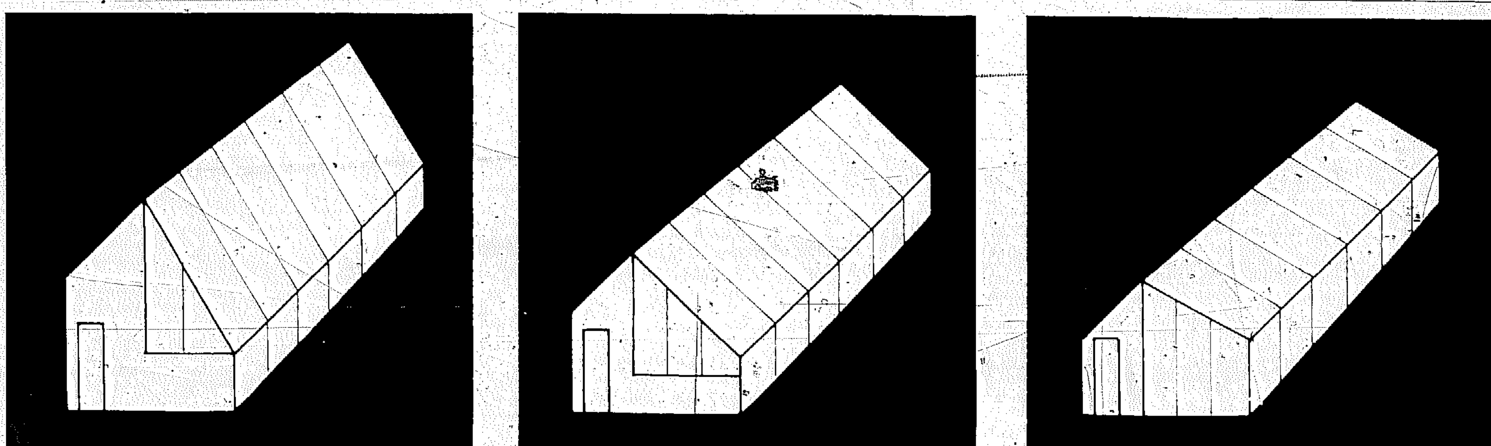


FIGURE 4.5 Possible shapes for attached greenhouses

The possible shapes for freestanding greenhouses are many. A few of the many possibilities for different climate regions are sketched in Figure 4.6 to give you an idea of approaches to designing according to climate.

FIGURE 4.6 Possible shapes for freestanding greenhouses



For cold winters, northern latitudes, and year-round use:

- *steep north roof pitched to the highest summer sun angle for maximum year-round light reflection onto plants;*
- *vertical north wall for stacking heat storage;*
- *40-60° sloped south roof glazing;*
- *vertical kneewall high enough to accommodate planting beds and snow sliding off roof;*
- *end walls partially glazed for added light.*
- *The Brace Institute design continues the north roof slope down to the ground (eliminating the north wall), allowing for more planting area in ground, but no heat storage against the north wall.*

For cold winters, middle U.S. latitutdes, and year-round use—(similar to the design popularized by Domestic Technology Institute—see resource list for plans and address):

- *45-60° north roof slope;*
- *vertical north wall for stacking heat storage;*
- *45° south roof glazing;*
- *vertical kneewall;*
- *part of end walls glazed for additional light.*

For milder winters, southern U.S. latitudes, and year-round use where less heat storage is needed:

- *45-70° north roof slope—roof slope steeper and north wall shorter if less space is needed for stacking heat storage;*
- *roof can extend down to ground, eliminating back kneewall if no storage is used;*
- *20-40° south roof glazing;*
- *front kneewall as high as is needed for access to beds in front;*
- *most of end walls glazed for additional light.*

Axis of orientation. A greenhouse, in general, should have its major length axis running in an east-west direction instead of north-south. At first glance, reasons may not be so obvious, but consider the following facts. In the northern hemisphere, both direct and diffuse light radiation come, predominantly, from the south, particularly in the winter. Large southern exposures tend to capture more of this radiation with less reflection losses than large east and west exposures. Any exposure from southeast to southwest is adequate (see the site survey section). A conventional greenhouse with the length axis north-south will allow for a more uniform distribution of light on the plant canopy than will a similar structure with the major axis east-west. However, an energy-conserving greenhouse must minimize glazing, especially to the north. The effects of poor light distribution are reduced by reflecting a considerable amount of light radiation off the interior of the north wall and back onto the greenhouse plants. Thus, an east-west axis of orientation is adequate.

SIZE

The optimum size of a solar greenhouse depends greatly on how it is to be used. As a solarium, the structure needs only to be big enough for the number of people who want to use it comfortably. As a heat producer, the size will depend on how much heat you would like to produce. Generally, for an insulated house in a moderate to cold climate, the area of south glazing on the greenhouse must approach 20 percent of the floor area of the main house in order for the solar heat to have a noticeable effect on heating fuel consumption.

Some general guidelines to help size a greenhouse for food production are as follows: A greenhouse can reasonably be expected to provide salad greens and some cooking vegetables during spring and late fall. During spring, summer and early fall, tomatoes and cucumbers can be grown in the greenhouse as well (if your outdoor climate is not warm enough to grow these in the garden). During the dead of winter in northern climates, greenhouse plants will not grow much due to short days. Yields during this period—if you operate the greenhouse at all—will be much lower than for other seasons, unless supplemental lighting is used.

About 40 sq. ft. of greenhouse growing area can produce most of one person's vegetable needs, given a reasonable level of skill at growing. Of course, at certain times there will be more food than can be eaten, and at other times, not enough. Also, growing skills and techniques vary greatly. Generally, though 40 sq. ft. per person is a good starting point when sizing your greenhouse for food production. However, about a third of the greenhouse floor area is generally taken up with walkways and heat storage, thus, 60 sq. ft. of greenhouse area is required per person for producing the necessary vegetables. A greenhouse used for *supplementing* vegetable supplies could be considerably smaller, about half this area, or 30 sq. ft. of greenhouse area per person. A reasonable size for a family of four in this latter case would be a total greenhouse area of 120 sq. ft., (about 80 sq. ft. of growing area). This could be an 8' × 15' or 10' × 12' attached greenhouse; a practical minimum size is 8' × 12'.

For freestanding greenhouses, though, it is generally not practical to build smaller than 10' × 18'. For anything smaller, the costs of construction are generally very high for the limited growing area obtained. In addition, the relatively large surface areas through which heat loss can occur make operating expenses high per square foot of growing area, unless the greenhouse shell is quite tight and well-insulated.

Planting and working space. Obtaining the maximum amount of planting space at the least cost is the prime consideration here. First, you have to decide whether you want to plant in raised beds or at floor level. Raised beds offer certain advantages—less stooping to work on the plants and more heat-storage volume (either in the soil of a deep bed, or in underbed storage volumes). However, both the south glazing and north insulated wall have to be sloped appropriately to accommodate raised beds and to minimize wasted interior floor space. A vertical kneewall on the south side can help. In addition, the cost of constructing and maintaining elevated beds is significantly greater than building floor-level beds.

On the other hand, planting in soil at or near floor level allows for better use of the floor area. Planting at a lower level enables plants to grow taller throughout the greenhouse and allows growers to work in wider beds from the same pathway (since you can walk between plants). The disadvantages of floor-level beds are that the soil can be used only minimally for heat storage; any cold air will settle automatically at the plant level; and, insulation will be necessary along the foundation walls at least to the depth of the planting beds. Although the extra insulation will keep the growing space warmer, it does increase costs.

If floor-level beds are used, then the glazed south wall can begin its slope at the foundation, assuming snow pile-up is not a consideration. Likewise, the insulated north wall in a free-standing structure can begin its slope at the foundation. Such optimal slopes allow the maximum amount of solar radiation to enter the greenhouse, and reflect off the back wall onto the plant canopy. But steep, single-sloped walls or roof sections can lead to excessively tall greenhouses and the associated problems of heat accumulation near the peak. This area is substantially glazed and subject to greater heat loss.

So, in practice, a kneewall is often used to give the plants room; to provide some heat storage volume; to permit the operator some head room in which to work; and, where necessary in snowy regions, to allow a place for snow to accumulate when it slides off the roof. Similarly, the back or north wall is usually vertical (almost invariably so in an attached greenhouse) for the first few feet and then sloped toward the south (in a freestanding structure) at some optimal angle for light reflection purposes. The use of elevated planter beds will increase the necessary height of the vertical kneewalls on both north and south sides.

Floor Plan.

There is a minimum useful width for a greenhouse. This width usually relates to the growing area relative to the total floor area of the greenhouse. For family-sized greenhouses in many parts of the country, the main growing areas should occupy 60 to 75 percent of the floor area. The remainder will be occupied by a walkway and some storage. (The minimum useful width of a walkway is about 20"). An eight-foot span allows a 3-ft.-wide planting area (about as far as an average person can reach) in the front, a 2-ft. aisle in the middle and a 3-ft.-wide bed in the rear. Thus, the minimum useful width of a solar greenhouse is about eight feet. A 12-ft. length thus would allow 72 sq. ft. of growing area (two 3'×12' beds)—a good ratio of growing area to total floor area.

$$\frac{72 \text{ sq. ft.}}{96 \text{ sq. ft.}} = 75\%$$

If you build much smaller than 12 ft. in the east-west dimension, there would be too much structural surface area (subject to heat loss) compared to the floor area inside. A greenhouse can be elongated in the east-west direction a far as your site and food-production needs dictate. Bill and Susan Yanda's book, **The Food and Heat Producing Solar Greenhouse**, for the Southwest U.S., and Ecotope's **Solar Greenhouse Guide for the Northwest** are useful references on outlining floor plans for small attached greenhouses (see Bibliography).

If the north-south dimension is increased to 10-12', as in a larger attached or freestanding greenhouse, the growing bed configuration would have to be changed to allow access to all parts of the beds. Also, a floor plan should take advantage of the existing building in every way possible. Examples presented in Figure 4.7 give you some ideas on how to design your floor plan.

North Wall Slope.

On an attached greenhouse, the north wall is of very little concern, since it will likely be the vertical south wall of an existing building. If the building is unheated, ensure that this vertical wall is well-insulated, and then cover it with white paint or other reflective surface.

In a freestanding greenhouse, the north wall should be properly sloped to allow sunlight to reach the back of the

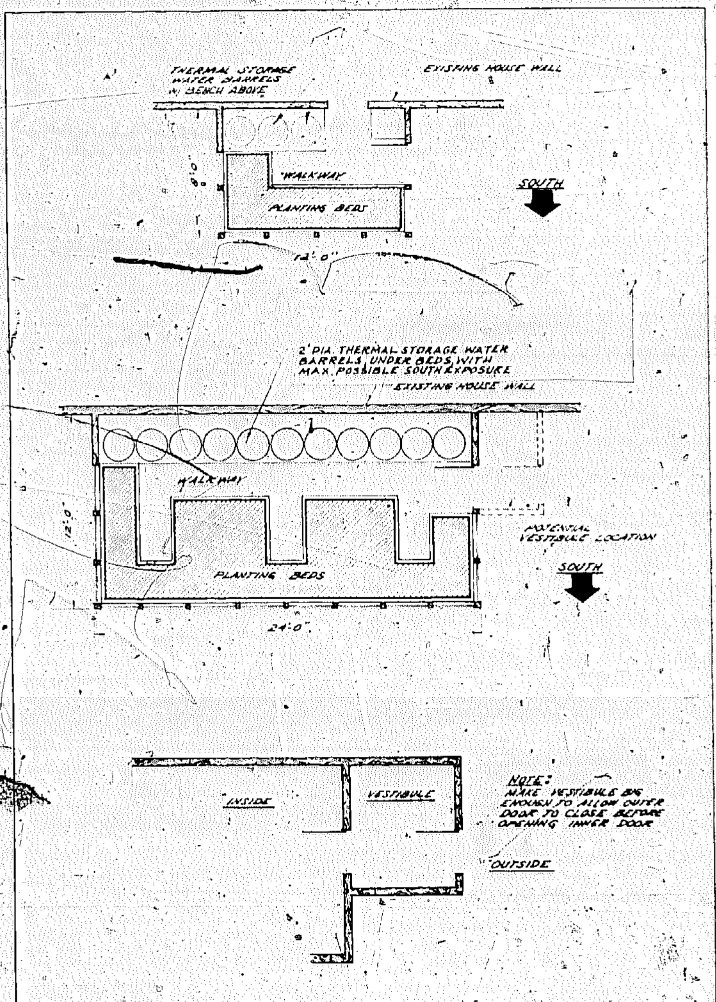


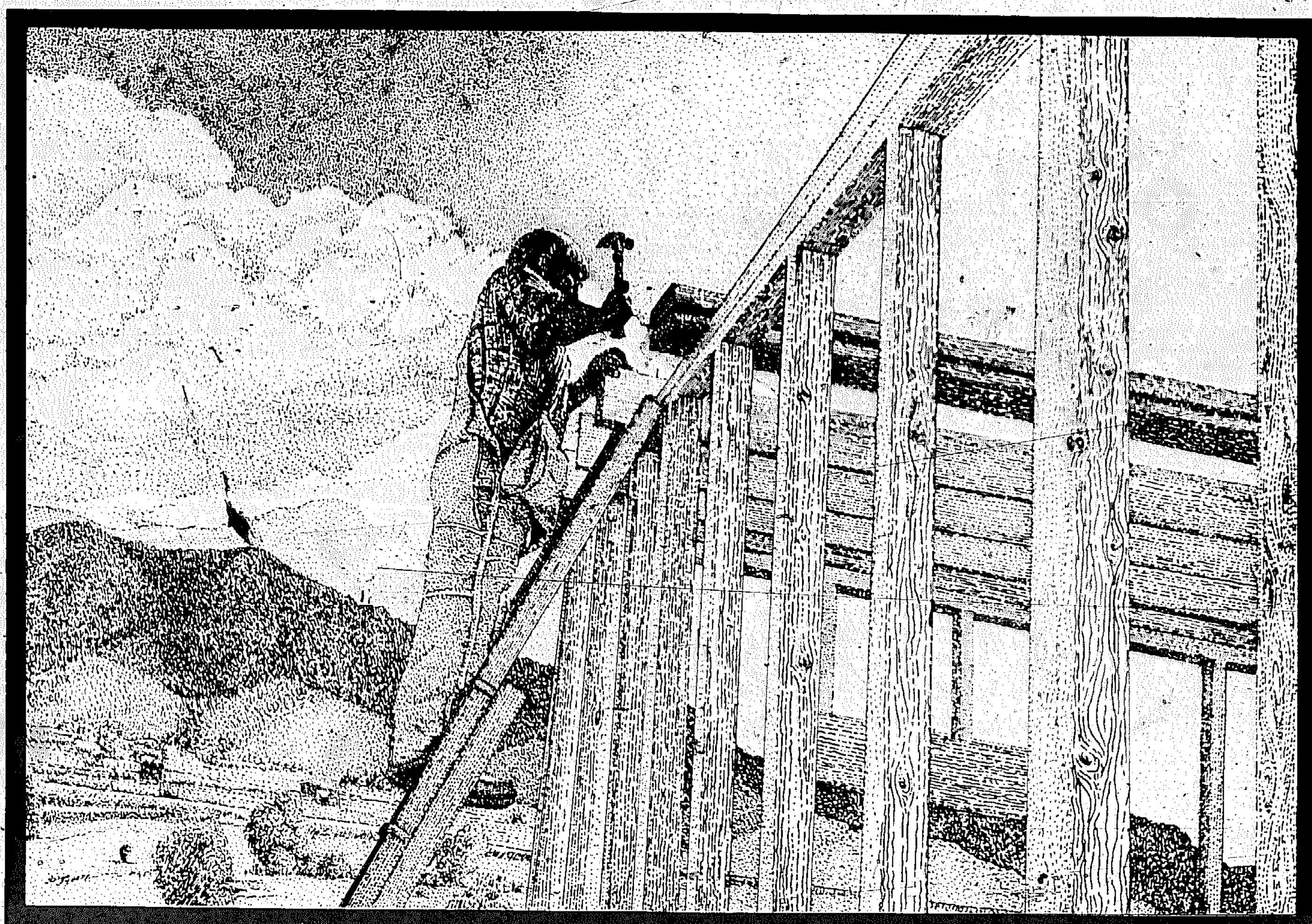
FIGURE 4.7 Three floor plan designs

greenhouse during winter and summer. That is, very little or no shading should occur on June 21 at the rear of the planter beds. (If you are worried about overheating problems in the summer and would like to provide some shading, then consider some of the temporary shading systems outlined in Chapter 8, ventilation and cooling.)

The proper slope of the north roof section is the angle of maximum solar elevation at your site latitude on June 21. That angle is calculated by taking the complement of your site latitude and adding 23°. (The complement of your latitude is 90° minus latitude.) For example, if your site latitude is 40°, the complement (90° minus 40°) is 50°. The optimum north roof slope therefore, is 50° plus 23°, or 73°. In practice, this slope can vary plus or minus 8° with little effect on greenhouse performance. Be sure to paint the inside of the north wall white or some other reflective color so that solar radiation striking it will be reflected down onto the north side of the plant canopy.

Architectural and Aesthetic Considerations.

The aesthetics of our environment are important, and a solar greenhouse should fit into its surroundings. If you are considering an attached greenhouse, it should related in some pleasing way to the existing building. Major achitectural features—such as lines, shapes, sizes, etc.—of the existing building will have to be considered in the final shape and size of your attached greenhouse. Use siding, paint and roofing which match the house on the solid portions of the greenhouse to help integrate the two structures. Freestanding greenhouses offer more latitude in shape considerations, but again, some effort should be made to harmonize the structure with its surroundings.



Part III

COMPONENT CONSTRUCTION GUIDE

Part I of this **Guide** was written to help you decide whether a solar greenhouse would satisfy your needs and whether you would make the necessary commitment to use it. Part II should help you determine where to locate the greenhouse and what type, size and shape would suit your needs best. Here in Part III, the purpose is to provide specific information to help you construct a greenhouse properly.

Included are design details for each component part of the greenhouse—from the foundation to the glazing. The goal is to help you build a relatively low-cost, durable, maintainable solar greenhouse. Design details can make the difference between success and failure. Water leaks, heat leaks, rotting, overheating and excessive maintenance are common problems resulting from poor construction—problems the information in this section should help you avoid.

Important differences between solar greenhouse construction and conventional construction techniques are reviewed and outlined. If you are unfamiliar with conventional construction techniques, please refer to one of the many good general construction texts available at your local library and/or seek advice from a local builder.

Chapter Five:

FOUNDATIONS

Generally, greenhouses are fairly light-weight buildings, and the primary functions of their foundations are to prevent the structure from sinking or shifting in the ground, and to hold it down so that the wind doesn't move it or blow it over.

The greenhouse builder must decide whether to use a continuous foundation or a post foundation. Each requires a different type of framing above the foundation and each is suitable for varying conditions. Traditional house building/framing techniques are used with continuous foundations: Each stud bears on the foundation and most of the roof's weight bears on the walls. Lighter framing techniques are used with post foundations: The framing is "hung" on or between the posts and the weight of the wall and roof is transferred to the posts by beams.

Owner/builders more frequently use continuous foundations (rather than the post system) because standard carpentry practices can be used. The post and beam system, however, has the advantage of allowing lighter, thinner framing—therefore, allowing more light to enter the greenhouse. Many commercial greenhouses, old and new, use this lighter post and beam construction. If the main purpose of your greenhouse is plant production, you should seriously consider this construction technique. In some localities, however, building codes may determine your foundation choice: Some city codes *require* continuous foundations of a minimum depth.

In this chapter, four foundations (with variations) are presented. The important details and uses for each are outlined. Actual costs are not specific because foundation materials costs vary widely from place to place. Instead, some general cost considerations are included. Also, the details of laying out foundations, building forms and pouring concrete are not discussed, except where the suggested designs differ from normal construction. Many people have basic foundation construction skills and there should be someone in your area who can help. In addition, a reference on the subject and these skills—Ecotope's **A Solar Greenhouse Guide for the Northwest** has a good step-by-step explanation—is cited in the Resource List (Part IV).

A level, squared foundation will make it much easier to build the greenhouse. Allow plenty of time to build the foundation. This kind of work always seems to take longer than is planned.

INSULATING FOUNDATIONS

In order to cut heat loss through the foundation walls and the earth, insulation is required, especially if you intend to plant crops directly in the ground (as opposed to using raised beds).

Solid wall foundations can be insulated on the outside or the inside. Neither procedure is significantly more difficult than the other. Outside insulation must be protected from exposure to sun, rain and physical abuse, while inside insulation also must be protected from physical abuse as well as from condensation running down behind it. Unless you live in an extremely rainy climate, the inside of the greenhouse will be wet (with condensation) more often than the outside (from rain and snow). One advantage of outside insulation is that the thermal mass of concrete or concrete block foundation can be used to store heat, even though the foundation mass is generally a relatively small portion of the total mass available for heat storage. Though outside insulation is illustrated throughout most of this chapter, either method is acceptable.

Moisture-resistant foamed styrene is a good underground insulation material. ("Styrofoam," the brand name for Dow Chemical's foamed styrene, is a common term and will be used here.) Be sure the material you buy is suitable for underground use. Moisture-resistant Styrofoam usually is blue in color—white "bead-board" foamed styrene will absorb a small amount of moisture and is not recommended as foundation insulation.

The amount of insulation to use varies with the climate. In cold climates where the ground freezes, two inches of Styroform about two feet deep in the ground is a reasonable balance between cost and benefit. Some builders, particularly in the northern U.S., elect to insulate the foundation down to the frost line. In areas where the air temperature goes below freezing but the ground freezes seldom or not at all, one inch of Styrofoam about one foot deep is sufficient. In areas where the air temperature rarely goes below freezing, insulating the foundation is probably not worth the trouble and expense. There also is some debate whether insulation under the greenhouse floor is necessary. Although it cuts heat loss by a small percentage, there is quite a bit of work involved. For low-cost greenhouses, insulation under the floor is not recommended.

When installing Styrofoam, remember that it is not a structural material. Backfill around it gently and avoid large rocks. When installing it between posts, be particuarly careful to backfill evenly—alternating from one side to the other. Above ground, support the Styrofoam with treated wood, old bricks or some other solid material to protect it from damage. It is generally easier to insulate the foundation before framing the greenhouse, so that you have earth to stand on instead of a dug-away trench.

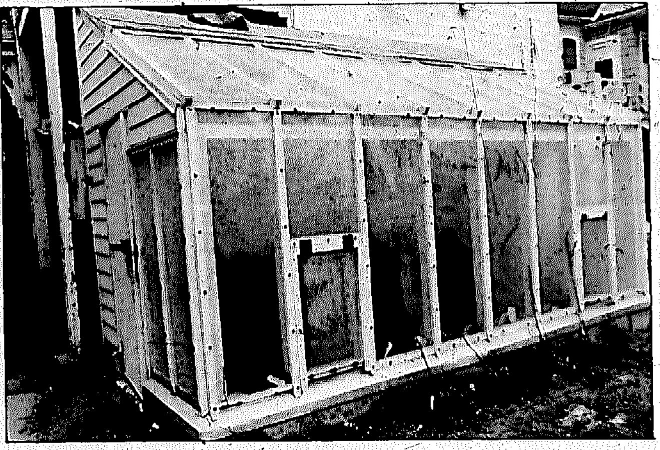
The insulation should extend high enough to cover the sill of the foundation to avoid exposing the foundation to the cold. (The top of the insulation can be beveled [See Figure 5.1A], or a beveled strip of wood can be used on top of the Styrofoam and under the flashing). To cut a clean bevel on the insulation directly, set the blade of a circular saw at the proper angle and push the saw along a straight board clamped onto the Styrofoam.

FLASHING: PROTECTING THE EDGES

The foundation should be built to extend 6" above ground level to keep the wood structure away from moist earth (and all the rot-producing organisms therein). Use pressure-treated wood for the framing sills or treat them with a copper-based preservative such as Cuprinol or copper arsenate to minimize problems.

Where the siding or glazing materials don't overlap the foundation, and where exterior insulation is used, flashing is needed to protect the insulation from moisture. Aluminum

Carefully bent aluminum flashing around corners helps protect the foundation insulation.



Notice how the flashing stops just below the sill and a non-corroding material extends below the soil line.

flashing is quite easy to work with—even fairly complex angles are easy to bend using the method outlined (see box). However, for larger structures where a lot of flashing is needed, you may want to have a sheet-metal shop do the work for you—it is more expensive but saves time and offers a cleaner finished appearance.

When joining flashing pieces to form a larger selection, or at corners, use caulk to seal the joints. If two pieces don't overlap uniformly, a pop-rivet or sheetmetal screw with a dab of caulk will hold one to the other. The flashing should be nailed to the bottom plate of the wall or glazing framing, before glazing or sheathing is attached.

Flashing must extend from the sill to the ground to protect the insulation. In the illustrations that follow (throughout the **Guide**), flashing is extended vertically *into* the ground. While this method may be the easiest way to protect insulation, it subjects the metal flashing to corrosion from the soil. One alternative is to terminate the flashing with a drip edge at the soil line. Another alternative is to terminate the flashing in a drip edge about three inches below the sill, and use a non-corroding material from the drip edge to the soil line.

The latter alternative is more appropriate if the vertical dimension between the soil line and the sill would involve a great amount of flashing. Cement-asbestos board is a non-corroding material, but it is expensive, potentially hazardous to handle, hard to cut, and requires predrilled nail holes. It can, however, survive burial in the ground. Other options include pressure-treated wood, stucco, trowel or brush coatings like Portland cement with liquid latex added, or some vinyl-acrylic coatings. The best bet may be rigid vinyl sheet, as supplied for mobile home skirting or in the form of vinyl siding. Far easier to work with than cement-asbestos board, vinyl sheet can be glued or nailed, and will survive below ground level. Check with mobile home suppliers or siding subcontractors for availability.

The important point to remember is that exterior insulation must somehow be protected from the sun, rodents and mechanical damage if it is to perform its function.

HOW TO BEND ALUMINUM FLASHING NEATLY

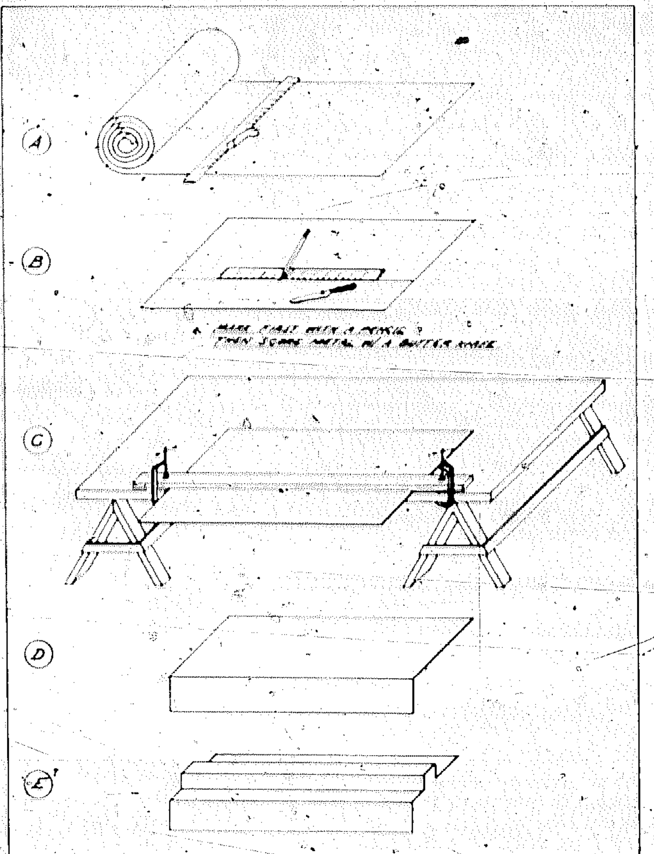
TOOLS YOU WILL NEED: pencil, straightedge, straight 2 × 4, C-clamps, table, utility knife

BENDING STEPS:

1. Rolls of flashing can be purchased in various widths. It should be available in the width you need. For example, in Figure 5.1A, there is eight inches of flashing below ground, six inches above ground, plus two and one-half inches needed at the slope of insulation and another two inches to tuck the flashing under the siding. Therefore, the width needed is 18½".
2. To cut for length, use a utility knife and straightedge (Figure A). Use an old blade (a new one will dull quickly) and watch those edges—cut aluminum edges are quite sharp! Generally, eight-foot lengths will bend fairly easily.
3. To bend:
   a) Mark the bend line with a straightedge (Figure B).
   b) Using a dull knife and the straightedge, score the flashing along the bend line.
   c) Clamp the flashing between a straight 2 × 4 and the edge of a sturdy table with C-clamps.
   d) Align the edge of the 2 × 4 and the bend line marked on the flashing with the edge of the table (Figure C); tighten the C-clamps at both ends of the 2 × 4.
   e) With a block of wood (about 12" long), push down on the aluminum near the middle; bend it a little at a time, switching from side to side. It may take three or four passes, back and forth, to make a 90° bend. With patience, though, a very neat, creased fold can be made (Figure D).

   With practice, complex bends (Figure E) also can be achieved with this method.

NOTE: Start with the pieces of flashing that won't show as much. Thin-gauge galvanized flashing also can be bent this way, but aluminum is much easier.



POURED CONCRETE FOOTING AND FOUNDATION WALL

A poured concrete footing and foundation wall is extremely strong and will support any type greenhouse. If durability and resale value are primary considerations for your greenhouse (or if building codes require) use this type of foundation. Reinforcing rod ("rebar") is recommended for soils where settling or frost-heaving is a consideration. A two-foot depth foundation, shown in the illustration (Figure 5.1A), is sufficient for most areas where the earth freezes. A one-foot depth is sufficient in freeze-free areas. The 5½" thickness accommodates a 2 × 6" sill to form a well-shaped structure. The footing is essential in unstable soils. In cases where the soil is particularly stable and local codes permit it, the footing can be omitted (Figure 5.1B). (**Concrete and Formwork**, referenced in the Bibliography, discusses site-built concrete forms, mixtures, etc.)

Construction: If the soil is stable enough to hold a neatly carved trench, the continuous foundation without a footing can be poured using the earth as the form (except, of course, above the surface of the earth). A narrow trenching shovel is very useful for digging a neat trench.

Insulation should be wired into position on the form or "pinned" into the earth with long nails before pouring the concrete. Be sure that the Styrofoam is secure so that it does not float in the liquid concrete. Also, make sure there are no unsupported areas of Styrofoam where the concrete could bulge and possibly break it. If wood forms are used, insulation can be applied after the concrete has set and dried.

Building the forms, installing reinforcing rods and positioning anchor bolts are not discussed here, as these steps are standard foundation practices.

A continuous foundation is the most expensive way to go. If you are experienced, though, you should be able to keep costs to a minimum. Every eighteen running feet of 2' deep, 5½" thick concrete foundation *with footing* will require one

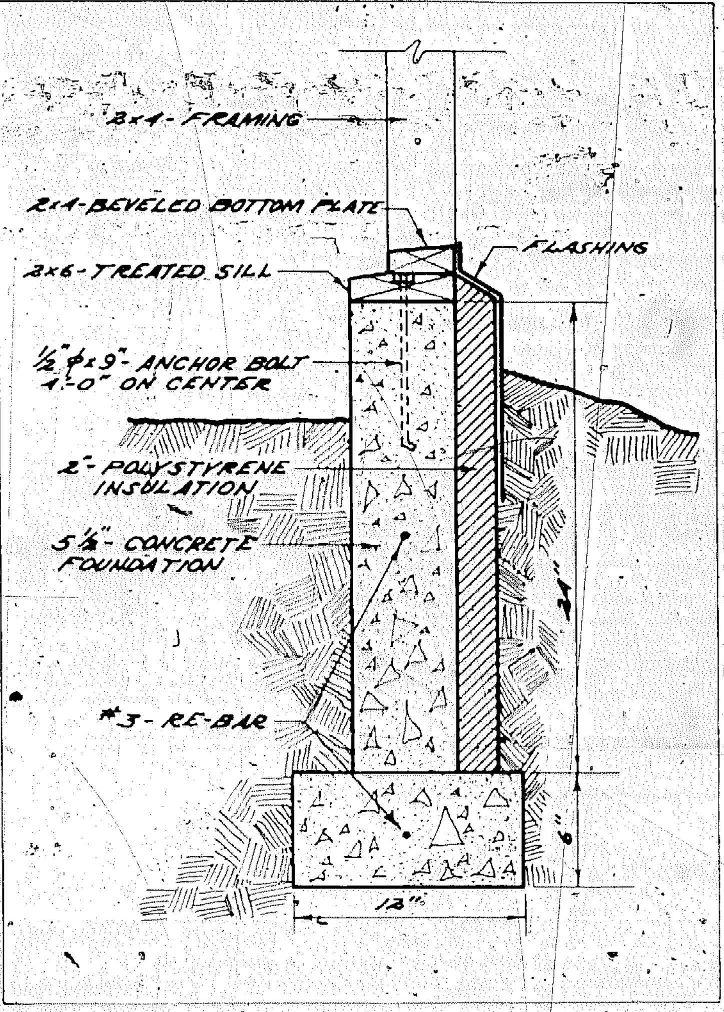


FIGURE 5.1A Poured concrete footing and foundation wall (shown with insulation on the outside)

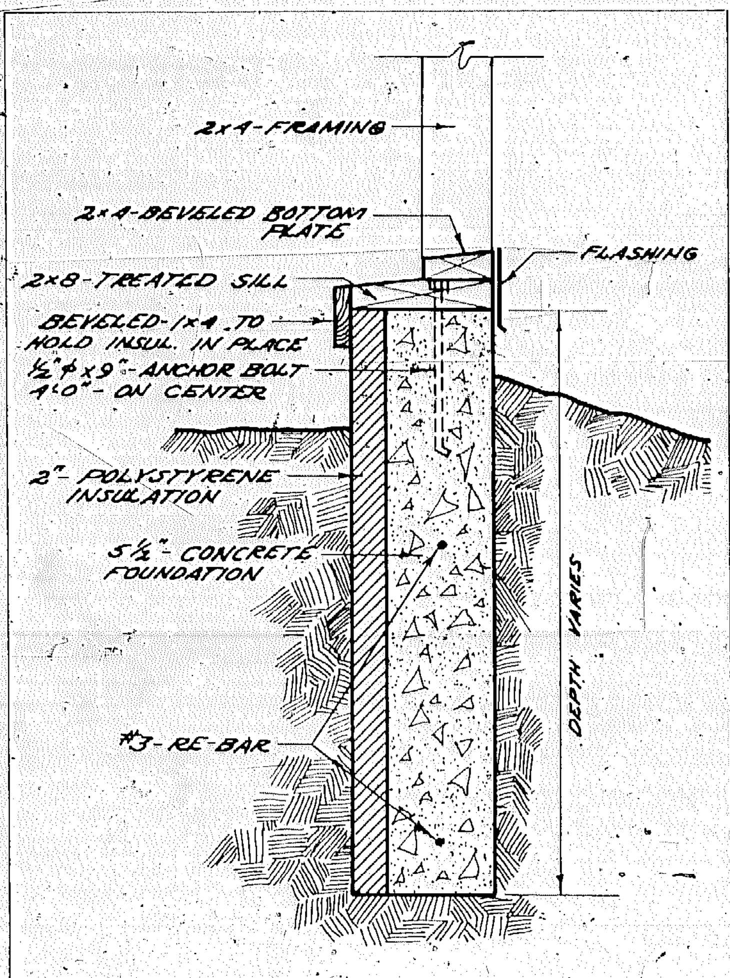


FIGURE 5.1B Concrete foundation wall without footing — for use in very stable soils (shown with insulation on the inside of the wall)

cubic yard of concrete. Every twenty-one feet of the foundation *without footing*, 5½" thick, 2' in the ground and 6" above ground, requires one cubic yard of concrete. Besides concrete and insulation, you also will need the rebar, wood for forms, anchor-bolts, and treated sills. Hiring a backhoe to dig the trench is another expense to consider unless you dig it yourself.

Recommendation: If a continuous foundation is needed for strength or to meet local building codes, use it. But, if you have little experience with concrete foundations and you want to cut costs, consider a different option.

POURED CONCRETE FOOTING AND CONCRETE OR CINDER BLOCK WALL FOUNDATION

The advantage of using concrete or cinder block (instead of poured concrete) for the foundation wall is lower cost for materials (although you should check local prices before deciding). Blocks are not as strong as poured concrete, but they are certainly strong enough to support a greenhouse if constructed properly.

Construction: The concrete footing can be poured directly into a trench in very stable soils, or can be poured in forms. The masonry skills required to build the block wall can be minimized by using surface-bonding cement (one trade name is Block Bond). After the first row of blocks is leveled onto the footing with mortar, the remaining blocks are leveled in place without mortar; then, the surface-bonding cement is troweled on both sides of the blocks. Follow the instructions that come with the material carefully: bonding cement is quite easy to use and quite strong. (See **Construction with Surface Bonding** in Bibliography and check your local building supply outlet.)

For additional support, a vertical core of blocks should be filled with concrete every four feet, and at the corners. As shown in Figure 5.2A, a rebar should be set vertically in the footing where each filled core will be. The rod should run to near the top of the filled core. Carefully plan your effort to set the bars in the wet concrete of the footing. Use anchor bolts in the filled cores to hold the sill down.

"Bond beam" blocks (Figure 5.2B) may be used for the top course of blocks on large greenhouses to add even more strength to the foundation. This type of block forms a trough into which concrete is poured, forming a beam. The added expense is worthwhile where extra strength is needed.

Recommendation: A block foundation wall is an excellent alternative to poured concrete. If a continuous foundation is needed for strength and blocks are cheaper than poured concrete in your area, use it. But, if you lack the masonry skills required, consider the following options.

POST FOUNDATIONS

Post foundations combine strength with low cost. They are not as strong as continuous concrete foundations, but nonetheless are adequate for windy areas and can be quite strong if constructed properly. One of the main considerations with post foundations is whether you are prepared to utilize post and beam construction. Traditional stud-wall framing, which is used with continuous foundations, is more familiar, but don't be intimated. Post and beam construction is not inherently more difficult, only different. (More on framing in Chapter 6.)

A variety of materials can be used as posts: small trees; 4 × 4" wood posts; galvanized metal pipes; treated posts; or other available materials. (Square posts are easier than round ones to build onto.)

A primary consideration is to protect wood posts from rotting. Wood posts (other than cedar) *MUST* be thoroughly treated with a preservative. Wood can last up to 50 years in the ground, if it is factory pressure-treated. Untreated or poorly treated wood may decay in five years or less, depending on

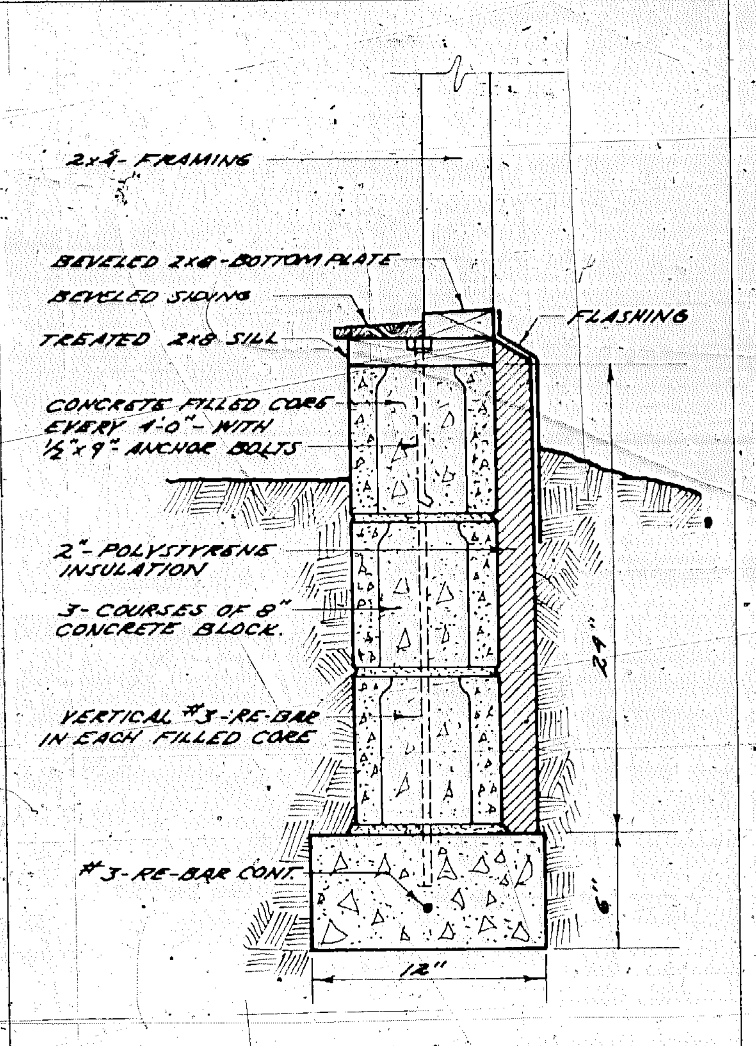


FIGURE 5.2A Concrete block foundation wall with concrete footing

the moisture content of the soil. Home treatment of wood is adequate if the preservative is applied properly. Use a copper-napthanate or other copper-based preservative which is non-toxic to plants. *Don't use creosote or pentachlorophenol:* These compounds are toxic to plants. Apply the preservative thoroughly and extensively to the part of the post that will be in the ground and within eight inches of the ground. Three or four coats are not too many. Follow all product instructions carefully. Be careful not to touch or breathe the fumes of the preservative. Where possible, cut the wood before preserving it to ensure a continuous treated surface and to avoid breathing poisoned sawdust. Remember, the preservatives work as well as they do because *they are poison.* If you opt for metal posts, they should be galvanized to prohibit rust.

Construction: Posts can be spaced one every four feet and embedded in two-foot-deep holes, or they can be spaced every eight feet and embedded in three-foot-deep holes. Eight-foot spacing is a practical maximum; wood posts spaced eight feet apart should be *at least four inches square (or six inches in diameter, if round).* In areas where frost-heaving is possible, posts should extend below the frost depth in the soil. Interior support posts (Figure 5.3) only need a concrete support pad about eight to ten inches square and about eight inches deep. Hopefully, the ground will not freeze inside the

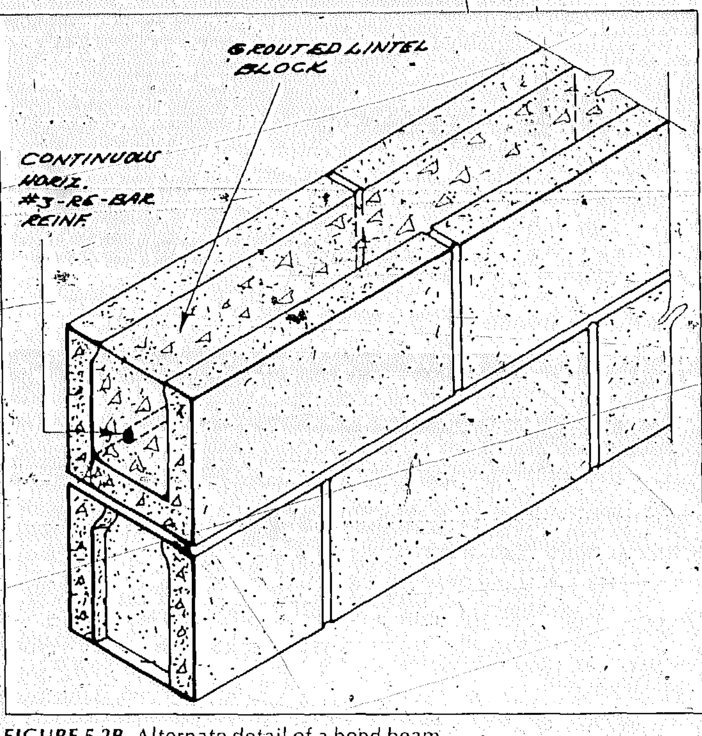


FIGURE 5.2B Alternate detail of a bond beam

NOTE: If the structure is subjected to extreme stresses i.e. seismic or hurricane loads a bond beam should be used and local codes consulted. A fully grouted and reinf. bond beam block forms the bond beam that ties the top course together with the vertical corner reinf. and allows the foundation to act as an integrated unit.

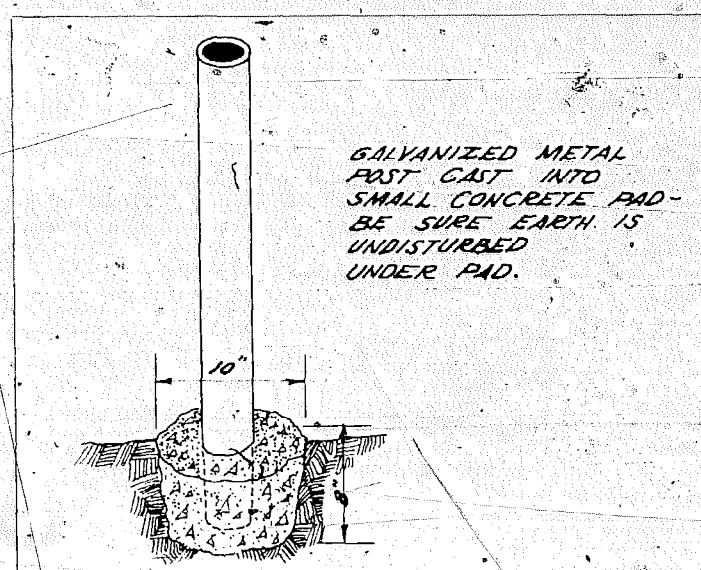


FIGURE 5.3 Interior post foundation

greenhouse. At sites where two-foot-deep insulation is required, you can dig a trench two feet deep to accommodate the insulation, and dig post holes another foot down where each post will be placed.

The post holes can be as small as eight inches across if your soil is firm enough and doesn't slough back into the hole. A posthole digger, or a hand or machine auger, is useful. If your soil won't hold an eight-inch diameter hole in which to pour concrete around metal posts, round cardboard forms (available from buiders' suppliers) are useful. Backfill around the forms before pouring the concrete, tamping carefully and thoroughly. The cardboard can be left to rot below the surface of the ground. Aboveground it can be soaked with water and peeled off. The concrete needs only protrude three or four inches above ground. Slope the top of the concrete slightly so that water will run off.

Wooden posts should be embedded in tamped earth and not in concrete. Some experiences with wood in concrete have not been good. The wood can absorb some moisture when the concrete is freshly poured, thus causing the wood to expand. When the concrete dries, the post may shrink and become loose. Two problems are created: instability and a place for water to enter between the concrete and the wood. A small footing of rock or six to eight inches of concrete should be set in the bottom of the hole for the post to bear on. These small concrete footings should be left to set for a day or two before placing the post.

Use temporary bracing and a long level or plumb bob to set the post in straight. The temporary bracing must be strong enough to hold the post still and straight if you bump into it (Figure 5.4). Using sturdy ground stakes or perhaps a nearby building, brace several posts together to be sure that everything is stable and secure. A crooked post can give you head-

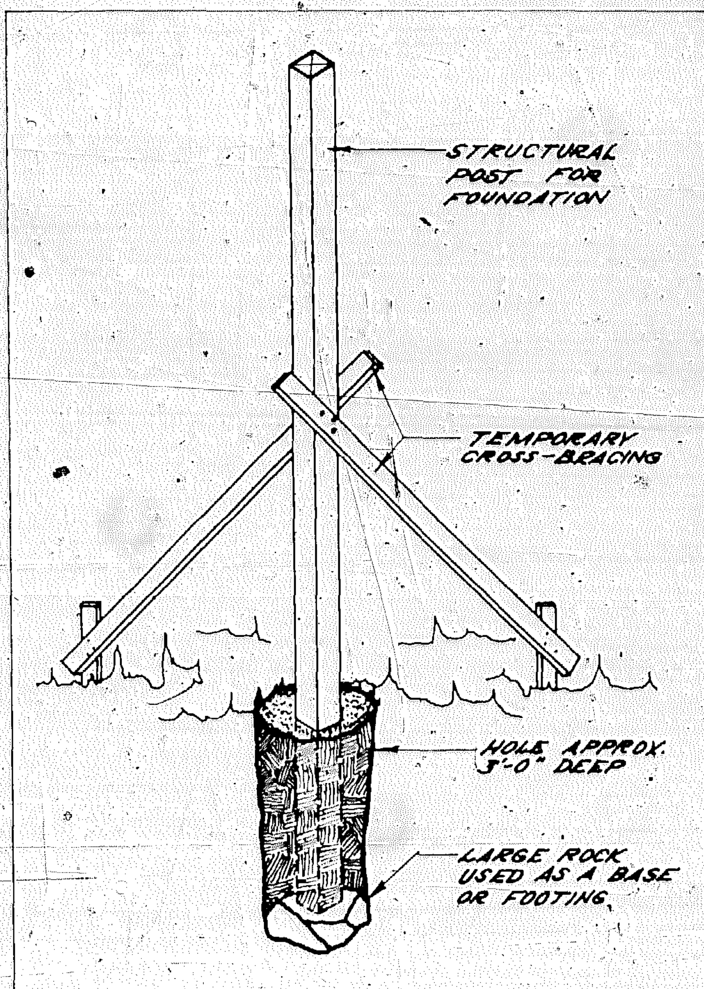
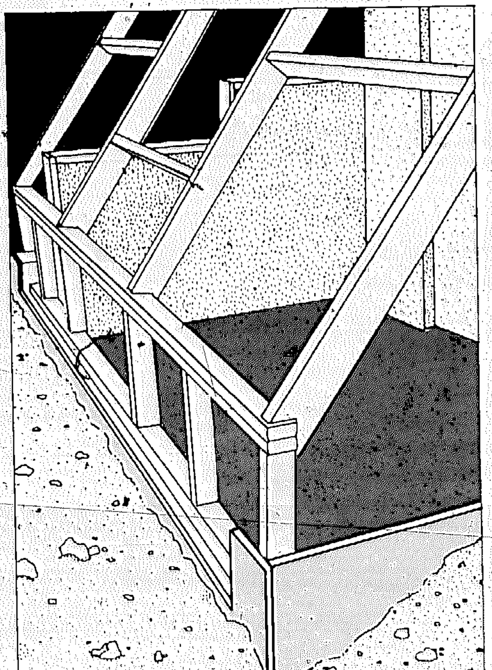


FIGURE 5.4 Method of placing a structural post



A concrete foundation wall provides heat storage in the greenhouse when (Styrofoam) insulation is placed on the exterior side.

aches with the rest of the construction.

Wood posts set in well-tamped earth are quite strong if installed properly. The technique of tamping the earth firmly around the post is very important. When the footing, post and bracing are in place, backfill two small shovelfulls of earth and tamp until the earth feels solid. Use a 2 × 2" piece of wood or a narrow pole cut flat on the bottom for tamping—a wider tamper will spread the force out too much, resulting in uncompacted earth and an unstable post. Continue this process, placing small amounts of earth into the hole and tamping until the hole is filled and post is rigidly in place. Do not throw wood scraps or other organic material into the hole, since they will eventually rot and create voids which could destablilize the post.

Insulation: In areas where two-foot-deep insulation is required, it is easiest to dig a continuous two-foot trench, with deeper holes for the posts. A backhoe makes this task much easier if you can afford it. Posts or concrete forms are set first, Styrofoam is installed next, and finally the trench is backfilled. Backfill around the posts and insulation slightly higher than the level of the earth, so that water will drain away from the foundation. Tamp most forcefully around the posts or forms, and more carefully around the Styrofoam. As mentioned before, avoid large rocks when backfilling around the Styrofoam, and fill each side equally as you go up, to avoid bulging or breaking the foam.

As illustrated in Figure 5.5A, a *treated* 2 × 4" is sufficient for spans of four feet or less, while a 2 × 6" is needed for larger post spacing. The Sytrofoam is fastened to the back side of the support board with a 1 × 2" and a few galvanized (see Figure 5.5A).

For one-foot-deep insulation, a small trench can be dug for the insulation after the foundation and greenhouse framing are done. Alternately the insulation can be installed as the posts are set. However, a good rule of thumb is to finish the foundation structure before you do anything else, such as install insulation or begin other construction.

Pier Foundation.

A variation on the post foundation is the pier foundation

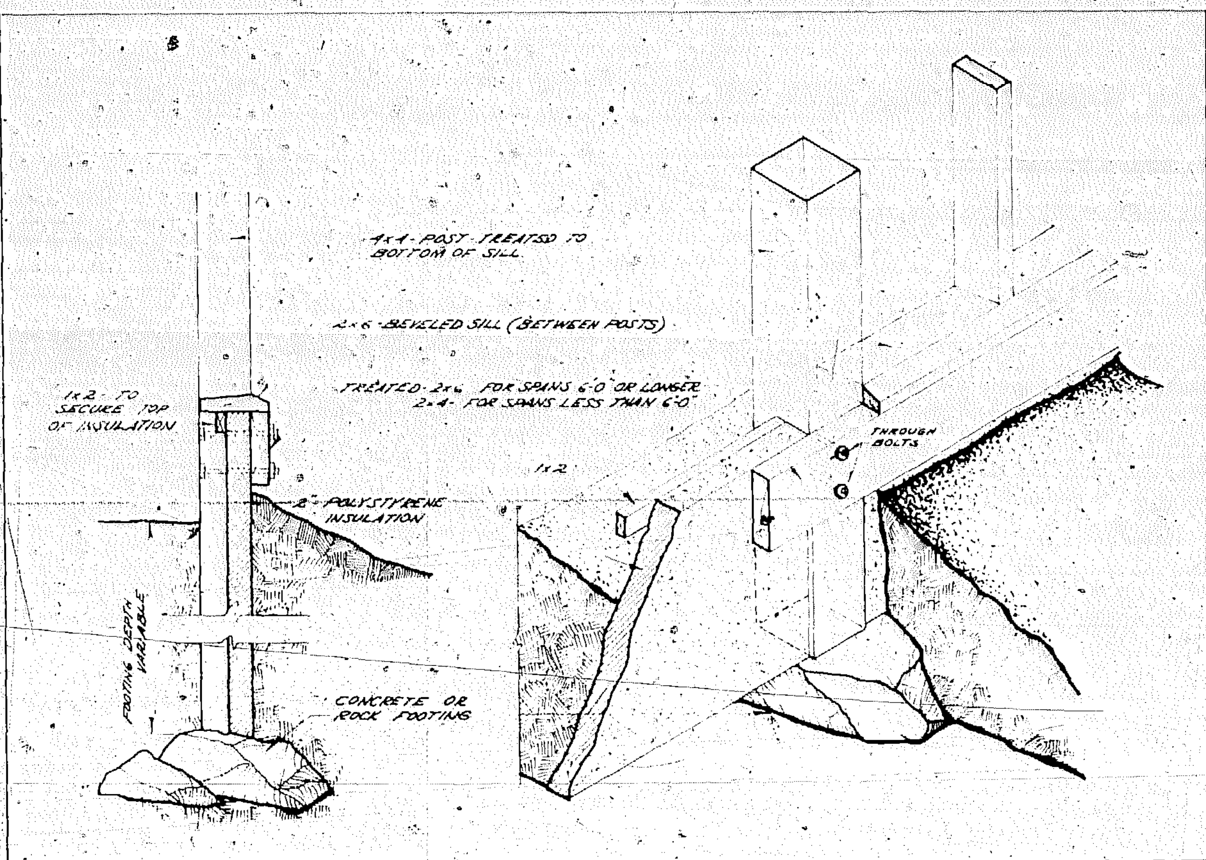


FIGURE 5.5A 4 × 4 post foundation

(Figure 5.6). It uses a poured concrete pier with a galvanized metal seat for the post. (Metal seats are available from building supply dealers.) The piers, generally used with 4 × 4" posts, are usually poured in an eight-inch diameter cardboard tube form, although an 8 × 8" square, home-built form certainly works as well. A pier foundation has the advantage of keeping the wood out of the ground to avoid rotting, but its disadvantage is being less strong against wind. More diagonal bracing is required in the greenhouse with this type of foundation, since the posts are fairly easily bent where they connect to the piers. Posts set in the ground avoid this problem. For unstable soils, add a 12" X 12" concrete footing, eight inches deep under the pier (Figure 5.6). Depth and insulation guidelines are the same as for continuous poured concrete foundations.

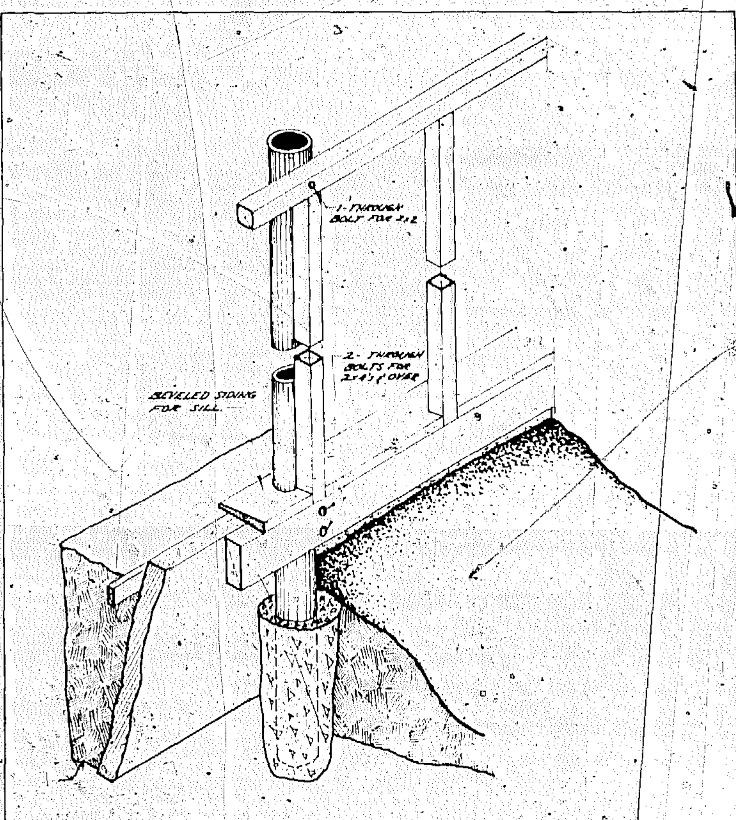


FIGURE 5.5B Metal post foundation with lightweight kneewall glazing support

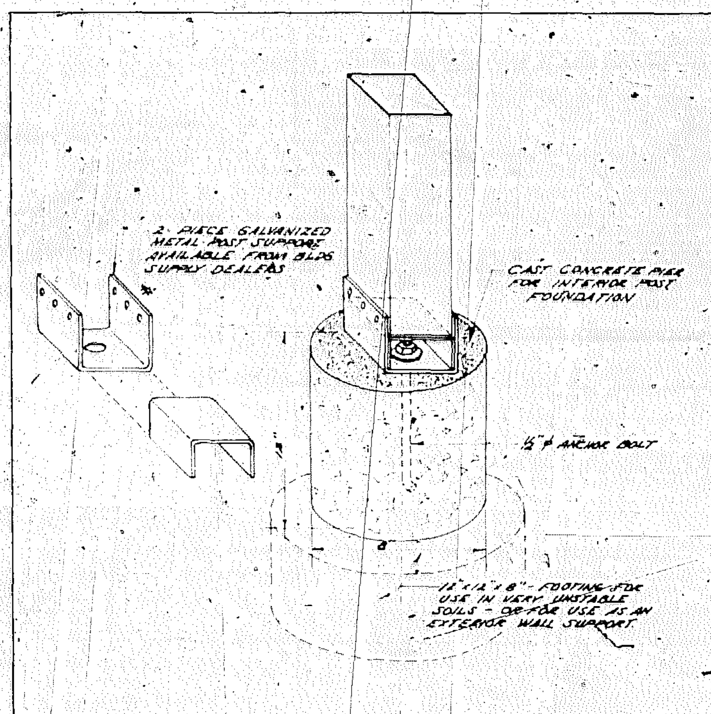


FIGURE 5.6 Pier foundation

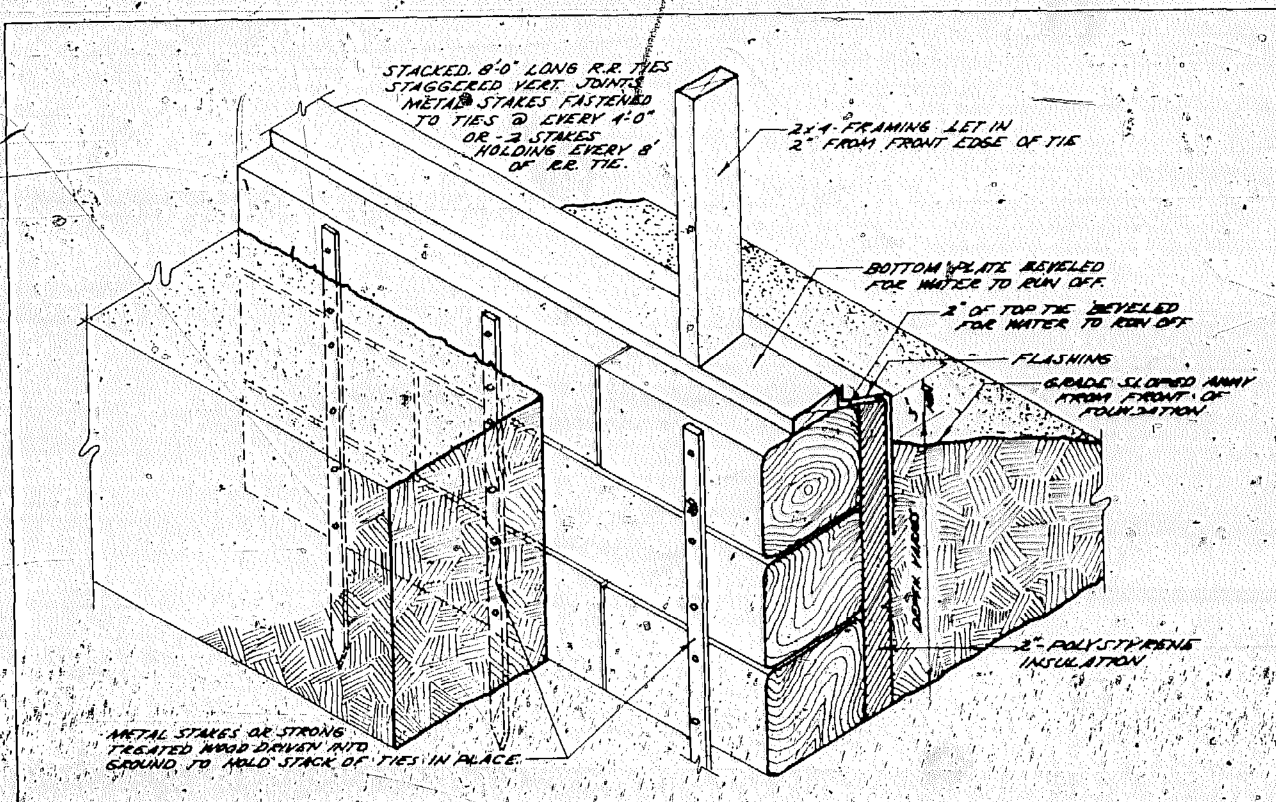


FIGURE 5.7 Railroad tie foundation (ties approximately 8" × 8" × 8')

Recommendation: Use a post foundation if you are prepared to use post and beam construction. You can lower your material costs considerably, not only for the foundation, but for the framing as well. Also, the lighter, more transparent construction with metal posts and beams allows more sunlight into your greenhouse. On the other hand, if you want to use traditional stud-wall framing, don't use a post foundation.

RAILROAD TIE FOUNDATION

One of the lowest-cost foundations can be constructed with used railroad ties. Easy to install, railroad tie foundations are most useful in areas where it is not very windy; they are very good for temporary structures. Railraod ties may last many years, depending on their condition when you get them, and provide a durable, inexpensive alternative for the greenhouse builder looking to keep costs to a minimum.

Construction: A depth of one railroad tie lying on its side can be used in areas where frost-heaving is not a problem, although a depth of at least two ties is recommended. Two courses of ties can be overlapped and spiked together. Sloping sites may require more courses. Dig the trench deep enough so that the top tie is about half-exposed above ground, and so that the insulation can be installed on the outside.

When selecting used ties, be careful not to choose moist-looking ones—those that still contain a lot of creosote. Creosote is toxic to plants. If you plan to plant directly in the ground (inside the greenhouse), the ties must be covered with polyethylene to keep the creosote from the plants. Line the trench with 4-mil polyethylene before placing the ties, and wrap the polyethylene around them, stapling the open ends across the top so that the bottom plate of the wall will hold the plastic down.

The railroad ties must be secured well. Drive stakes into the ground directly next to the ties (on the interior or both sides), Figure 5.7. The stakes can be metal or sturdy, treated wood. The stakes should be two and one-half feet long in areas with very low winds and at least three feet and preferably four feet long in windy areas. Stakes should be spaced every four feet or so, although the number of stakes used should be increased in windier areas.

If the ground is hard or rocky, metal stakes will be necessary. One-half-inch diameter, solid metal stakes, used for holding concrete forms in place, are good. They already have holes drilled in them for easy fastening to the ties. Metal fenceposts or scrap metal pipes also will work, but holes must be drilled. Use two 16d or 20d galvanized nails per tie to anchor them to the stakes. Additional 10" or 11" spikes can be used down through the ties for more strength. Drilling holes in the ties will make it much easier to drive the spikes. (Note: Pieces of reinforcing bar can be used instead of spikes.)

The bottom plate of the wall should be centered on the top railroad ties. Use a chalk line to mark the center line of the top ties, and install the bottom framing plate accordingly. Bevel the outside edges of the top row of ties to eliminate water buildup. Use a large chisel and hammer, or a chainsaw or circular saw—the beveled ties will be covered with flashing, so don't worry if it's not perfect.

Clean out the trench to install the insulation, being careful not to disturb the earth under the ties. Backfill partially at first to hold the insulation in place, then install the flashing. Then, backfill completely.

Recommendation: If your budget is tight and you are building a temporary greenhouse, a railroad tie foundation may be exactly what you need, provided you get the ties at a reasonable cost in your area. But in areas with a lot of frost heaving or a lot of wind, consider another option. Also, a railroad tie foundation is not recommended for permanent structures.

Railroad ties are getting expensive—$10.00 apiece in some places. But check around: sometimes a stack of ties, laying idle in a field, can be obtained for the asking.

Chapter Six:

FRAMING CONSTRUCTION (Glazing Support, Solid Walls, Roofs, Floors, and Doors)

GLAZING SUPPORT

The glazing support system needs to strike a balance between adequate support for the glazing and maximum light penetration for solar heating and photosynthesis. The old wood-and-glass greenhouses strike this balance fairly well. Solar greenhouse builders would do well to review old solutions to their present problems—not only for solutions but for inspiration as well (See Chapter 7 for glazing details of old greenhouses).

Different glazing materials will span different widths in different installations. The following rules of thumb may be used to size glazing rafters for most snow and wind loads. These rules assume the use of good solid timber with no splits or large knots. Also, the term "span," referred to below, is defined as *the horizontal distance between rafter supports* (Figure 6.1).

For spans up to eight feet, 2 × 4" rafters may be used 24" apart or, as builders say, on 24" centers. Blocking should be installed every four feet along the rafter and at the ends. For tempered glass or double-glazed units, use 2 × 6s on three-foot centers (or centers that match the widths of the glass) to support the weight of the glass. A galvanized pipe or wooden post support at the midpoint of 2 × 4" rafters also may be used to accommodate heavy glazings. Galvanized pipe posts and beams are strong, rot resistant, and do not block much light. Lighter framing can be used, provided there are no structural defects in the wood. For example, old glass greenhouse glazing rafters (called "glazing bars") are only 1½" × 2" and span five or six feet on 16" centers.

For spans up to 12 feet, use 2 × 6" rafters on 24" centers, or use 2 × 4s with support at the center. For tempered or double glass, use 2 × 6" members *with central support*, on centers as the glass requires. Also, whenever using large glass pieces, use blocking or *continuous rafter plates* at the ends of each glass section.

For larger spans or in special cases, such as areas with heavy snow loads or high winds, consult an engineer or architect. Also, some building codes may require heavier framing than the recommendations above, so check with your local building inspector. In general, though, use the lightest, smallest wood you can get away with for the glazing rafters: greenhouse plants will appreciate the extra light.

For vertical glazed sections—kneewalls and end walls—less framing support is necessary: 2 × 3s or even 2 × 2s are adequate as long as the weight of the roof is supported elsewhere (as with post foundations and beam supports for the rafters); 2 × 4s are adequate for tempered or double glass. If the kneewall is supporting the roof rafters, use 2 × 4s at the same frequency as the rafters; that is, the end of each rafter will be supported by a vertical 2 × 4 directly underneath (see Figure 6.2). This type of structural kneewall is used with continuous foundations such as concrete, block wall or railroad ties, and can be used with any type of glazing.

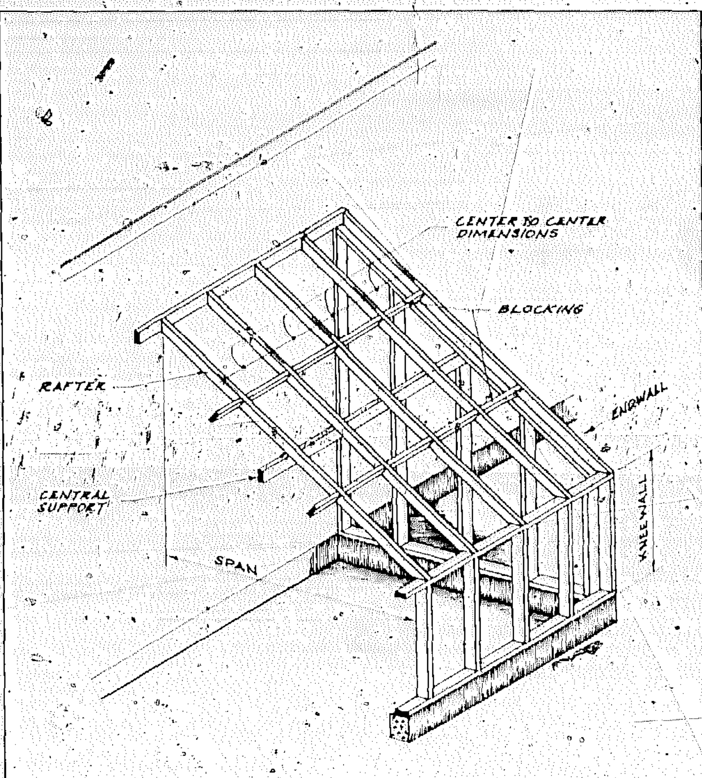


FIGURE 6.1 Construction terms to understand

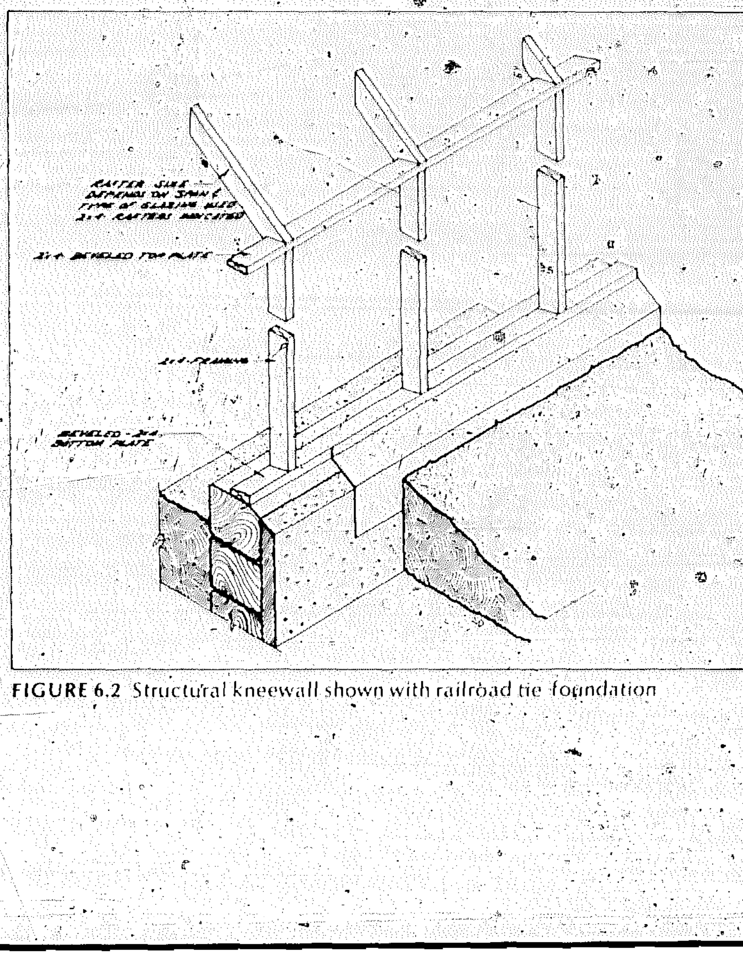


FIGURE 6.2 Structural kneewall shown with railroad tie foundation

The structural kneewall shown with notched vertical supports (Figure 6.3) is used primarily with glass and rabbeted rafter arrangements, as this makes the rabbetting work simpler. *Triangular blocking* is used between the tops of the vertical kneewall 2 × 4s, or a continuous triangular member is let into the vertical supports to carry the top of the kneewall glazing (see alternate technique, Figure 6.3).

With the post foundations (Figure 6.4 or 6.5) a considerably

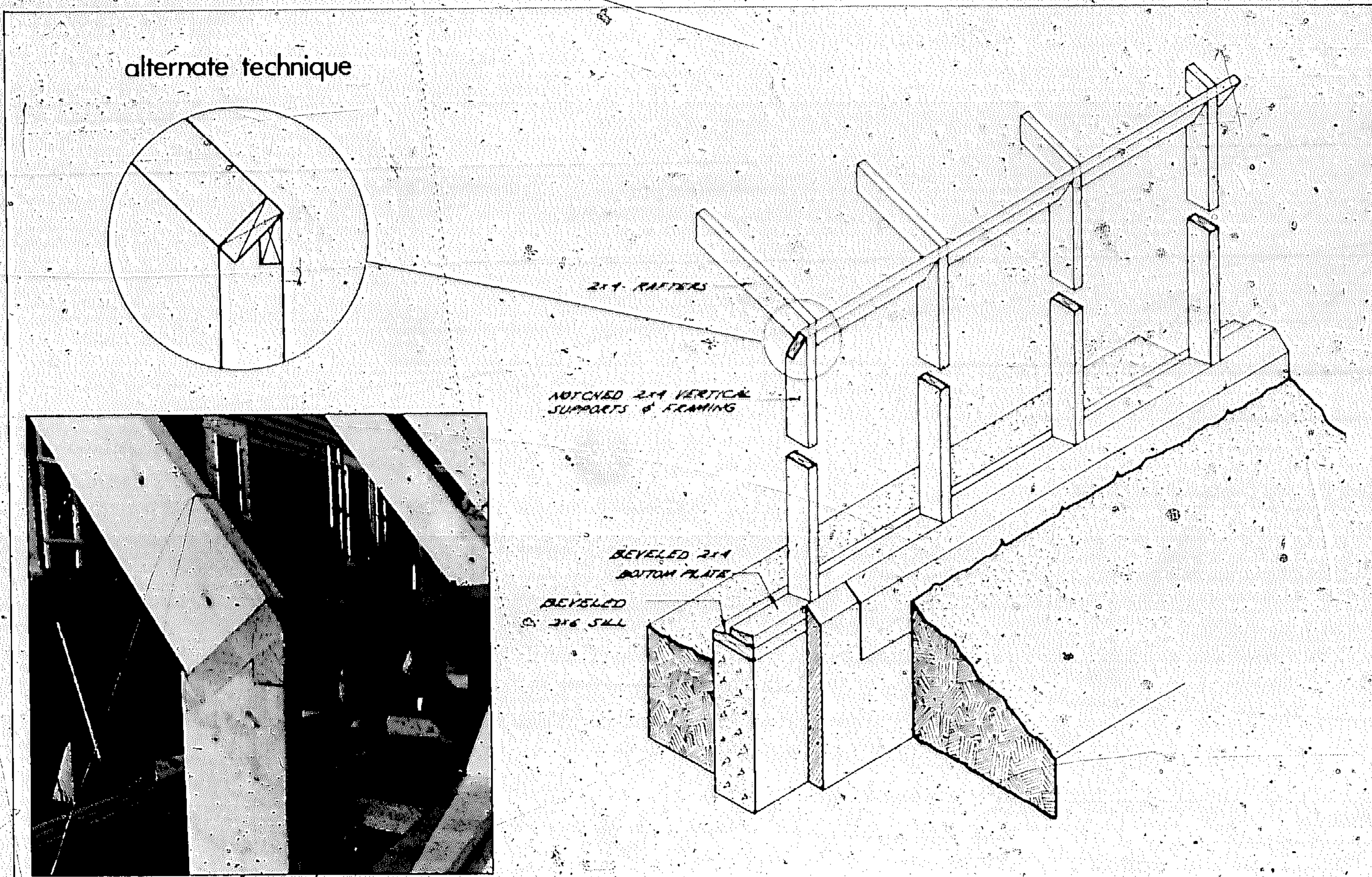


FIGURE 6.3 Notched structural kneewall shown with concrete foundation

lighter framing may be used for the kneewall, as long as the rafters are supported by pipes (or other beams and posts). On the older greenhouses with post foundations, the whole kneewall is comprised of long vents which open to give remarkably good ventilation. In such cases, the kneewall is not supporting the rafters. Some support is given the rafters by the eave (or bottom plate of the rafter) which is held up by posts; the rest is given by pipe supports inside the greenhouse. The lighter

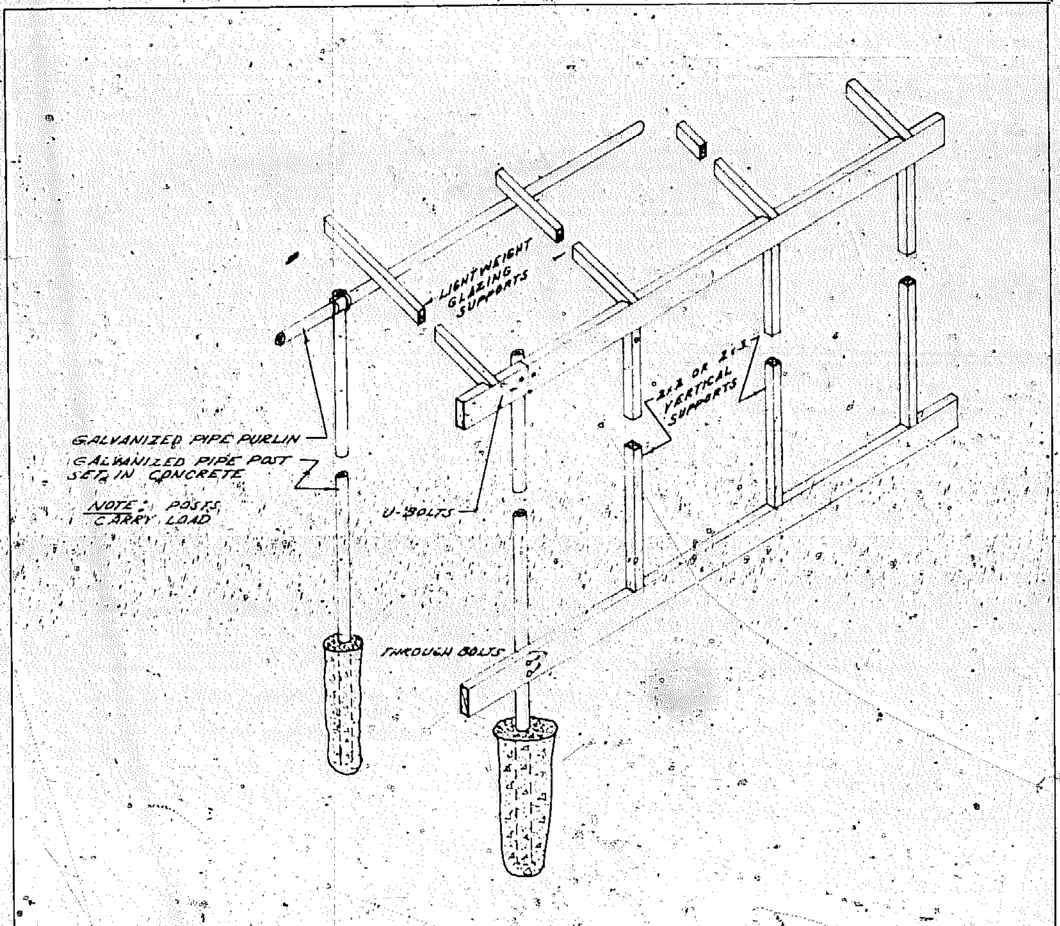


FIGURE 6.4 Lightweight glazing support using metal post foundation

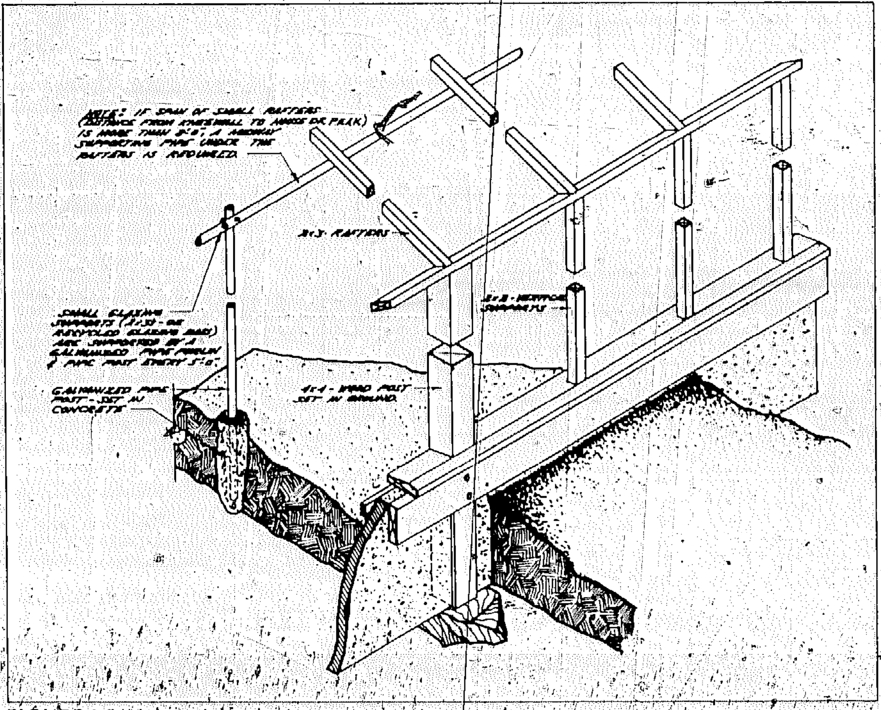


FIGURE 6.5 Lightweight glazing support using wood post foundation and metal and pipe interior support

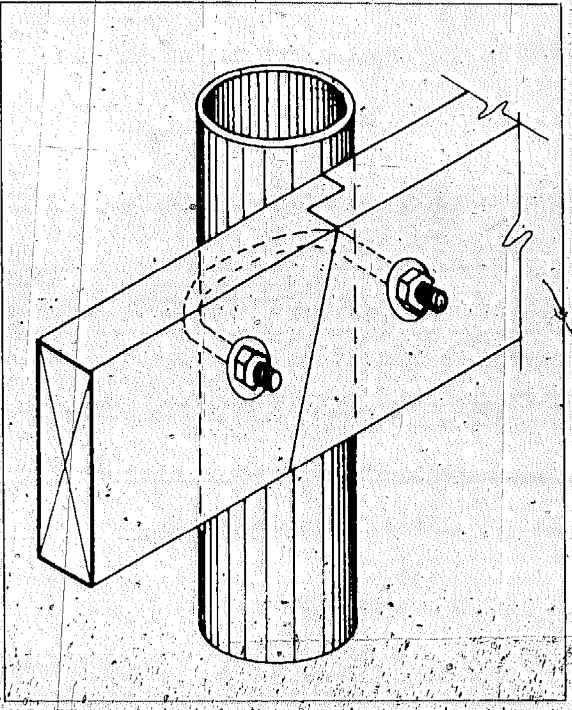


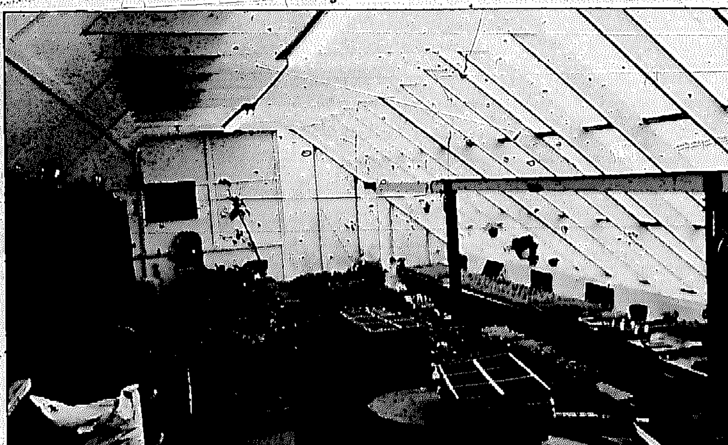
FIGURE 6.6 Method of splicing two horizontal members with a round metal post

framing is generally used with single glass, fiber-reinforced plastic or polyethylene glazing. (Figure 6.6 illustrates the method of splicing two horizontal members to a vertical post.)

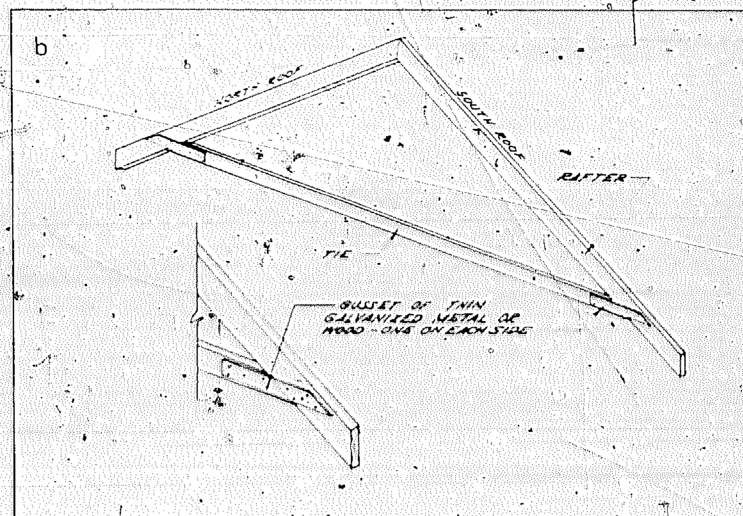
For freestanding greenhouses, with floor plans larger than 8′ × 12′, ties across the rafters are recommended to help keep the roof from collapsing. The ties can be wooden or galvanized cable to lessen light obstructions. The number and size of the ties depend on the configuration and size of the greenhouse, as well as snow and wind loading conditions.

Generally, though, *every other glazing support rafter* is tied at its midpoint to the midpoint of the rafter opposite it in the north roof. Various materials and methods can be employed to execute these connections. A lapped tie, gusset tie or cable tie (Figures 6.7) are equally suited to the task. You should use whichever connection is easiest and most convenient.

Another factor to consider here with respect to glazing supports is night insulation. Make sure your glazing support system is compatible with your glazing insulation scheme. Some interior insulating blankets require a clear span all the way across the glazing, so rafter ties, blocking, or support pipes cannot be in the way.



In this freestanding greenhouse, rafter ties help support the roof while post and beams support the glazing rafters.



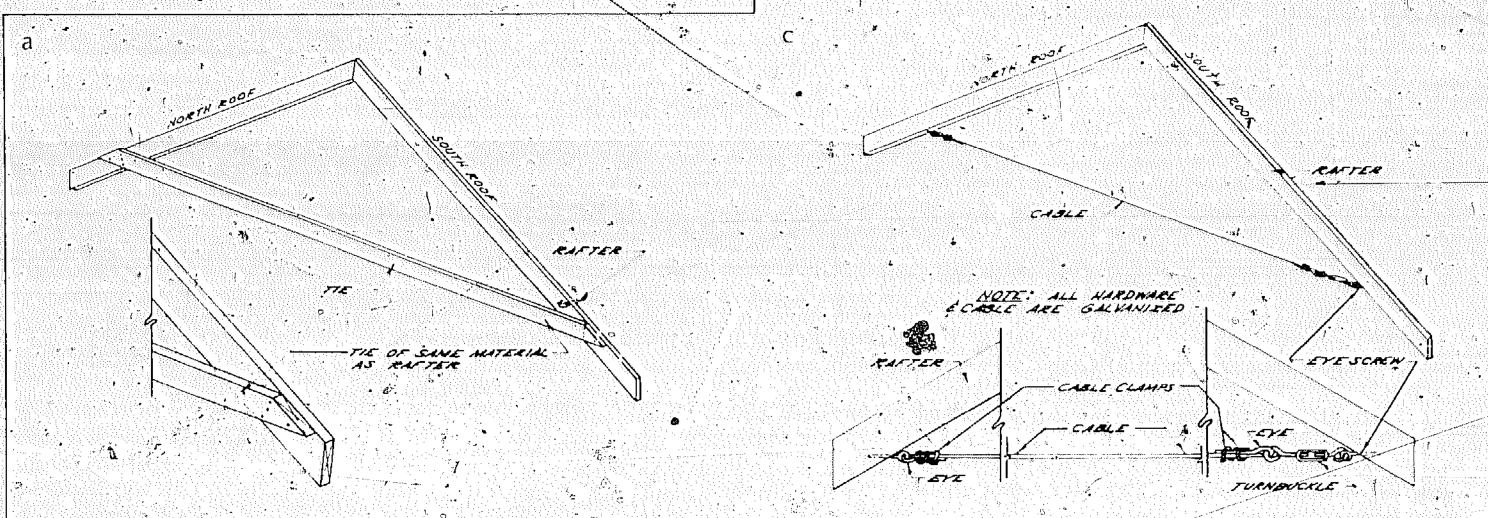


FIGURE 6.7 Rafter tie connections (for freestanding greenhouses): A. Lapped tie, B. Gusset tie, C. Cable tie

Joining rafters of attached greenhouse to the house. Where rafters or rafter ties join the house, a plate or ledger (usually 2×4" or 2×6") is lag-screwed into the studs of the house wall (see Figure 6.11). There are several options for making this connection. On low pitches, a galvanized joist hanger can be used (Figure 6.8A).

On steeper pitches, though, the notch in the bottom of the rafter may take too big a bite out of the rafter. Angled metal rafter hangers are available in some places. Alternately, a scrap piece of ½" plywood can be nailed on the end of the rafter before the rafter is installed; the plywood is then nailed securely to the plate on the wall (Figure 6.8B). Be sure that the plywood is exterior grade, and that the edges are primed, well-sealed and painted.

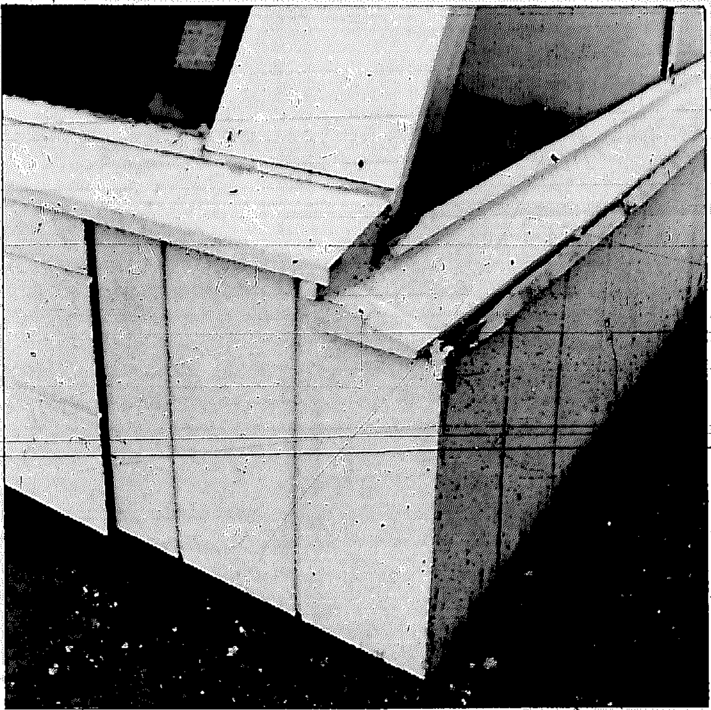
Rot protection for glazing support systems

A great deal of water, in the form of condensation, will collect on the inside surfaces of the greenhouse glazing and the glazing supports. The water, transpired by plants, condenses on the cold glazing and support surfaces, and flows down via the most convenient path. Water condensation is somewhat less of a problem in attached greenhouses: For at least part of the year, moist air in the greenhouse is vented into the main house and replaced with drier house air. However, such venting is not operational year-round. Thus, care must be taken to build all surfaces of both attached and freestanding greenhouses—inside and out—to shed water.

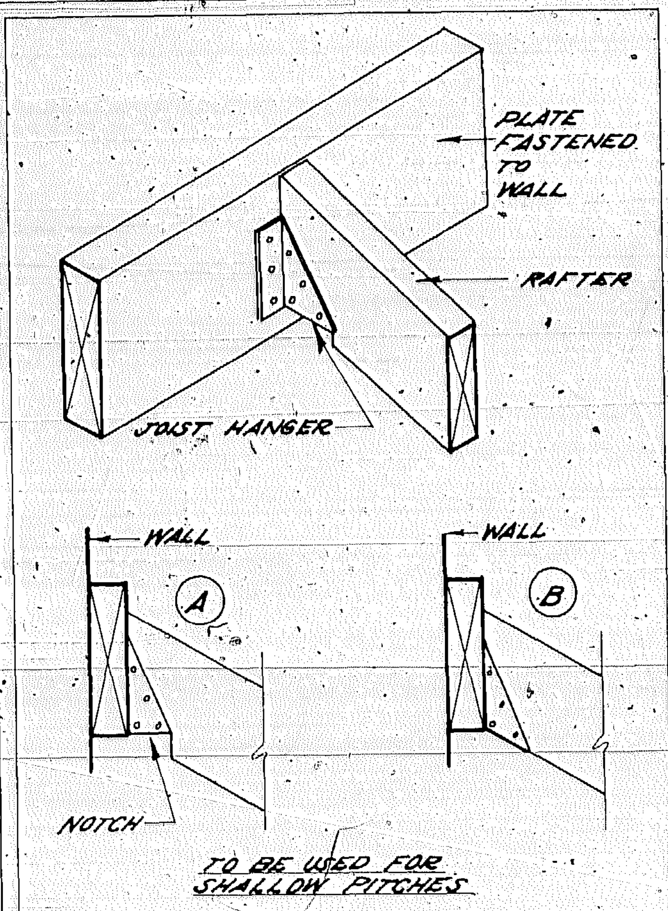
In the old, single-glazed, lapped-glass greenhouses, water condensation channels were provided in the rafters themselves (see Chapter 7). The water ran down each piece of glass to an overlap, where it then ran sideways to the glazing bar (supports). It then dripped down channels in the rafters, into a gutter at the eave, and off to a convenient collection area. Preventing dripping was important in many of these greenhouses, since water drips could spoil valuable flower crops.

In *double-glazed* solar greenhouses, less water tends to condense on the inner glazing because its surface temperature stays warmer than does single glazing. Solar greenhouse builders need not worry about channeling all the condensation off to a single locations, but must be concerned about keeping this water from rotting the greenhouse surfaces.

The most important step is to eliminate all surfaces where water can build up. The top and bottom plates of kneewalls are the most common place inside the greenhouse where water settles and rots the wood. Thus, all plates should be sloped inwards slightly to shed water. Plates should be beveled



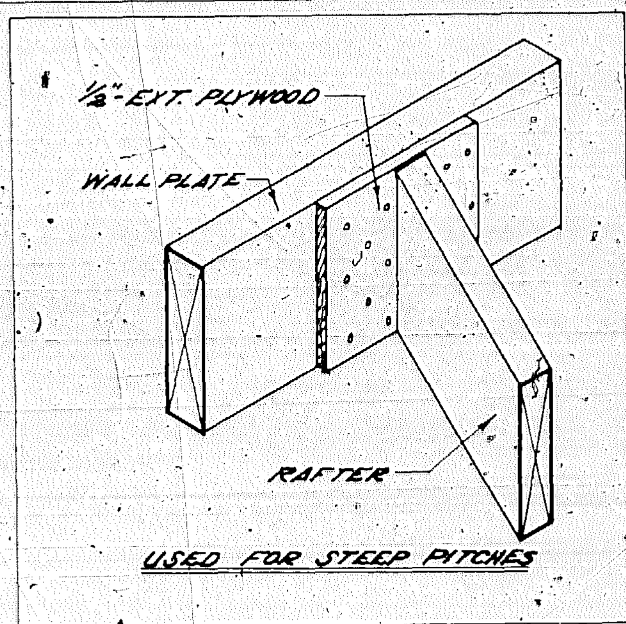
This corner detail shows consideration for rainwater runoff. The slope on the sills below the glazing helps protect the wood from rotting.



A. Using joist hangers

NOTE: That on steeper pitches the notch in the bottom of the rafter may take too big a bite out of the rafter affecting the depth needed for a particular span. (A)

Rafter hangers that fit a set pitch (B) may be available to alleviate this problem.



B. Using a plywood gusset

NOTE: For steep pitches a scrap piece of 1/2" exterior plywood can be nailed to the end of the rafter before installation, and then the plywood nailed securely to the plate on the wall to form a gusset plate. Be sure the edges of the plywood are primed, well sealed and painted.

FIGURE 6.8 Rafter to wall connection and all studs and rafters connected to the plates should be cut to account for this bevel. You may think that beveling a board (for the sill) along its entire length is too difficult and time-consuming, especially if you must use a hand plane. An alternative is to add a piece of beveled redwood siding on top of the plate (see Figure 7.16 in Chapter 7). Whichever method you prefer, the extra effort will add significantly to the lifespan of the greenhouse.

A second step is to use rot-resistant wood. Redwood or cedar often is used, but both are quite expensive. The alternative is to treat the wood to resist rot. Preservatives containing copper napthanate are acceptable—the greenhouse can be used approximately one week after applications. Remember, don't use pentachloraphenol or creosote—these preservatives will damage plants.

It is most critical to *treat the wood used for the sill* (the first board attached to the foundation). Concrete or earth carries moisture to this wood, eventually causing rot problems. Some people treat all the greenhouse wood with preservative, then prime and paint. Use a good quality, oil-based primer and two coats of oil-based paint on all interior greenhouse parts (except planter beds). Prime and paint before the glazing is installed, so that all wood surfaces are protected. Also, it's easier to paint before the glazing is in place.

If the wood is treated with a preservative undercoating, it will last longer than if it is just primed and painted. On the other hand, if untreated wood is kept well-painted, it will last a long time. A fresh coat of paint from time to time also will enhance light reflection onto the greenhouse plants.

When cutting treated wood, use a dust mask. **DO NOT** breathe the sawdust; separate the sawdust from any that you may use for mulch or composting. Also, be careful with preservatives—keep them off your skin and away from living things in general. If you plan to plant directly in the ground inside the greenhouse, treat the wood elsewhere so that no preservative drips onto the soil.

Finally, use only galvanized nails. "Bright" nails, as non-galvanized nails are called, will rust and contribute to rotting the wood.

SOLID WALL AND ROOF CONSTRUCTION TIPS

Moisture-proofing the walls and roof

Generally, standard construction practices can be applied when building the solid walls and roof of a solar greenhouse. One main exception is that the inside must be moisture-proof. During extremely cold weather, water vapor can condense on the inner surface of insulated walls, particularly where insulation was missed or where solid material (such as blocking) is in the wall.

Builders must compensate for moisture. Standard exterior building practices are essential, and if you follow the suggestions listed below regarding the interior, you should have little trouble with moisture in your solid walls and roof.

- *Use glass fiber and/or Styrofoam insulation. Moisture will not destroy these. Do not use cellulose.*
- *Use a continuous 4-mil polyethylene vapor barrier on the interior surface of the studs and rafters. Patch any holes in the polyethylene before sheathing.*
- *Use water-resistant interior sheathing. Exterior plywood with a finished side ("A" side) toward the interior; exterior siding; or waterproof sheetrock are all acceptable. Do NOT use interior plywood, regular sheetrock, Homasote, particle board, Masonite, or cardboard. All of these less durable materials can be treated and painted, but they won't last very long after the first cracks appear in the paint.*
- *Use galvanized nails only.*
- *Prime the interior surfaces with oil-based primer.*
- *After priming, caulk all the joints and cracks with latex or butyl caulking.*
- *Paint with two coats of gloss white enamel. Don't use a specular reflector inside the greenhouse as it may concentrate too much on a particular spot and burn the plants. (A specular reflector is one in which you can see an image reflected clearly, such as a glass mirror or aluminized Mylar.)*

- Be sure the interior sheathing overlaps the edge of the foundation, so that condensation can run off.
- Vent the insulation in the walls and roofs as in Figure 6.9, so that any moisture which does get into the insulation can escape. (For very small solid roof or wall areas on some attached greenhouses, venting may not be worth the effort. Venting is more critical on larger roofs and walls.)

Wall and roof insulation: How much is enough?

Super-insulated walls and roof are not warranted in a greenhouse, simply because such a large portion of the heat lost from the greenhouse goes out through the glazing. In a typical small solar greenhouse, doubling the insulative value of the solid walls and roof may cut the heat loss for the whole greenhouse by only five percent. With this in mind, the following rules of thumb may be used for designing walls and roofs for greenhouses. *For cold climates, 2 × 6″ framing with 5½″ fiberglass insulation or 2 × 4″ framing with 3½″ fiberglass insulation and 2″ of Styrofoam under the exterior sheathing may be used. In more moderate climates, 2 × 4″ framing with 3½″ fiberglass insulation is adequate.*

Solid wall framing guidelines

When using continuous foundations, solid wall framing is identical to conventional house framing. With the post foundations, however, the wall will span the distance between posts. If the wall is sheathed on both sides with plywood, the plywood (with sheets applied horizontally) in combination with the studs will act as a beam and supply the necessary strength to span up to eight feet between posts. Use galvanized nails, spaced six inches apart, to secure the plywood to the studs. If plywood isn't used, a treated 2 × 6″ board bolted to the lower outside of the posts will act as a beam to help support the wall between the posts (see Figure 6.10). A treated 2 × 4 may be used for posts spaced every four feet. The wall may be framed flat on the ground, lifted up onto the treated 2 × 6″ beam, and nailed in place. This process is easy for

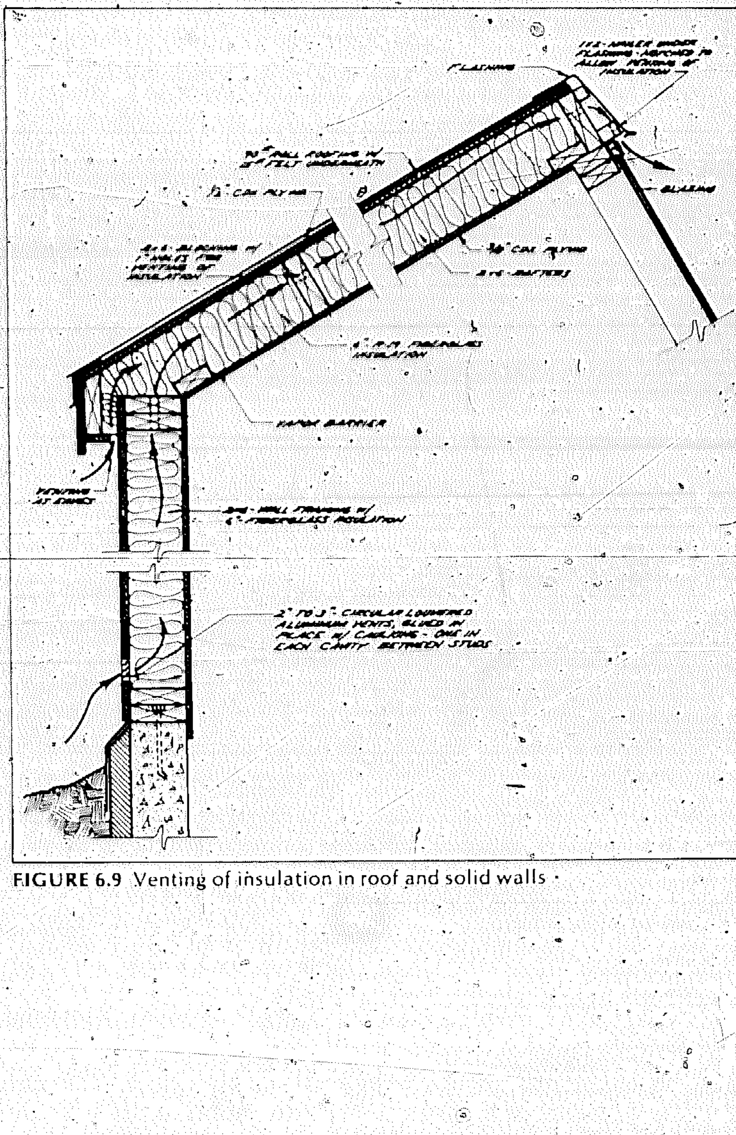


FIGURE 6.9 Venting of insulation in roof and solid walls

rectangular north walls of freestanding greenhouses. For end walls, where you may be filling-in between rafters and the treated 2 × 6″ beam, it may be easier to nail the bottom 2 × 4″ plate to the treated 2 × 6″ beam, and then put the top plate and studs in place separately.

Attaching Solid End Walls to a House: For attaching end walls to a house, it is easiest if you are able to place the last stud of the greenhouse side wall against a stud in the wall of the house. The greenhouse stud then can be lag-screwed into the house stud. If the greenhouse wall does not end at a stud in the house wall, the greenhouse stud can be lag-screwed into the bottom plate of the house wall (and the top plate if the greenhouse wall is tall enough) and expanding bolts can be used to fasten the middle and top of the stud to the exterior sheathing of the house (see Figure 6.11). If the greenhouse framing or sheathing is in contact with the house foun-

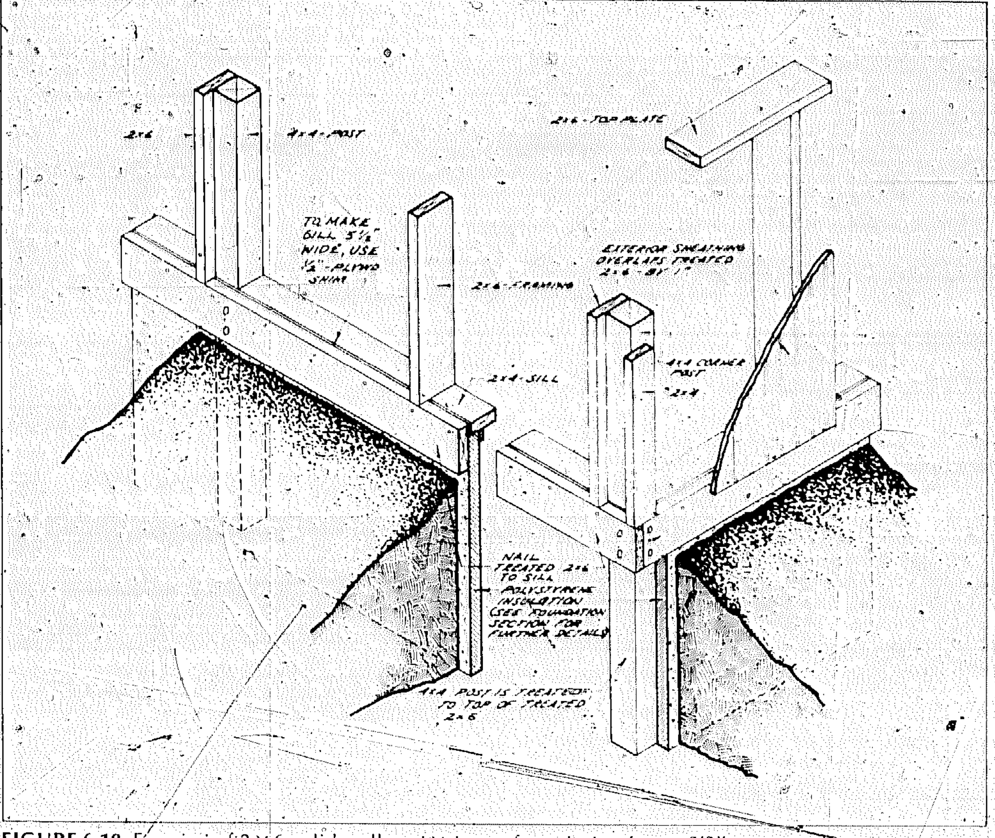


FIGURE 6.10 Framing of 2 × 6 solid wall on 4 × 4 post foundation (posts 8′0″ on center)

dation, preservative should be used on the greenhouse wood at contact points.

For end walls on post foundations, the treated 2 × 6, which is bolted to the posts, can be supported by bolting it to the last stud of the end wall of the greenhouse (Figure 6.11) which is in turn bolted to the house. In this case, the bottom of the last stud of the end wall should be treated with perservative, as it will end up close to or touching the earth. Additionally, a sturdy metal angle should be bolted to the foundation of the house, using an expanding leadshield bolt in the concrete or masonry, on which the treated 2 × 6 will bear.

Roof Framing: In terms of structure for the roof, 2 × 4" rafters on 16" centers are adequate for up to an eight-foot span. For six-foot spans, 2 × 4s may be used on 24" centers. 2 × 6" rafters on 16" centers will span up to 12 feet. For 10 feet or shorter, 2 × 6s may be used on 24" centers. These rafter specifications will provide adequate roof support for most snow, wind and roofing material loads encountered.

EXTERIOR SHEATHING, ROOFING AND PAINTING

The exterior of the solid roof may be treated the same as the exterior of any structure. Roll roofing is inexpensive and fairly aesthetic. Be sure to use "drip-edge" flashing around the edges. If part of your south roof is solid and part is corrugated fiber-reinforced plastic (FRP), corrugated metal roofing for the solid part will neatly overlap the corrugated FRP. Be sure the corrugations match before buying!

Cutting through galvanized corrugated sheet metal is somewhat difficult. A sheet-metal cutting blade for a circular saw is available which speeds the process considerably, or a jig saw with a metal-cutting blade can be used. Use goggles and ear plugs. The aluminum-corrugated roofing can be cut with tin snips. The installation is identical to the corrugated FRP (see Chapter 7), with the exceptions that galvanized nails are used with the galvanized roofing and aluminum nails with aluminum roofing, and that butyl caulk or roofing tar may be used for metal-to-metal joints. Silicone should be used where the metal roofing overlaps the FRP.

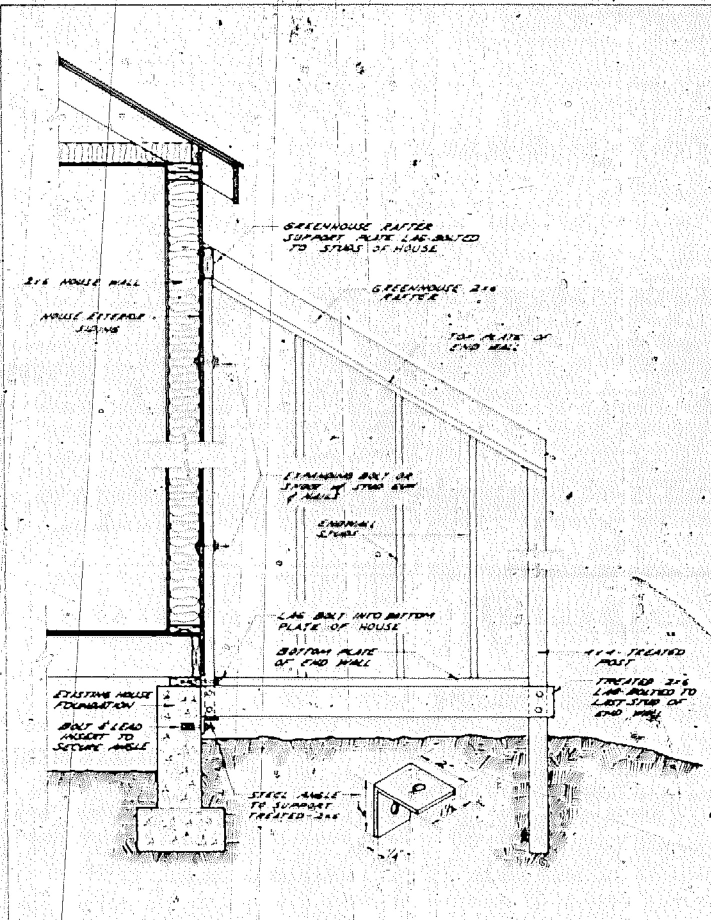


FIGURE 6.11 Framing for an endwall of a greenhouse to the house (using a post foundation for the greenhouse)

To best integrate the greenhouse with the house, the exterior of the walls should be sheeted and painted like the attached building, where possible. Any exterior treatment should include siding of reasonable quality, tight trim around corners and eaves, flashing where necessary, caulking between trim and siding, and a paint or stain finish (see a general construction text). Particle board, plywood or other glued materials tend to decay quickly if they are not painted or if the edges are exposed. Before using these somewhat delicate materials, carefully evaluate the likelihood of continued maintenance. If you do use them, batten all exterior corners and vertical joints, caulk all horizontal joints and be sure the bottom edge of the material is kept painted and unexposed to splashing water.

FLOORS

For a low-cost greenhouse, a dirt floor is fine. The addition of some gravel in the pathways will help keep the floor from getting muddy and keep greenhouse users from tracking mud into the house. Old bricks or chunks of concrete also can make nice pathways.

A poured concrete floor is rather expensive, although it has a distinct advantage: It can be cleaned. Being able to clean the floor ~~is useful~~ for controlling pests in the greenhouse. Pests lay eggs in nooks and crannies everywhere, and a rough floor presents many inviting locations.

Insulation under the floor is not recommended for a low-cost greenhouse. The expense is high relative to the amount of heat saved. Insulation around the perimeter (as suggested in the Foundation section) is far more useful.

DOOR AND VESTIBULES

For attached greenhouses, one door should lead directly into the attached building if at all possible. Direct access saves heat, eliminates the need for a vestibule, and minimizes shock to the plant during cold winter months. Quick and easy access also promotes better management and greater use of the greenhouse, especially during the cold months. Install a screen door as well, if you plan to use this "direct access" opening to vent solar heat: It will help keep greenhouse pests out of the house, and house pets out of the greenhouse!

A second door should be installed that leads to the outside. This "work access" will be used to move dirt, plants, wheelbarrows and people in and out. The outside door, wide enough to admit your wheelbarrow, should be placed on the least windy side of the greenhouse if possible. If the "least windy side" also is an area that should be glazed, a transparent door with any plastic glazing should be built (see Figure 6.12). It should be double-glazed (if the greenhouse is double glazed), tightly sealed, and weatherstripped. If the "least windy side" is a solid wall section, most any door will do. An insulated door is recommended, but it is more important that the door be tightly sealed and weatherstripped. If you can see daylight anywhere around the door when it is shut, the door is not tight enough for winter use. (Recycled doors can be insulated neatly with Styrofoam sheets. Cover the Styrofoam edges with wood strips and glue the sheets to the door.)

If you are unable to build an attached greenhouse around a "direct access" door, or if you are building a freestanding greenhouse, a vestibule should be built. Vestibules help conserve heat, prevent shock to the plants when the door is opened, and provide some storage space. A vestibule should be big enough to let you enter the outer door and close it before opening the inner door. However, if you don't plan to use the greenhouse during the cold winter months, or if you are building in a mild-weather area, a vestibule is probably not worth the expense.

A wintertime alternative to a vestibule is an old blanket nailed up inside the outer door. When you open the door on cold days, you can scoot behind the blanket without letting out too much heat or letting in too much cold.

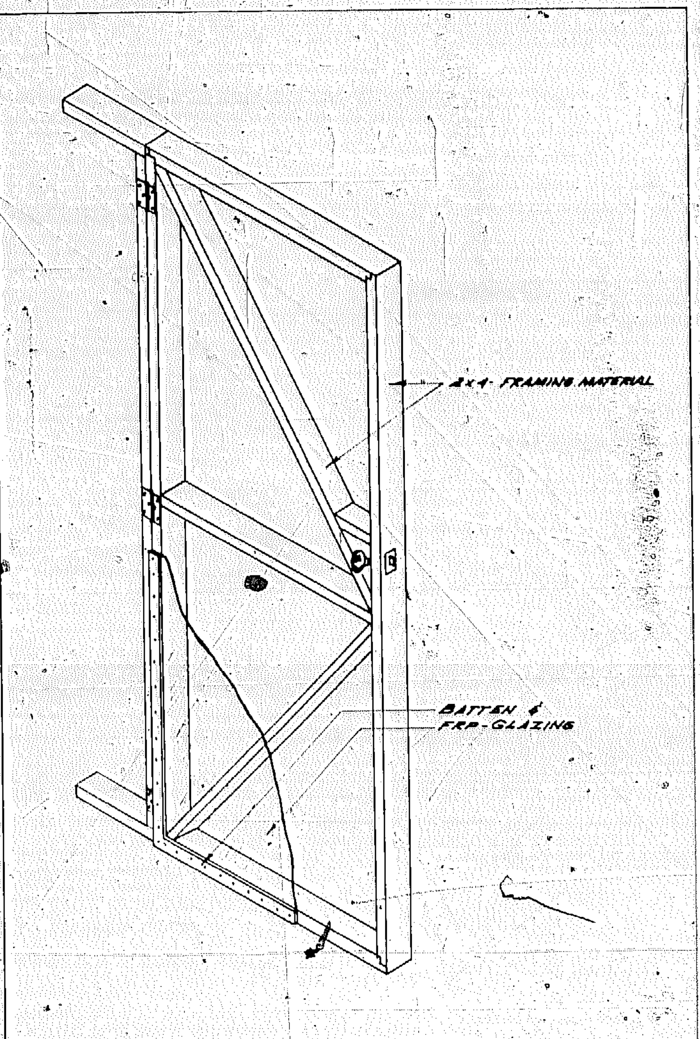


FIGURE 6.12 Glazed door

Chapter Seven: GLAZINGS

One of the most often-asked questions in greenhouse design is: What is the *best* glazing to use? The fact is that there is no "Best" glazing; every greenhouse is different. Each is built in a different climate, for different reasons, by different people, under different circumstances, and with different amounts of resources (time and money). Given that the greenhouse glazing choice must be consistent with all other design decisions, the best glazing to use depends on the particular application.

There are many factors to consider before making your glazing decision. Obviously, **low cost** is a prime consideration—you need to be very selective. **Durability** (lifespan), **light transmission**, and **installation** are three important considerations as well.

If you are building the rest of your greenhouse to last a long time, you need to choose a durable glazing, or install less durable glazing in such a way that it is easy to replace. If vandalism is a problem in your area, a main consideration should be the glazing's resistance to thrown rocks.

Sunlight is the lifeblood of greenhouse productivity and the glazing surface is a key to capturing the sun's rays. Most glazing materials are comparable in respect to light transmission, but they vary when it comes to heat transmission. Different glazings also require varying support systems—heavier glazing support systems block more sunlight. Recognizing the interdependence of glazings and their support system is a key to good design.

Glazing installation is another consideration that should weigh heavily in your decision. Obviously, some glazings are easier to install than others. Choosing a glazing and glazing support system within the range of your construction skills is as important as choosing ones within your budget.

In cooler climates, where double glazing is recommended, you must make two glazing decisions: **inner** and **outer** glazings. Certain materials are well suited in combination with certain other materials—and are more cost-effective as such. You need to determine the right balance of the two layers.

In this chapter, nine different glazing options are discussed—certainly not all the possibilities, but a range from which a choice can be made for most situations. For each type of glazing we will outline cost, lifespan, light transmission, installation considerations, support system details, and how to decide if a given material is the right choice for your greenhouse. The information should be treated as an outline to help you make good decisions. You must supplement the material presented for each type of glazing with "localized" information: installation specifications from the manufacturers; ordering, pricing and delivery information from distributors and retailers—also note delays, practical tips and labor estimates from builders.

If possible, go see a greenhouse which uses the particular glazing you have in mind. See how it looks; find out how it works; learn as much as you can about the construction details that were needed. Compare cost estimates and product information carefully. Understand the time and labor involved with each glazing installation, and if less durable glazings are used, consider the time and money needed for replacements in the future.

RECYCLED WINDOWS

One of the most appropriate glazing options for a low-cost solar greenhouse is recycled windows. Old wooden storm windows—unused and stashed away in a neighbor's garage—may be available. Or, perhaps the wood frame windows on a nearby office building have been replaced recently. There may be a similar opportunity in your area to acquire glass windows at a reasonable cost. In fact, the windows may be free for the taking in some situations. Check around and use what is available.

Recycled glass windows are best utilized on *vertical* greenhouse walls. Wood frame windows should be used vertically only, because they are not designed to shed water or snow when tilted, and as a result, tend to rot prematurely when installed on a slant (Figure 7.1).

When using recycled windows, you must be prepared for some extra work. Often, recycled windows must be re-puttied,

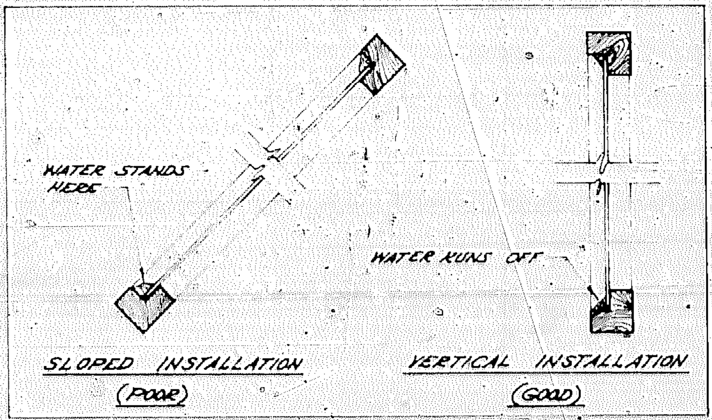


FIGURE 7.1 How and how not to utilize recycled windows

scraped, primed, and repainted before they are suitable for greenhouse use. If you have the time to manage these tasks, though, recycled windows can last indefinitely, albeit the associated problems with breakage.

LIGHT TRANSMISSION: One layer of glass transmits 85 to 90 percent of the sunlight that falls on it. However, bulky wood window frames and the support structure required for glass can reduce the overall light transmission quite a bit, to approximately 50-80 percent of radiation striking the surface. If possible, choose windows with larger glass panels and smaller wood framing. If pairs of wood windows are used as double glazing, light transmission will be reduced. But unless the wood frames are unusually large or there are many small panes of glass in the windows, light transmission should be adequate.

INSTALLATION: Repair the putty and repaint the windows before installation. All cracks must be repaired and all wood surfaces painted to achieve an airtight seal and lasting finish.

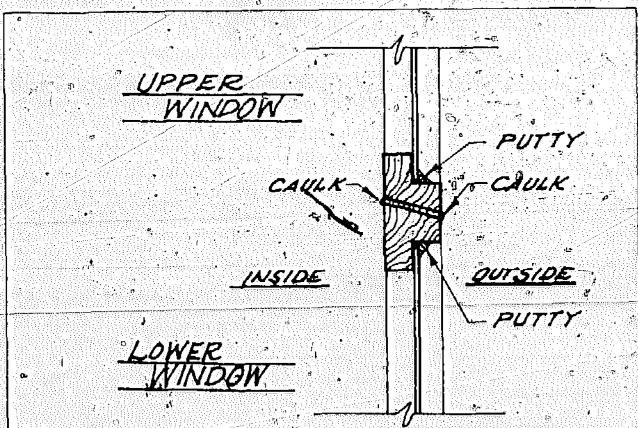


FIGURE 7.2 Horizontal joint between two courses of recycled windows

Examine the windows carefully. The lower sash of double-hung windows and wooden storm windows have a beveled bottom edge. Use these sashes as your bottom, outside course of windows—complementing the beveled sill to shed water. If none of your windows have this beveled sash, you should bevel the bottoms to match the bevel of the sill (about 15°). Use a plane, a circular saw, or a table saw. (Watch out for nails!) Be sure to paint the wood exposed by the cut (primer and two coats of enamel) before installation. If you are using more than one course of windows (one on top of another), bevel and paint the edges where the two windows meet (Figure 7.2). No horizontal framing is necessary between courses of windows with beveled edges.

The spacing between the framing members of your knee-wall should be ¼" wider than the width of your windows to allow enough room to fit the windows easily (⅛" inch on each

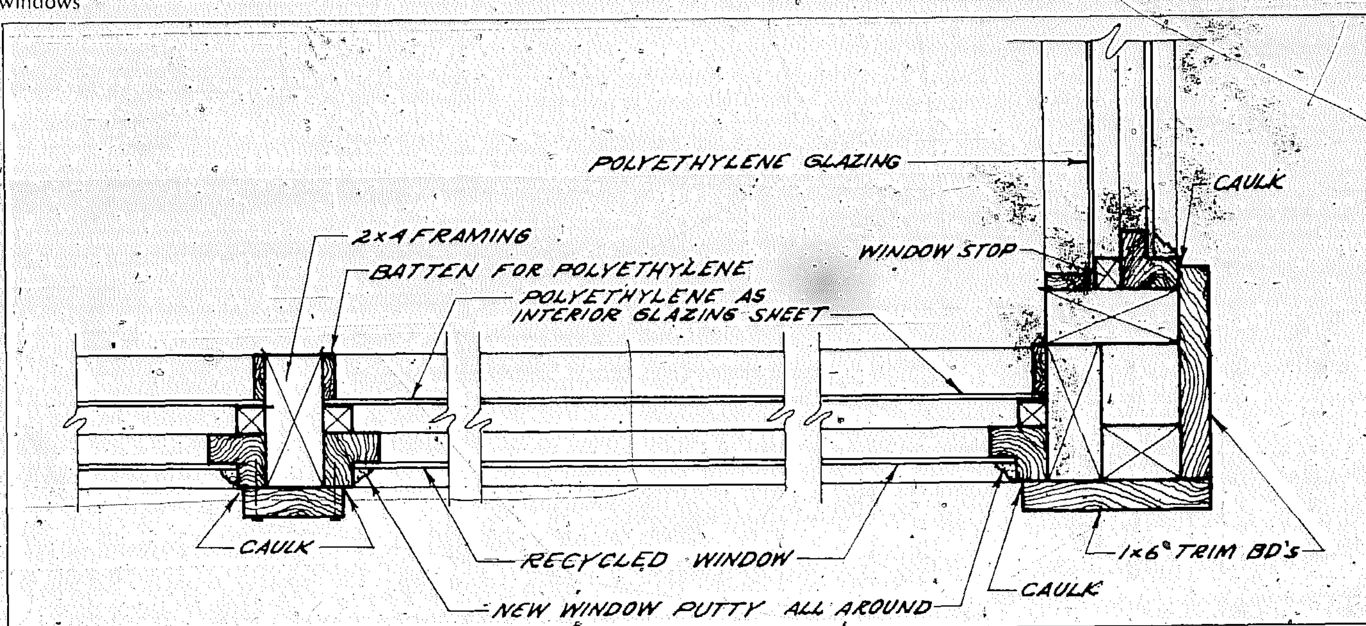


FIGURE 7.3 Corner plan showing recycled windows and polyethylene inner glazing

side). Be careful—DON'T leave a gap around the windows so large that it prohibits sealing the cracks with caulk. If the gaps do end up larger than can be caulked—larger than ¼"—you will have to use a finish batten to cover the cracks. (This batten isn't shown in the illustration.) It is a good idea to insulate the cracks with fiberglass or some other material before applying the batten.

Window stops should be placed carefully so that the exterior surface of the window is flush with the exterior surface of the framing. Place the stops on each side (Figure 7.3), and screw the windows in place. It is important to be able to remove the frames so glass can be replaced if broken.

One or more of the windows with fairly sturdy frames can be hinged like doors and used for vents. Reinforce these windows with diagonal wires twisted around screws in each corner (Figure 7.4). *Weatherstrip* between the stops and this vent window. Use one hook and eye bolt for a latch to keep the window closed, and another to keep it open. Polyethylene for double glazing can be applied directly to the back of the vent window with small wood battens. (More on window vents in Chapter 8.)

If pairs of recycled windows are used as double glazing, drill *two* one-half inch (½") holes near the bottom and *two* more near the top of each outer window to vent the cavity between the windows (Figure 7.5 B). Drill two holes instead of four for windows smaller than 3'×3'. Drill the holes at an angle to keep water out. Place a very small piece of fiberglass insu-

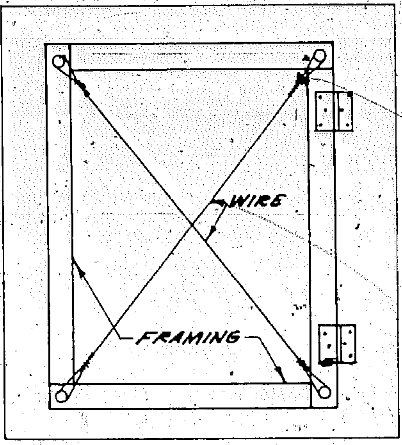


FIGURE 7.4 Reinforced window vent

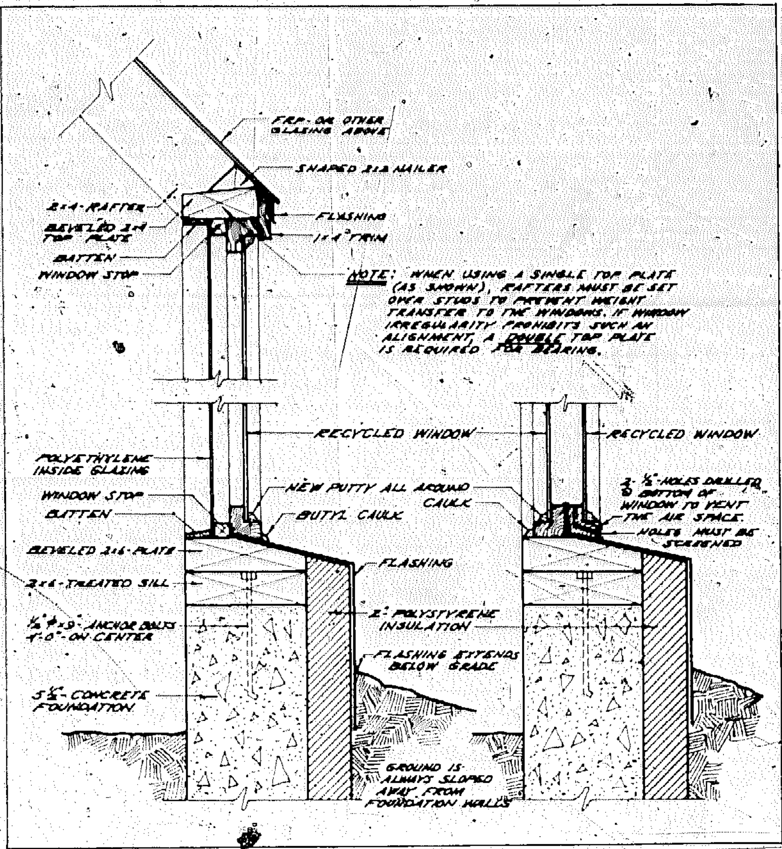


FIGURE 7.5A Recycled window with polyethylene inner glazing

FIGURE 7.5B Double recycled windows

lation —packed very loosely— in the hole; the fiberglass will act as a dust filter. Cover the holes with a fine screen to keep insects out, and caulk between the two windows before installing the outer one. Venting helps eliminate condensation between the windows. Drier outside air (instead of moist greenhouse air) circulates between the windows. The small decrease in the window's insulative value created by this venting is more than offset by the increased sunlight that penetrates a condensation-free window.

In order for this ventilation system to minimize condensation, it is important to seal the inner window *from the inside* so that air exchange takes place with the outside air, and not with greenhouse air.

Note in Figure 7.5B that the putty on the inside window faces the interior of the greenhouse. It is on the interior surface where water will condense and, therefore, where a watertight surface is necessary. Putty on the inside also makes it easier to replace glass. The stop and sill below this surface should be beveled if they extend beyond the window to avoid standing water and rotting.

Recycled windows, although installed on a slant, have worked well for this greenhouse in New Hampshire.

Polyethylene is an easily installed, inexpensive inner glazing to use with recycled windows. It can be installed as shown in Figure 7.5A, or as one large sheet battened to the back side of the framing. More on polyethylene later.

RECOMMENDATION: Recycled windows are best utilized in vertical installations and in areas where vandalism is *not* a problem. If recycled windows in decent condition are available at a reasonable cost, use them. But if you need to glaze a sloped surface, or if the style of windows available doesn't fit in aesthetically with the main house, you should consider a different option.

POLYETHYLENE GLAZING

Polyethylene is the lowest-cost commercially available greenhouse glazing. Although it doesn't last long, it can be used as a temporary glazing and is especially suitable if you anticipate having enough money in the future to install a more permanent glazing. Also, because it is inexpensive and doesn't require heavy framing, polyethylene is a common glazing choice among commercial greenhouse operators.

Generally, the six-mil, ultraviolet-resistant (UV-resistant) polyethylene is used because it doesn't break down in the sunlight so quickly. Non-UV-resistant (regular) polyethylene, on the other hand, is a good, inexpensive *inner* glazing, since the outer glazing intercepts much of the damaging ultraviolet light of solar radiation.

Regular six-mil (one mil = 0.001" thick) polyethylene costs about three cents (3¢) per square foot. UV-resistant, six-mil polyethylene (such as 6 oz. Monsanto) costs about five cents (5¢) per square foot. Rolls of polyethylene come in many sizes, but often not in the size you need. Thus, any excess polyethylene you may have to buy, as well as battens and small galvanized nails, should be included in your cost estimate.

LIFESPAN: UV-resistant polyethylene may last two years, although in windy locations it may last only one. In many cases, it is replaced annually to avoid the chance of a tear in the middle of the second winter. Untreated (regular) polyethylene may last only six months in severe circumstances.

Either type will probably last longer as an interior glazing, particularly behind glass or fiber-reinforced plastic glazings.

LIGHT TRANSMISSION: New polyethylene transmits about 90 percent of the sunlight, but the percentage decreases as the plastic gets older and less transparent. Double-layer polyethylene, inflated between the layers by a small blower, can span larger distances; thus, less light is blocked by glazing support framing. On the other hand, the type of installation outlined below—polyethylene stretched and attached to the framing—uses more commonly available materials and lends itself to a more permanent glazing replacement later on, than does the inflated method. For more information on inflated glazing construction, review the commercial greenhouse catalogs referenced in the Resource List.

INSTALLATION: Ease of installation is one of polyethylene's strong points: You may have to do it yearly, but it isn't difficult. Six-mil polyethylene should be used for the exterior, four-mil can be used for the interior. Polyethylene must be nailed to all framing supports with continuous battens to keep it from tearing. Flapping in the wind rips sun-weakened polyethylene, so the tighter it is stretched, and the more often it is supported and battened, the longer it will last.

One-inch by two-inch battens nailed with 6d or 7d galvanized box nails every 8" to 10" should be sufficient. Be sure to prime and paint all wood surfaces and battens before installation. Any horizontal battens should be cut somewhat short to leave end gaps for water to drain off (Figure 7.6).

If you plan to install more permanent glazing later, remember to space the framing to accommodate the future glazing.

When polyethylene is used on the roof, the roof should slope at least 30°, and should be unobstructed at the eave to allow snow to slide off easily (Figure 7.6). One way to avoid obstructions completely is to use one large sheet of polyethylene which covers the roof and the kneewall; use tapered horizontal battens at the top of the kneewall; and use no batten at the lower edge of the roof.

For double layers of polyethylene, mounting both layers on

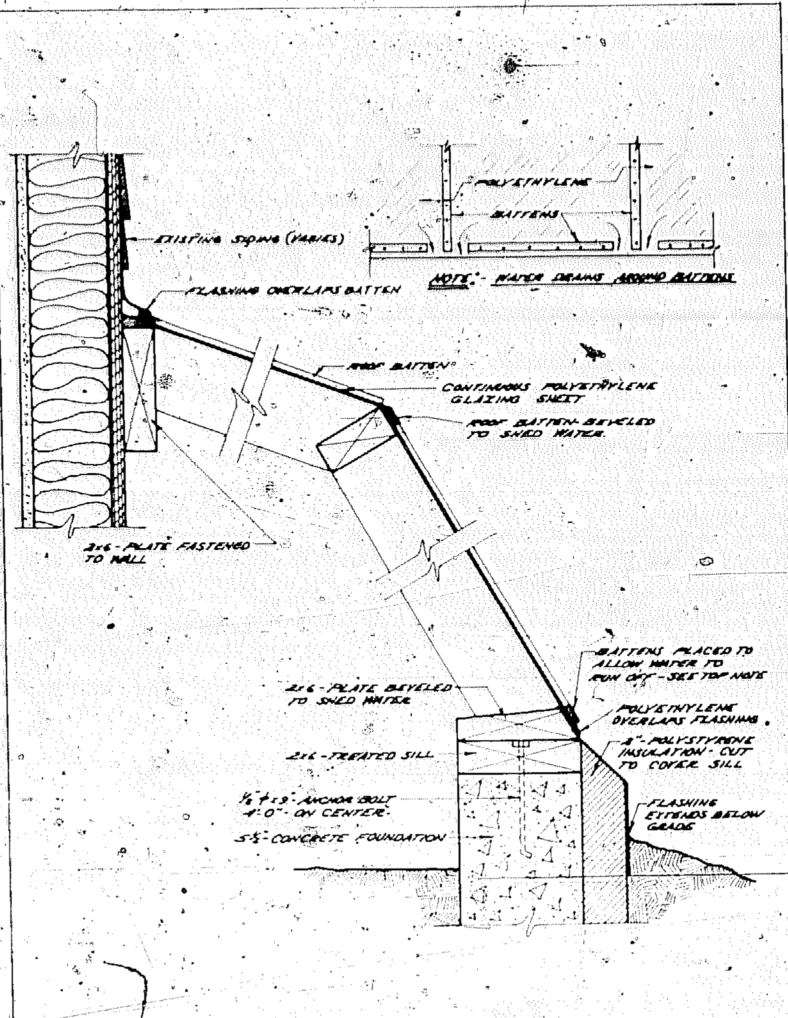


FIGURE 7.6 Single layer of polyethylene glazing (inner glazing not shown)

the exterior of the framing is preferable (Figure 7.7C). This method will trap the *least* moisture around the structural 2 × 4″ framing, and will probably cause the least structural damage due to rot.

Enclosing the framing itself in polyethylene (one layer covering the exterior edge and the other covering the interior edge) also is commonly done. It is probably the easiest installation (Figure 7.7B). This method facilitates replacements since the inner layer is less prone to damage when removing the outer layer.

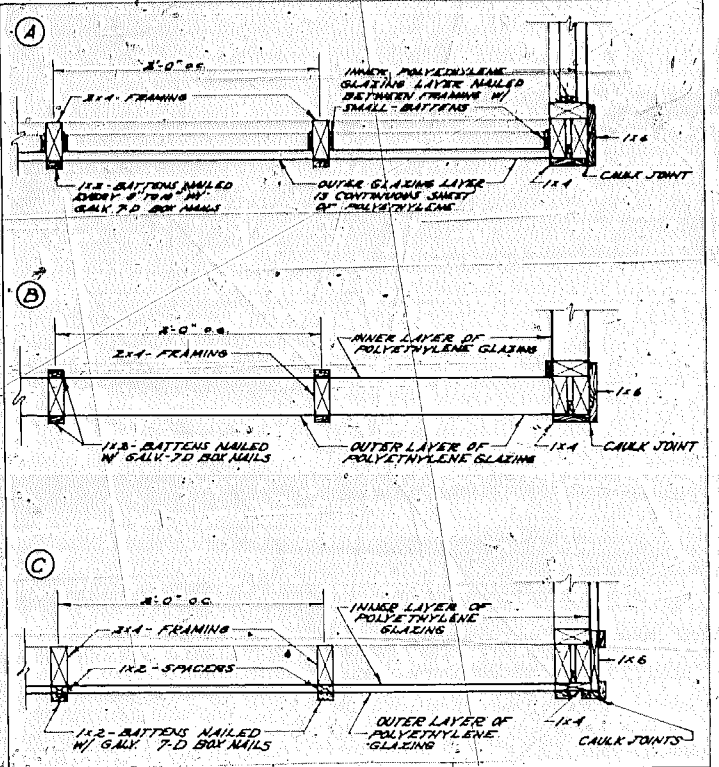


FIGURE 7.7 Three methods of installing polyethylene glazing

A third method is illustrated in Figure 7.7A. In this case the outer layer is fastened to the frame's exterior and the inner layer is nailed *between* the framing.

RECOMMENDATION Polyethylene is a "pay-now-and-pay-later" option that spreads glazing costs over time. For those with little money to spend up front during initial construction, it is a good choice. Although it must be replaced yearly, polyethylene allows for flexibility—you can install a more permanent glazing later as money becomes available.

On the other hand, polyethylene is fragile. Do not install where it can be easily poked, scratched, or pierced. Also, in high wind areas, or where vandalism may be a problem, consider a different option.

FIBER-REINFORCED PLASTIC (FRP)

Fiber-reinforced plastic is a popular greenhouse glazing because it offers a reasonable compromise between cost and lifespan. Also known as fiberglass, or by various trade names such as Kalwall, Filon, Glasteel and Lascolite, among others, FRP is an acrylic plastic resin reinforced with glass fibers. It is the reinforcement that gives this thin material—.025″ to .060″—its remarkable strength. It is one of the most vandal-proof glazings discussed in this manual.

FRP is available in flat roll (48″, 49½″, and 60″ widths), in corrugated sheets (26″ and 50″ widths by various lengths), and (from some manufacturers) in a step pattern (like the surface of clapboards). There are several grades. The medium and high grade FRPs have an ultraviolet inhibitor in the acrylic resin to slow decay caused by the sun's ultraviolet rays. Additionally, the outer surface of high-grade FRP has a thin coating of Tedlar—a highly weather-resistant plastic film. Low quality FRP is not recommended for greenhouse use because it decays too quickly to be worth the investment in time and materials.

Factory-made, double-glazed FRP units are available, but are not discussed here because of their high cost. However, the labor and installation costs for these units are much less than for two individual layers of FRP. Thus, if you are not installing the glazing yourself and are paying high labor costs, you may want to consider these units. Check with the Kalwall Co. for details (see Resource List).

COST: As a moderate-cost glazing, FRP outer glazing with polyethylene inner glazing—with a combined materials cost of about 80¢ per square foot—is a common choice. Include the following items in your total glazing cost estimates: gasketed nails or screws, rubber or wood corrugated strips (needed for the ends of corrugated sheets), silicone caulking, other hardware, and wood battens (which can be surprisingly expensive if you buy them cut to width). The cost of these incidentals may increase the total glazing cost quite a bit.

LIFESPAN: Different grades of FRP have different lifespans. Some medium grades are guaranteed (materials only) for five years; some top grades as long as 20 years. The moist greenhouse environment and the intense sunlight on southern exposures tend to decrease lifespan.

Sunlight, air, dust, and water together react with the resin in the FRP to deteriorate the glazing. As the non-Tedlar-coated FRP—generally the medium grades—ages, the acrylic resin between the glass fibers decays, leaving fibers exposed. This reaction is known as "blooming."

Regular maintenance will increase the lifespan: Keep the outside of the glazing free of dust and soot—particularly in the city. Old and dirty surfaces can be cleaned with steel wool and painted with a restorative clear coating (available from FRP dealers) to extend the lifespan and restore some light transmission. Always check the guarantee carefully before buying FRP.

LIGHT TRANSMISSION: Single-layer FRP transmits 85 to 90 percent of incident sunlight when it is new. Transmission decreases as the material ages, although there is little agreement as to how fast light transmission will decay. Transmission decreases more slowly with the higher quality material and if the outer surface is kept dust- and dirt-free.

FRP diffuses part of the sunlight passing through it, distributing light in a greenhouse more evenly than very clear, transparent glazing materials. Some growers feel that the diffused light promotes more uniform growth in the greenhouse. On the other hand, since FRP is translucent rather than transparent, many people choose other materials if the greenhouse covers a window with a favorite view.

INSTALLATION: Obtain installation instructions from the FRP dealer when you order the material, and follow them. If some of the information presented below conflicts with the manufacturer's instruction, be sure to *follow those instructions or the guarantee may be voided.*

Store FRP in a *dry location, out of the sunlight.* High temperatures or moisture can build up inside a stack or roll of this material and cause clouding.

If you are using the Tedlar-coated material, be sure you *install the FRP with the coating on the outside.* If the sheets or rolls aren't marked, ask your supplier which side is coated. Generally, the inside of the roll is the exterior, coated surface.

FRP can be cut with a carbide-tipped circular saw blade, or with tin snips. The maximum span suggested by one manufacturer for the *flat* FRP in either .025" or .040" thickness is 30 inches.

When fastening the FRP, *neoprene washers should be used* with either nails or screws. Aluminum nails with washers are available in various lengths from FRP dealers. If battens are not used, space the nails 6" apart. With flat FRP, battens are recommended for a neater, longer-lasting installation. However, many greenhouses have been built without them. The nails or screws should be no closer than ⅜" to the edge of the FRP; otherwise, the glazing may break at the edge when cold weather contracts the plastic.

Use silicone caulk and sealant in all joints of the FRP, both where the glazing touches the wood framing and where two pieces of FRP touch each other. Silicone is recommended because it is compatible with the acrylic resin and is elastic enough to withstand the FRP's high expansion—about ¼" per ten feet of length with a 100°F temperature change. Be sure the piece of FRP fits the framing well before applying the silicone. Don't slide the FRP around on the silicone as you will get a messy, poor seal.

Remember that all framing and battens should be primed and painted with white enamel before glazing.

Installation of corrugated FRP (Refer to Figures 7.8, 7.9, 7.10). Corrugated FRP is perhaps the simplest type to install. Corrugated sealing strips are used under the ends of the sheets to seal air leaks. Flat neoprene foam tape of silicone caulk may be used under the sides for sealing.

The wood or solid rubber corrugated end strips are better than the foam rubber end strips, because foam rubber decays too quickly. If you buy wooden strips ("Wiggle board"), be sure the strips match the corrugations of the FRP.

Rafters should be on two-foot centers and should be spaced accurately to accept the 26" FRP sheets. As shown in Figure 7.9, this spacing allows adequate overlapping of adjacent FRP sheets. Space the rafters so the glazing overlaps the sides of the greenhouse about two inches (to eliminate the need for flashing on the side). Also, overlap the bottom edge of the roof enough to shed water over the kneewall glazing. If used on a vertical wall, overlap at least ½" over the corrugated end strip at the bottom.

The corrugated end strips must be caulked and nailed down to the framing before installing the FRP. Use small finish nails. A half-round ~~moulding laid on top of the rafters, will~~ support the overlap joints in the fiberglass. The gasketed nails should be long enough to go through the corrugated strips and the half-round, and bite into the wood below (about 1½" gasketed nails will work). Nails should be spaced every six inches.

The first sheets are installed at the bottom, leeward corner of the roof so the subsequent sheets will overlap to shed wind-blown rain. Pre-drilling nail holes through the FRP will avoid cracking. Nails go in every third *peak* of the corrugations. No nails in the valleys—this causes leaks since water flows down the valleys. If the wood strips tend to split, you will have to drill these, too.

Either a corrugated flashing (available from the FRP dealer)

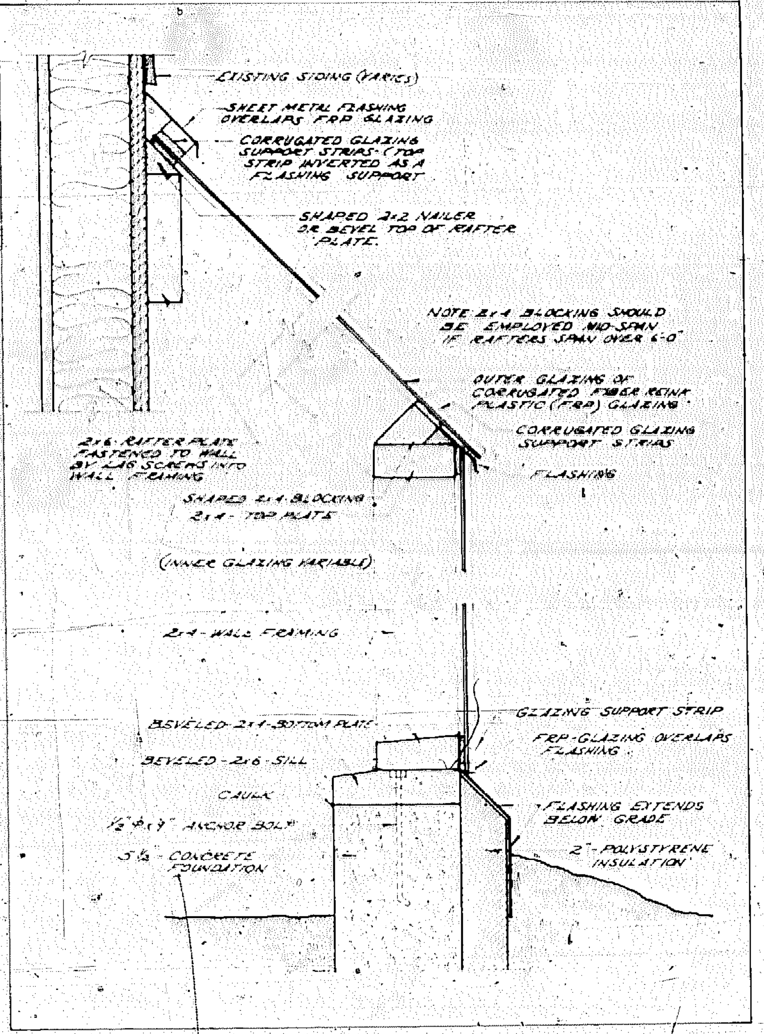


FIGURE 7.8 Corrugated FRP glazing

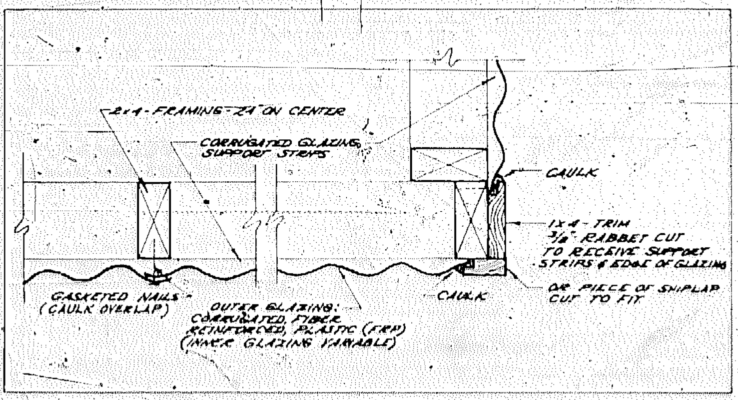


FIGURE 7.9 Corner detail—corrugated FRP glazing

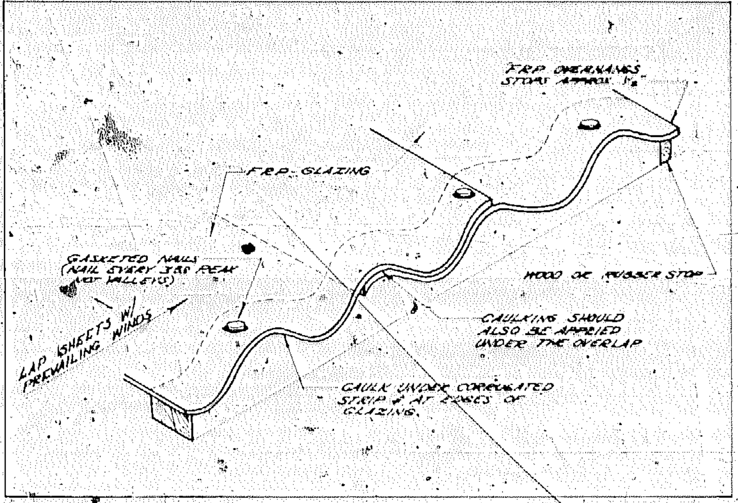
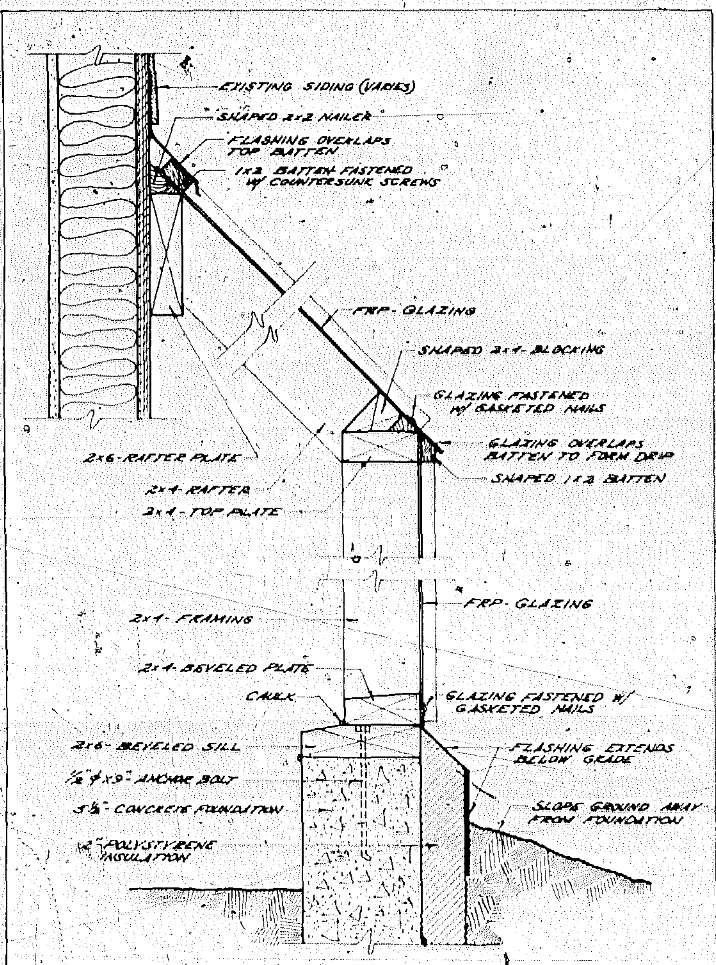


FIGURE 7.10 Application of corrugated FRP glazing

or an inverted corrugated wood strip supporting a flat flashing can be used where the greenhouse roof joins the main house, or at the peak of a freestanding greenhouse. If you use the inverted corrugated wooden sealing strip, drill nail holes. The nails should be galvanized and must reach down into the blocking below. Again, nail through every third peak of the FRP. Use short roofing nails (every 6") and caulk to hold the flashing to the corrugated strip. Pre-drill for these nails, too, to avoid smashed thumbs and split strips. Remember that the aluminum flashing needs to slip under the siding on the house. Be sure to loosen the siding (if any) *before* glazing the greenhouse. It will be difficult to get to the siding afterwards.

Use the same procedure outlined above when installing corrugated FRP on vertical walls (Refer to Ecotope's **A Solar Greenhouse Guide for the Northwest** for a more detailed explanation of corrugated FRP Installation. Also, thanks to Ecotope for some of the tips included above).

Corrugated FRP installed on this pit-type greenhouse in Wisconsin provides a durable glazing for winter snow loads.



• **FIGURE 7.11** Flat FRP—single glazing

Installation of flat FRP (refer to Figures 7.11, 7.12, 7.13). For flat FRP, framing should be on 24" centers if the glazing is 49½" wide; or on 23¼" centers if it is 48" wide. Use blocking in the middle if the framing members are six feet or longer. All joints in the FRP should occur over framing members or blocking, so your rafters must be spaced accurately to fit the FRP.

Cut the FRP to length and try it out for size. If it fits properly, apply silicone to the framing. Then, with a few people holding the top and bottom in place, or with the corners tacked in place with temporary nails (driven half-way in), start nailing the FRP to the framing. Use small nails with heads—4d galvanized box nails—every 12-18" to hold the FRP on until you get the battens in place. Start nailing at the center of the sheets and work your way up and down the edges, alternating from side to side to avoid wrinkles. Pull out the temporary nails at the corners accordingly.

This procedure is not particularly easy. If possible, install the glazing during warm weather (for maximum extension) when there is little wind. Use silicone caulk or Maxi-Seal between overlapping pieces of FRP. (Maxi-Seal is an EPDM rubber seal which laces the flat FRP edges together. For further information, see the Resource List). Silicone is not necessary under the batten.

For double glazing with flat FRP, nail the inner batten down with 7d galvanized box nails (Figure 7.13). Be sure the nails won't be in the way of the screws that hold the outer batten down.

To fasten the outer battens, mark and drill holes (every 12") through the battens while they are on the ground. These holes should be large enough for the **shank** of the screw to fit snugly. Put the batten in place and drill the rest of the hole through the FRP (and the inner batten and inner FRP if you are double glazing) and into the framing. These holes should be the size of the threaded screw **shaft** (see Figure 7.14).

Use metal washers **with neoprene washers** underneath each screw or metal washer and add a dab of silicone before the screw is in all the way. A screwdriver bit in a variable speed drill or in a drill-brace makes the screwing easier. Use #10 round-head plated screws—1½" long for single glazing; 3" long for double glazing.

Vertical battens parallel to the rafters or studs should cover the entire length of the FRP; the horizontal battens must be aligned with the cross blocking. Don't use a horizontal batten at the midpoint or bottom of the outer glazing—it will catch rain and snow. Instead, use gasketed nails every six inches.

Curved installation of flat FRP. Compared to a flat installation, there are several advantages to installing FRP with the surface curved inward between the rafters. The curved installation is better looking and the FRP doesn't wrinkle or have a wavy surface. The curved installation is stronger than the flat installation, so it requires fewer supports. Rain or melting snow on the outside is channeled into the center of the plastic, away from framing members and joints, thereby decreasing the chances of water leakage.

On the other hand, this installation requires a great deal of finish carpentry work, particularly in sealing the top and bottom pieces of FRP. Curved blocking must be constructed to accommodate the bottom side of the FRP at the bottom of the glazing run. Due to the amount of work involved, this glazing method is justified only on glazing runs of 12 feet or

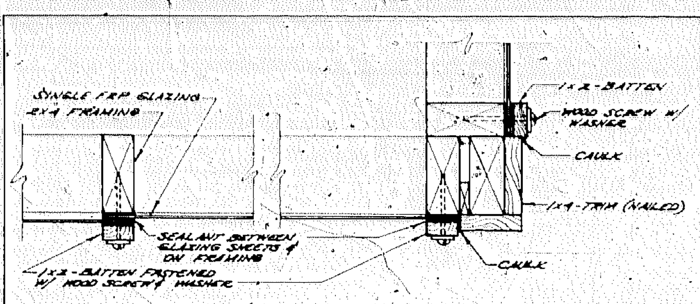


FIGURE 7.12 Flat FRP—single glazing detail

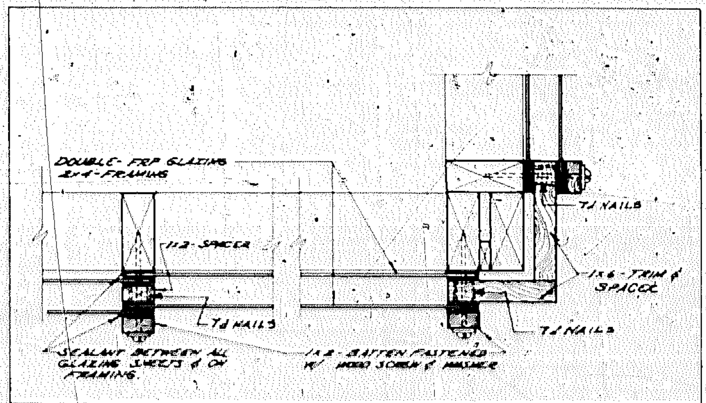


FIGURE 7.13 Flat FRP—double glazing detail

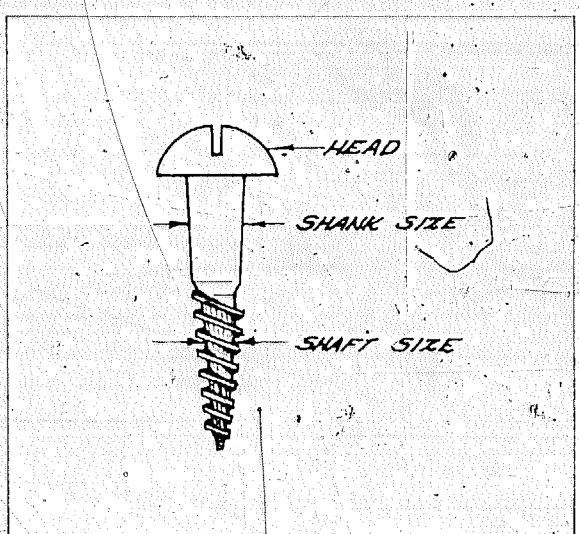


FIGURE 7.14 Sketch of screw

more. Aluminum extrusions have just been developed to make this glazing process simpler. The extrusions, available from Norman B. Saunders (see Resource List), are used on two-foot spacing. Without these extrusions, though, this installation presents many construction difficulties and is not detailed in this manual.

RECOMMENDATION: If you anticipate a favorite view through the greenhouse glazing and want the glazing to last a long, long time, don't use FRP. But for a medium cost, medium-lifespan glazing, one that is fairly easy to install and protects you against vandalism, fiber-reinforced plastic is an excellent option.

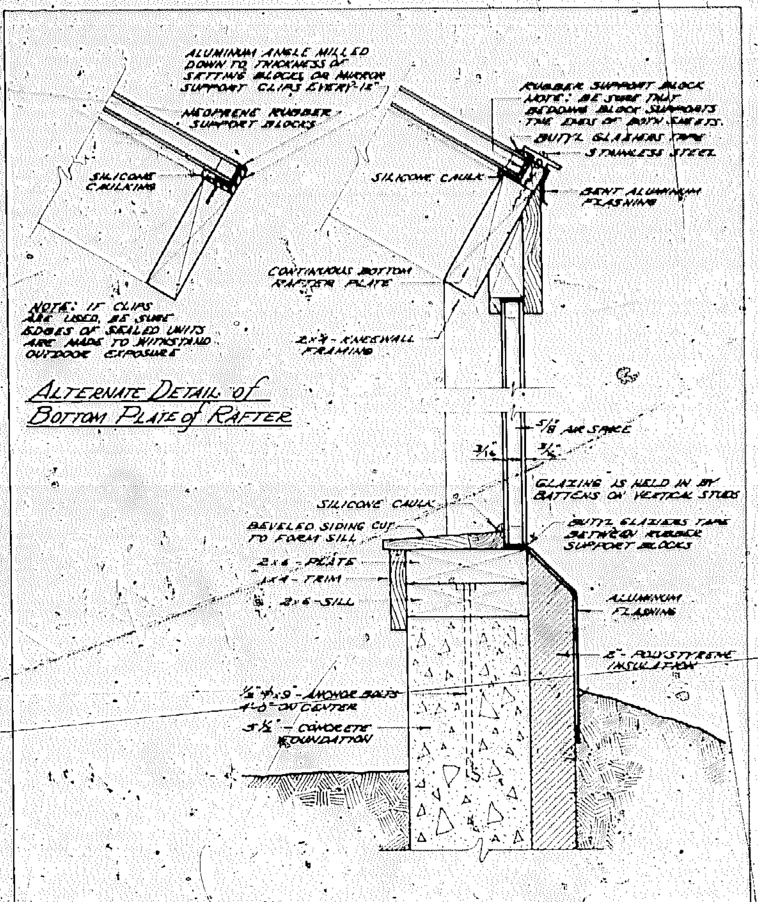


FIGURE 7.15 Double glazing section details

FACTORY-SEALED TEMPERED DOUBLE GLASS

(Refer to Figures 7.15, 7.16, 7.17, 7.18.) Factory-sealed double glass is used most often in cases where the owners prefer to maintain views out windows which may be covered by an attached greenhouse. Often referred to as Thermopane—one of many brand names—sealed glass units also are used if resale value or aesthetics are strong considerations for greenhouse owners.

Top quality units are rather expensive, although standard sizes of sliding glass doors—called "patio door lites"—can cost much less. Also, a glass dealer may sometimes order the wrong size units or accept returned units from customers for other reasons. Hence, he may sell the glass at a low price. If you do find some of these lower-cost units, be sure that the glass is *not* tinted. Standard sizes for patio door lites are 34" × 76" and 46" × 76", and these sizes are considered in this section.

COST: Sealed-glass unit costs vary according to the guarantee on the seal. Lower cost, double-glazed units are often guaranteed for one to five years against condensation forming between the layers. Some higher price units are guaranteed for 10 to 20 years. We will discuss only the lower price units. Always remember to check before buying to make sure the guarantee is valid for units installed in a greenhouse or for units installed on an angle. Incidentally, for safety reasons, any *overhead* double glass units should be made of tempered glass.

Costs can vary from $2.50 to $5.00 per square foot of glass— not including installation hardware. Costs are lower for rejects and standard sizes, and are lower from distributors than from retailers. If your order is large enough, try to get a distributor to handle it. As for associated costs, aluminum batten may run 50¢ per running foot and glazier's tape, 6¢ per running foot. Check local prices.

LIFESPAN: The glass itself will last indefinitely if not broken. But the seal may break, allowing condensation between the panes. The condensation, if there is a lot of it, will run down the glass surfaces, leaving streaks which will decrease transmission of light somewhat. Streaking, though, is more of an aesthetic nuisance than a functional disadvantage.

LIGHT TRANSMISSION: About 70 to 75 percent light transmission can be achieved through double-tempered patio door lites. Large glass sheets will minimize the number of framing members, thereby allowing good overall light transmission.

INSTALLATION: There are many ways to install glass. If the glass is in wood frames already, follow the same procedures outlined for recycled windows. For mounting unframed glass, the following details have been used in several greenhouses. (They are taken primarily from a talk given by Jeremy Coleman at the 1979 Solar Greenhouse Conference in Plymouth, Mass.)

One general consideration when framing glass units is spacing: leave at least 1/8" space all around between the glass and the wood frame—for expansion of the glass and to allow for shifting or settling of the building. Also, be sure that the sealant used at the factory to seal the units is compatible with whatever caulk you use in contact with it. (Check with a local glass dealer.)

The grooves or "rabbets" in the framing members are done on a table saw or with a router before the framing is put in place. The 1" depth of the groove is for sealed units made with 3/16" glass and 5/8" air space. Adjust the depth of this rabbet for other glass sizes: the depth should be the thickness of the glass plus 1/8" for every layer of glazier's tape. Also, the depth must be adjusted if a Kalwall aluminum batten is used, since

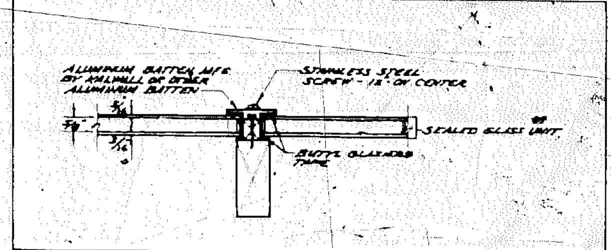


FIGURE 7.16 Section through glazing and rafter (or stud)

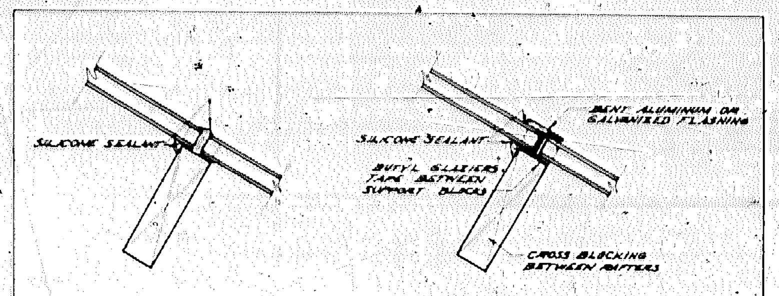


FIGURE 7.17 Section through two types of horizontal joints (between two sealed glass units)

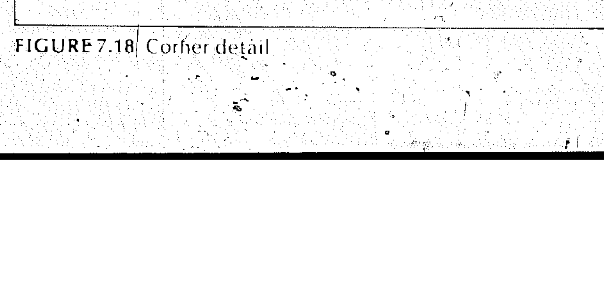


FIGURE 7.18 Corner detail

this batten has legs (see Figure 7.17). Use minimum 2×6″ rafters for 76″ glass lengths. Consult a structural engineering table for larger spans. When the framing is built, take care that the rafters, top and bottom rafter plates, and any other surfaces on which the glass will bear are all in the same plane. If the framing surfaces are warped, the glass or the factory seal may break when tightening down the battens. Again, prime and paint all wood surfaces before glazing.

Use three neoprene setting blocks under each glass unit at the bottom. The blocks, available from glass dealers or installers, must support the edges of both sheets of glass in the unit. Use butyl glazier's tape between the glass and the framing for bedding, and between the glass and the batten for sealing. Pre-shimmed glazier's tape is recommended for use under the glass. This tape contains a small cord of neoprene which prevents the weight of the glass from compressing the tape too much. (Note that a 46″×76″ double patio door lite weighs over 150 lbs.) The tape comes on a roll and is available from glass dealers or installers. It is quite sticky and will squeeze out between the glass and the wood, and also between the glass and the battens when the screws are tightened. For a good visual check on screw tightness, tighten the screws until the butyl just begins to squeeze out. The batten must not contact the rafter.

The aluminum battens sold by Kalwall (check Resource List) are recommended because the stiffeners (the two tabs on the bottom of the batten in the illustrations) prevent the batten from becoming wavy and ensure that it is bearing down tightly between the screws. Simple 1″×1/8″ aluminum bar stock may be used in place of this extrusion but, in that case, screws are required every six inches instead of every 12 inches. 1″×2″ wood battens also have been used, but warping and leakage can be a problem. If you do use wood, use a rot resistant wood and/or prime and paint quite carefully. Do not use a batten on the bottom of the glass as this will catch rain and snow—the side battens will hold the glass in place securely.

Use of common, hardware store plated screws is *not* recommended with aluminum. The galvanic action between the aluminum and the plating will cause corrosion and eventual destruction of the connection. Stainless steel screws, on the other hand, will not react with the aluminum. Although these screws are expensive, not many are required. It has been suggested that a small amount of silicone caulking between plated screws and the aluminum battens would be sufficient to keep the two from touching (and hence from galvanically acting on one another), but this is risky at best. Predrill the battens to the shank size of the screw; then, with the batten in place, drill the holes into the framing to the screw shaft size. (See Figure 7.14 for explanation of "shaft" and "shank" sizes.)

If mirror clips are used as fasteners, seal under the outer edge of the glass with silicone, and use setting blocks on the surface of the clip itself to cushion the glass.

Under the bottom edge of vertical glazing, it is important to use setting blocks and to caulk the inside. Thus, condensation will be channeled away from the groove in the wood. Again, the vertical battens (on the studs) will be sufficient to hold the bottom edge in place. The aluminum flashing should come up just slightly behind the glass so it is securely in place.

Horizontal joints between two glazing units (Figure 7.17) will occur only on long runs of glass. The silicone sealant method is adequate, although not quite as safe as the flashed unit (7.17). Put a small 1/8″ spacer (such as a nail) between the units near each edge and use enough silicone caulk so that the silicone sticks out above the glazing. As soon as the silicone is dry, trim it with a sharp razor blade so it is flush with the exterior surface.

The flashing method requires some patience with bending the aluminum flashing. (A sheet-metal shop could form these parts for you.) The flashing should fit snugly over the bottom of the upper glazing unit.

RECOMMENDATION: If appearance, resale value and views through the greenhouse windows are important to you, use factory-sealed tempered glass. But if vandalism is a problem in your area, and you are trying to keep material costs to a minimum, consider a different glazing option.

SINGLE LAYER OF GLASS

In very warm climates, where freezing weather is infrequent, one layer of glass is sufficient for a solar greenhouse. Or, in cooler climates, a single layer of glass in combination with an inexpensive polyethylene glazing may be used.

COST: Single-layer, tempered $^3/_{16}$" patio door lites should be available from a glass distributor for as little as $1.20 per square foot. Double-strength window glass (single layer) can cost quite a bit less, particularly in case lots. Installation hardware costs are the same as for double glass units.

LIFESPAN: Glass lasts indefinitely, unless it is broken. However, untempered glass should be used only on a vertical or near-vertical wall. Commercial growers with large glass greenhouses who use tempered glass report up to ten percent breakage per year. Untempered glass is not recommended for shallow-sloping attached greenhouses.

LIGHT TRANSMISSON: Light transmission through the glass itself is 87 percent. The more framing you use, the less is the overall transmission.

INSTALLATION: All of the details presented for double-factory-sealed glass units apply to single layer installations—simply decrease the depth of the rabbet. For $^3/_{16}$" tempered glass, use a rabbet depth of $^1/_8$". The depth should be such that the batten will compress the glazier's tape above and below the glass.

In **Solar Greenhouse Guide for the Northwest** an excellent single-glass installation is detailed (Figure 7.19). Instead of rabbeting grooves in the stud, Ecotope recommends using a square neoprene spacer in the center of the studs, glazier's tape under the glass on each side of the neoprene, and a wood batten on top to compress the neoprene and the tape. At the bottom plate, ½" wooden dowels support each piece of glass, and silicone is used in place of the tape. Drawings from Ecotope's book—which is highly recommended, particularly

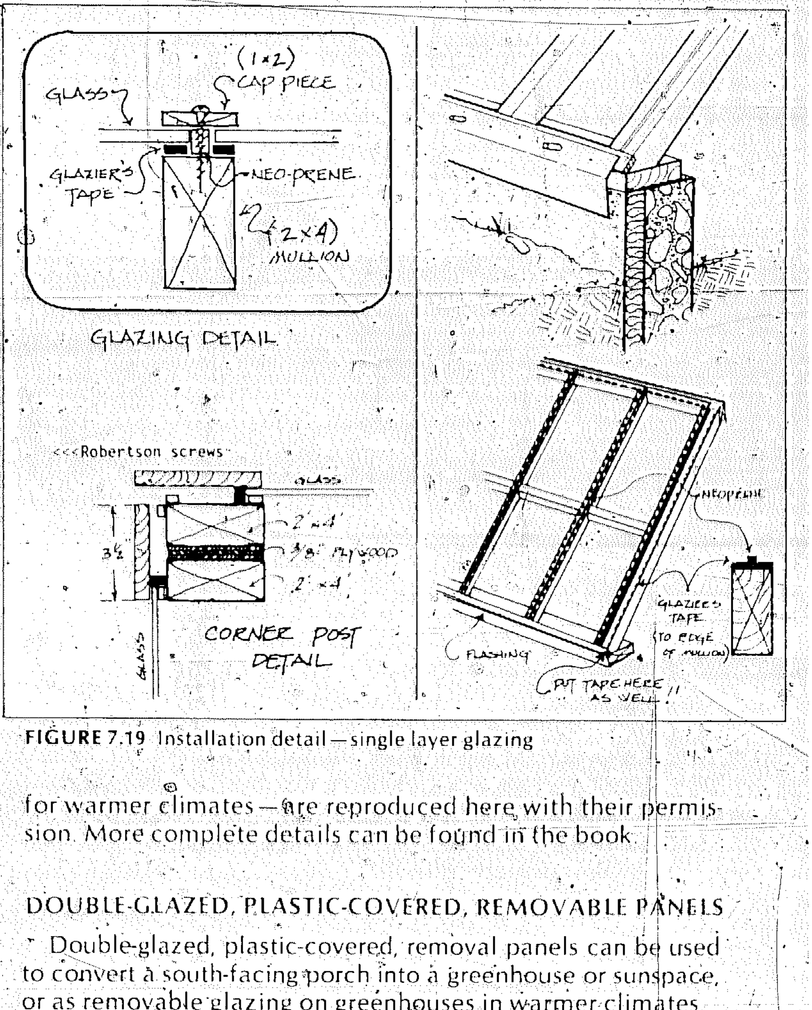


FIGURE 7.19 Installation detail—single layer glazing

for warmer climates—are reproduced here with their permission. More complete details can be found in the book.

DOUBLE-GLAZED, PLASTIC-COVERED, REMOVABLE PANELS

Double-glazed, plastic-covered, removal panels can be used to convert a south-facing porch into a greenhouse or sunspace, or as removable glazing on greenhouses in warmer climates.

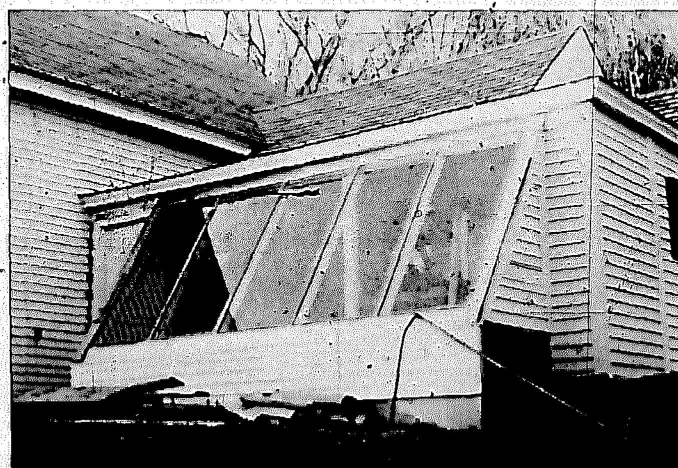
Many older houses had window frames that fit between the porch roof and floor. Depending on its location, the porch was used as a vestibule or sunroom in the winter, and the windows were removed for the summer. If you have a porch that faces anywhere from southeast to southwest, you may be able to convert it to a seasonal greenhouse or sunspace by using removable panels.

Since the glazing will be vertical, little sun will penetrate the space in the summer. Thus, the space will be useful as a greenhouse only in the spring and fall, unless you insulate the roof and floor, and install heat storage for winter use as well. Nonetheless, the space can be quite useful for extending your food production season. Seedlings can be started in the spring, and potted vegetable plants can be brought in from the garden in the fall to avoid the frost. What's more, an uninsulated, glazed-in porch can be a remarkably warm sunspace on a cold, clear winter day. Removable glazing panels also are useful for renters, who would like a greenhouse but do not want to spend a lot of money on someone else's property.

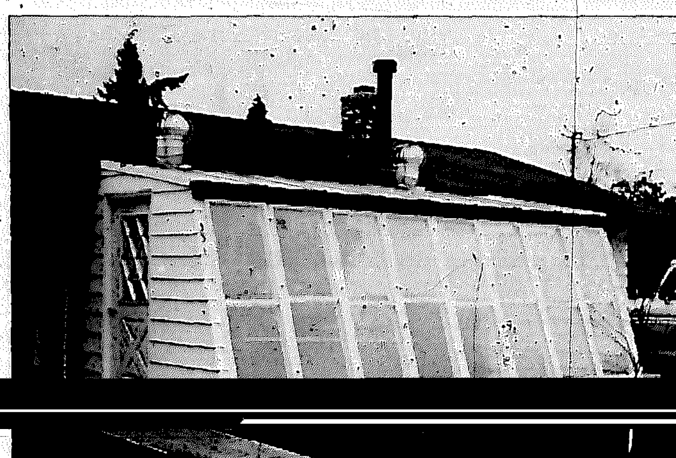
Removable glazing panels made out of plastic and wood have been used with some success on greenhouses in the mild southeastern United States. Operators are able to start vegetables quite early in the spring inside the closed-in greenhouse, and then the greenhouse is opened up to the outdoors when the danger of frost is gone. For more information, check the Federation of Southern Co-ops greenhouse plans, referenced in the Resource List.

COST: Four-mil polyethylene costs about 2¢ per square foot. Four-mil vinyl can cost from 6¢ to 25¢ per square foot, depending on where and how much you buy. ("Vinyl" is short for "polyvinyl chloride" or "PVC.") Six-mil thickness for either plastic is usually 1½ times the cost of four-mil. To get the best use from the material, plan your framing size to accommodate the width of plastic that is available. Figure your costs on what you buy, not on what you use. Generally, vinyl is available from plastics distributors in major cities, from some hardware stores (although it can get expensive there) [illegible]

Cost estimates also should include wood for frames and stops, hooks and eyes (four per panel), little galvanized nails



A New Hampshire family uses double-glazed, factory-sealed, patio door lites to maintain their view to the south (above). In Oregon (below), a single layer of glass provides an attractive glazing for a frontyard greenhouse. Notice how matching siding is used to integrate each greenhouse with the existing structure.



of various sizes, paint, and a roll of tape for patching and reinforcements.

LIFESPAN: The wood frames will last quite a long time if they are kept painted. Polyethylene may last only one year. Vinyl, which costs more, will last up to three or four years, depending on whether it contains UV inhibitors, and on the amount of exposure to wind, sun, punctures, city pollution, etc. Four-mil (.004" thick) vinyl is adequate unless it will get bumped frequently, in which case six-mil is preferable. In most locations, two types of vinyl should be available—you should buy the *more flexible type* for building glazing panels.

For longer-life glazing panels, FRP glazing can be used in place of the plastic films. In that case, use a 2 × 2" frame instead of the 1 × 3" suggested below and follow the installation instructions previously outlined for flat FRP.

LIGHT TRANSMISSION: Two layers of plastic transmit 70 to 75 percent of the light striking them. Fairly large frames can be made with thin wood, allowing good overall light transmission. Also, vinyl is clear enough to permit a reasonably good view through it.

INSTALLATION: There are four basic steps: 1) build stops and supports onto the porch floor or railing, as needed; 2) construct wood frames; 3) fasten plastic film onto the wood frames; and 4) install the panels onto the porch.

Install stops (and posts if necessary) before building the panels. This way, the panels can be built to fit the available spaces. Nail small stops onto the floor or railing of the porch, up the posts, and across the ceiling. 1 × 2s make fine stops, although an even smaller piece of wood, such as ¼" quarter-rounds, would work. Stops should be nailed as close to the outside edge of the porch railing or porch floor as possible to minimize the area where water can accumulate. If the remaining "lip" catches rain, you should bevel it to shed water with a rasp or a plane; then sand and repaint it. Be sure to install the floor stops so rain can drain off the porch when the panels are not in place.

You may have to add posts between the existing porch posts. Straight and dry 2 × 4s are fine for this task. Prime and paint the posts and stops to match the porch, as these pieces will be in place permanently. As always, use galvanized nails.

Measure the spaces for each panel carefully—old houses are rarely square—and make the panels ⅛" *less* in height and width than the measured openings so they will fit easily.

Three suggested methods for building the frames are shown in Figure 7.20. The doweled and the lapped joints are stronger, but the steel reinforced joint also is acceptable if the panels are handled carefully. The steel reinforced joint may be easier to build for people with few carpentry skills.

For small panels — less than 3' X 3' — the frames can be

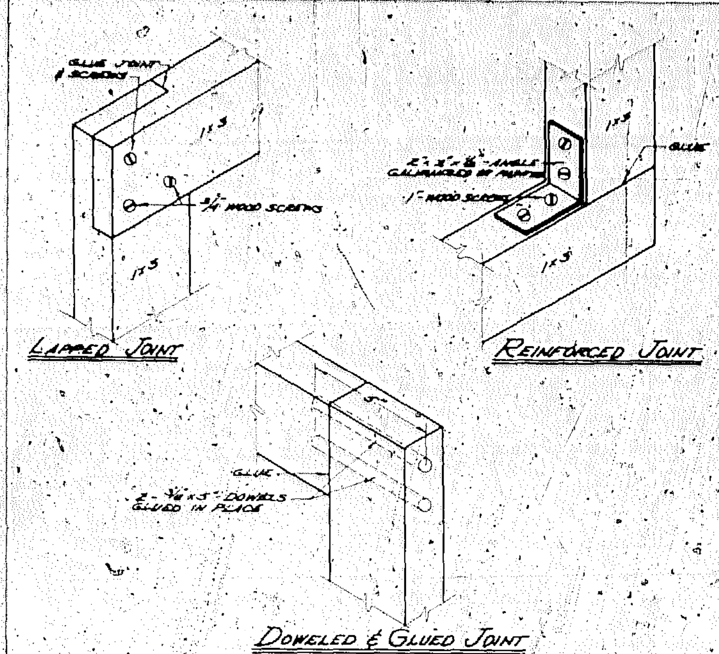


FIGURE 7.20 Three corner details for glazing panels

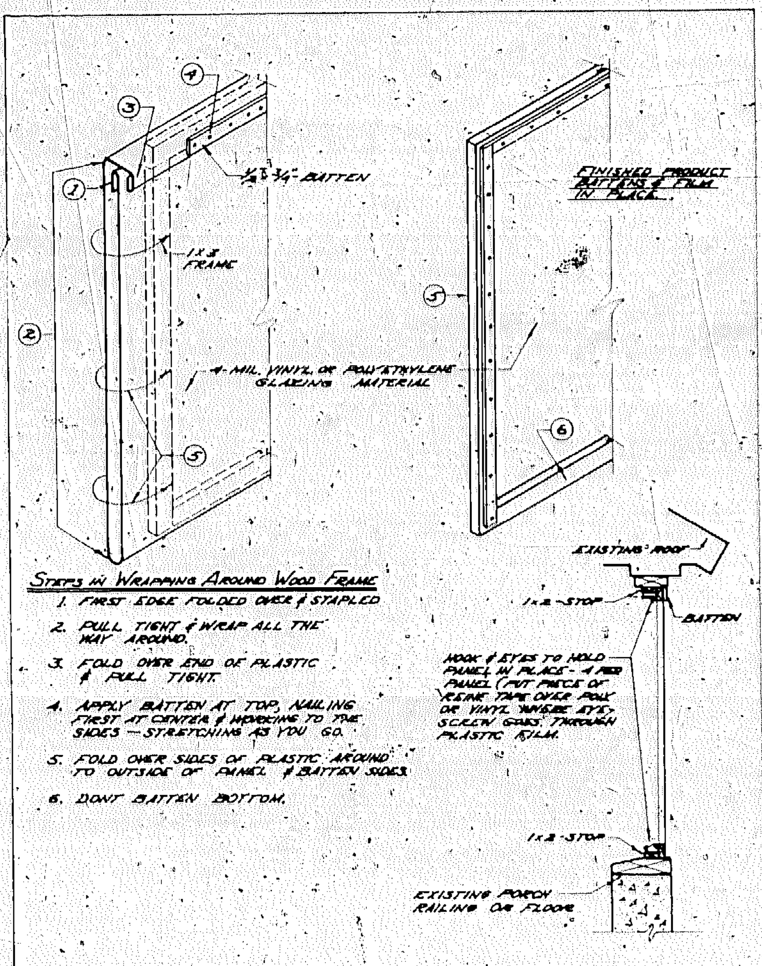


FIGURE 7.21 Double-glazed, plastic-covered, removable panels

made with 1X2s, and for larger panels, 1X3s. If the panels are larger than five feet in either height or width, a center cross-member is advisable for strength. Panels larger than about 6' X 6' should be framed with 2X2s instead of 1X3s.

The wood edges should be smooth and unabrasive against the vinyl. Sand the edges if necessary. Painting the frames will make them last longer and will give the whole job a neater appearance. White is the best color for reflecting light into the greenhouse, and keeping heat off the plastic as much as possible. The plastic will last longer if it is kept cool.

To stretch the vinyl or polyethylene of the frames, see Figure 7.21. With a little care and effort, it's easy to get nicely stretched plastic. If you are doing this during very hot weather, don't pull the plastic as tight as possible. The plastic will contract in cold weather, and may split if it is too tight. At around 60-70°F, though, feel free to stretch it tight. The vinyl will sag a bit as it expands in very hot weather — this will be a problem only if it gets windy. The panels should be removed in hot weather, anyway.

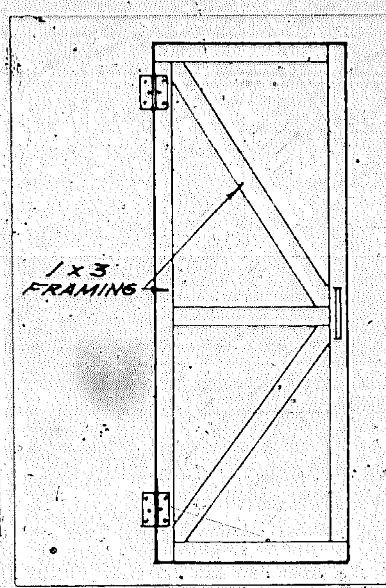


FIGURE 7.22 Sketch of door panel with framing brace

Use four hooks and eyes on each panel (one near each corner) to hold it in place; more may be necessary on larger panels to hold them securely. The eyes go in the stops, the porch posts and the framing; the hooks are fastened to the panels. These hooks double as handles to pull the panels in tightly, and the eyes aren't obtrusive on the porch when the panels aren't there. Before drilling holes for the hooks, place a piece of tape on the vinyl or polyethylene so that the hole doesn't enlarge itself.

A large hinged panel can be used as a door. Omit the bottom stop, and use a framing brace as illustrated in Figure 7.22. Also, you should hinge at least one panel for a vent if you plan to use the sunspace for growing.

RECOMMENDATION: Plastic-covered removable frames are used to convert southerly-facing porches into greenhouses or sunspaces, or for removable glazing for warm-climate greenhouses. They are especially suitable for renters. Don't use plastic-covered, removable frames on slopes less than 60° unless precaution is taken against water leaks.

DOUBLE-WALL EXTRUDED GLAZING

(Figures 7.23, 7.24.) These double-glazing materials are made from either polycarbonate or acrylic resins. The clear plastics are extruded to form long, narrow air channels between two separate sheets. Polycarbonate plastic is quite tough, even tougher than FRP, and some formulations are very fire-retardant. For these reasons, polycarbonate glazings are sometimes used in urban greenhouses. Only one particular brand of the acrylic material, Exolite, is discussed here, but the procedures are similar for other manufacturers' materials (see Resource List).

Exolite is an ultraviolet-resistant acrylic resin that is extruded into a cellular double glazing (Figure 7.24). The material itself, is rather expensive, but only a small amount of labor is required to install it when the factory-made mullion extrusions are used. Thus, if your labor costs are high, you might consider using this material. Another redeeming feature of Exolite is its architectural attractiveness.

Exolite and other materials like it are relatively new in the U.S., although they have been used in European greenhouses since 1970. Exolite is available in 47½"X8', 12', 16' and 20' sheets from CYRO Industries (check Resource List).

COST: The cost is about $2.10 to $2.50 per square foot, plus shipping and the aluminum/PVC mounting extrusion and stainless steel screws.

LIFESPAN: More than 20 years. Acrylics do not yellow.

LIGHT TRANSMISSION: Exolite diffuses the light that comes through it somewhat, especially early and late sunlight. The manufacturer claims 83 percent light transmission through this double-layered material. This estimate, though is probably for brand new material with light shining directly perpendicular to it. Since the sheets are wide and strong, framing can be widely spaced, allowing good overall light transmission. The polycarbonate version of Exolite sheet, recommended when superior impact resistance is required, tends to lose about 1 percent light transmission per year.

INSTALLATION: With the aluminum/PVC extrusion, installation is relatively simple. However, because acrylic plastic expands and contracts considerably with temperature changes, a good deal of care must be taken during installation to cut the plastic sheets to the proper length. The method described below uses the aluminum extrusion on top of wood-rafter framing. The manufacturer suggests several other methods, one of which uses purlins as the only support for the extrusion. (See CYRO's literature for details.)

The extrusions are not predrilled. Thus, counter-sunk holes need to be drilled through the aluminum extrusion, one per foot, alternating sides, to mount them on studs or rafters. One-inch countersunk stainless steel wood screws are fine for use with wood framing. The extrusion is screwed down to the framing underneath. The framing must be built on four-foot centers to accommodate the 47½" width of the plastic.

To eliminate any exact-length sizing, CYRO recommends to install Exolite sheet with floating top ends, covered by a aluminum flashing as shown in 7.23. (See also manufacturers instructions).

Also, for sloped applications, using the shown PVC-AL glazing system, no glazing bars are recommended to be installed horizontally at the eaves. The lower ends of Exolite sheet are closed with the supplied ATS (aluminum terminal section) and PVC-AL mullions are installed in slope direction.

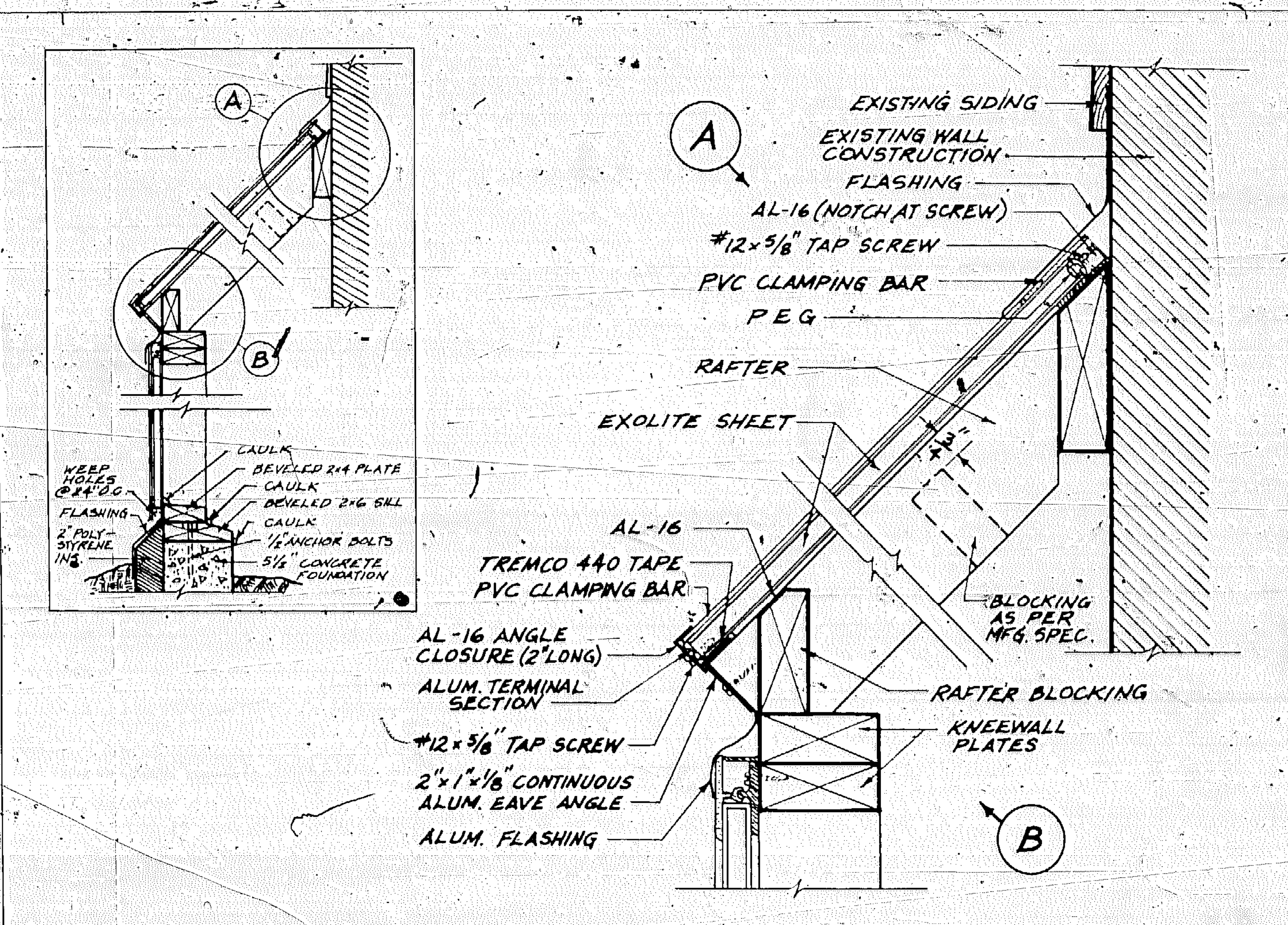


FIGURE 7.23 Exolite glazing using PVC aluminum glazing system mounted directly on wood rafters and studs

4'-00" center to center. To keep the glazing material from sliding down, aluminum fastening angles are screwed into the lower ends of each mullion and a retaining clip is located at the lower panel end in the middle of each sheet to secure Exolite from lifting.

For vertical applications the PVC-AL glazing system can be used to frame Exolite sheets on 4 sides, up to panel length of 8 feet with a top clearance of .25 inches.

With the protective covering still in place on the sheet, cut the Exolite with a 12-tooth-per-inch plywood blade or a 6-tooth-per-inch aluminum cutting blade in a hand-held circular saw. Use a straightedge to guide the saw. Wear goggles and ear protection because little chips of hot plastic can be thrown at you and the cutting makes quite a bit of noise. Vacuum or blow the sawdust out of the air channels and install the end caps provided with the material.

Center the Exolite in the opening using temporary shims between the Exolite and the center part of the extrusions at the lower end of the glazing. Peel off the protective paper coating. Carefully hammer the PVC extrusions on the vertical extrusions using a large rubber mallet, or a wood block and a metal hammer. This must be done when outside temperatures are above freezing because the PVC will crack when hammered in the cold. Then remove the shims. Silicone caulk the joints in the PRV extrusion. It is not recommended to caulk the edges of the PVC where it touches the Exolite. The exposed ends of the horizontal extrusions can be capped with small scraps of flashing and caulk.

To supplement these instructions, get any available literature from the manufacturer.

RECOMMENDATION: If labor is expensive, appearance is important, and/or vandalism is a problem, use these long-lasting acrylic or polycarbonate plastics. But if you are trying to keep materials costs down and prefer to see through the greenhouse glazing, consider a different option.

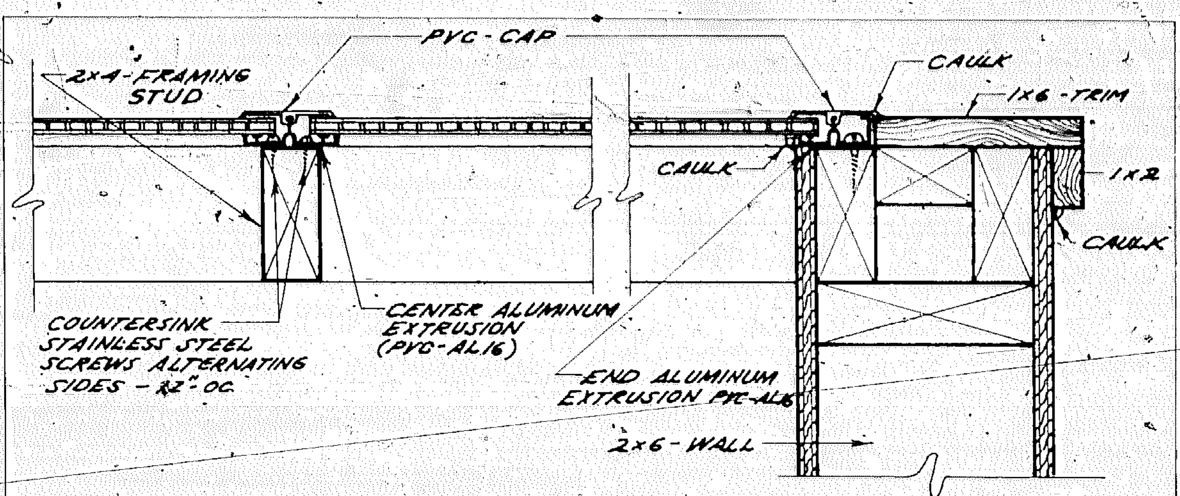


FIGURE 7.24 Corner detail—Exolite glazing using PVC aluminum glazing system mounted directly on studs.

Glazing	Cost/ft.²*	Lifespan	Light transmission percent: Single layer	Light transmission percent: Double layer	Comments
Recycled windows	$.25 – $2.00	Indefinite (if not broken)	50-80**	25-64**	Look for windows in decent condition — recycling/repair efforts can become excessive; should be used in vertical installations, not on sloped surfaces; breakage (vandalism) can be a problem.
Polyethylene	.03 – .10	one – two years	80-90	60-80	The lowest cost but least durable option; must be replaced periodically, but allows flexibility on a more durable replacement; is easily torn or poked; can't see through — no viewing; good inner glazing option
Fiber-reinforced plastic (FRP)	.70 – .90	five — 20 years (depending on quality, care and environment)	85-90	72-81	Medium cost, medium lifespan; very sturdy — offers good protection against vandalism; no viewing; will eventually need replacement.
Factory-sealed, tempered double-glass units	2.50 – 6.00	Indefinite; seal lasts two — twenty years		75	Most expensive option, but thrifty bargains can be found; breakage can be a drawback; attractive appearance offers good resale value; good viewing
Single layer, tempered glass	1.00 – 2.00	Indefinite	85-90	72-81	Good single glazing option in warm climates
Untempered glass	.60 – 1.00	Indefinite	85-90	72-81	Should be used on vertical or near vertical walls only; breakage is a drawback, good viewing
Double-glazed, plastic-covered, removable panels	.25 – 1.50	Depends on plastic used: see above for poly., FRP; vinyl — one to four years		60-80	Good temporary, retrofit option for renters in a warm climate, i.e., enclosing a porch to extend growing season; not for year-round use.
Double-wall extruded acrylic (Exolite)	2.10 – 2.50	20 years minimum		83 (new)	Attractive and sturdy but fairly expensive; easy to install; no viewing
Recycled glass greenhouse	.25 – 2.00	Indefinite	60-70**	36-49**	Be prepared to spend time and laboar to recycle materials properly; breakage is a drawback

* Glazing materials only — no hardware costs included; estimates based on Spring, 1979 prices.

** Percentage includes compensation for framing materials; all other transmission percentages are for glazing materials only.

TABLE 7.1 Summary of glazing options

RECYCLED GLASS GREENHOUSES

In many parts of the United States there are the remains of old commercial glass greenhouses which can often be had for the dismantling. The single-glazed, energy-inefficient structures were abandoned when fuel costs forced operators out of business. Now owners are anxious to be rid of the potentially hazardous remains.

The reason the greenhouses are still standing and still worth salvaging is that they were built to last. The detailing and choice of materials—cypress and cedar wood often were used—were designed to shed water and protect the structures. In addition, the glazing designs minimize solid pieces so that light entry into the greenhouse is optimized. Vent mechanisms can be reused effectively for large passive vent openings.

The pieces can be reassembled relatively easily for use in an energy-efficient solar greenhouse, if reasonable care is taken in dismantling and attention is paid to how the pieces were originally assembled. A second glazing can be added on the inside of the glazing bars without too much difficulty. Plexiglass or polyethlene could be used.

The recycled greenhouses offer not only a charming appearance but an excellent example as well. All greenhouse builders should study the craftsmanship in the design and construction of these durable, old greenhouses.

The following illustrations are reproduced (with permission) from a 1940's Lord and Birnham catalogue. (L&B is still one of the largest commercial greenhouse companies.) These greenhouse details are just a sampling of the many designs from years ago—old greenhouse framing you encounter may be different from those pictured here. Note the attention to sloping surfaces and to the removal of condensation.

(Thanks to Mark Ward—see Resource List—for his help in preparing this section and his excellent work in recycling greenhouses.)

COST: The structures are often free for the taking if you dismantle them properly and clean up the site. Paint, putty and often glass will have to be purchased to reassemble the units.

LIFESPAN: If reassembled correctly, the materials should last indefinitely, except for glass breakage. Scraping off old paint and putty and repainting is necessary to prolong preservation of the wood and steel.

LIGHT TRANSMISSION: Probably about 60-70 percent of the sunlight is transmitted through this system's light frame construction. Note the dimensions of the glazing bars.

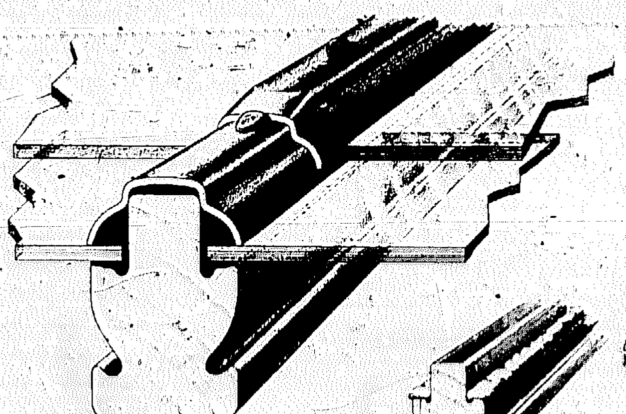
INSTALLATION: When dismantling an old greenhouse note carefully the way the pieces go together. Measure distances between glazing bars, between purlins, between support posts at the edges and in the interior, and make sketches with dimensions. Note the way the vent mechanisms go together, again with sketches. Note also the way the gable ends meet the roof, how the corners are put together, where the nails are put, and the overall dimensions of the greenhouse and foundation. Don't hurry.

RECOMMENDATION: Use recycled greenhouses if the structures are available and if you are prepared to spend the time (and labor) to recycle the materials properly. Don't use recycled greenhouses if vandalism is a problem and labor is expensive.

The New Aluminum-Capped Bar

No Bars To Stripe • No Glass Slipping • No Leaky Roofs

SAVES YOU TROUBLE - MONEY - LABOR ***Protects Glazing With An Impervious Seal***



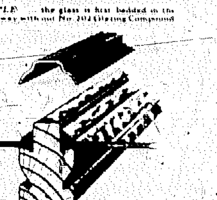
Patent applied for

1 FIRST, the glass is bedded in greenhouse glazing compound (Special L. B B No. 202). No nails are used to hold the glass in place. After the glass is bedded, a lighter grade glazing compound (Special L. B B No. 303) is applied on the face, as illustrated. The Aluminum cap is then bedded in this compound, and held in place with a galvanized screw which is insulated from the Aluminum by a fibre washer.

2 The caps are the same length as the lights of glass, and lap over one another, as pictured. The upper end of each cap forms a solid glass stop for the light of glass above. The cap is held firmly in place by the overlap of the cap above. That raised boss on the upper end of each cap is a spacer, and determines the exact position of the next cap up the roof so the glass is spaced exactly right.

3 Caps are furnished for glass 18, 20 or 24 inches long up the roof. The glazing is started at the eave—one course at a time. The caps are put in place for each course as you go. Caps are cut for short header or other odd lights.

SIMPLE ... the glass is first bedded in the usual way with our No. 202 Glazing Compound

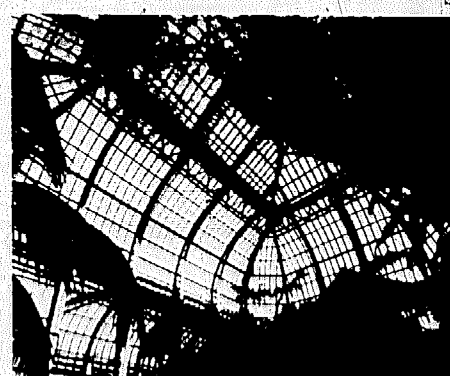


Then the cap is bedded in our No. 303 Glazing Compound

Time-Tested

Great Advancements in greenhouse construction like the new Aluminum-capped bar don't just happen, but are the results of many tests and lifetimes of experience. The basic idea has been used for many years on the finest of private conservatories with outstanding success.

The first greenhouses designed with an aluminum-capped bar were built by us in 1930 at the U.S. Botanic Gardens at Washington, D. C. Caps only half the thickness of the new aluminum bar cap were used. Now, after 10 years, entirely without maintenance, they are as good as the day they were installed.



U. S. Botanic Gardens at Washington, D. C.

Durable

The metal used for the new Aluminum Bar Cap is 18 B & S Gauge, alloy S-3, which is the most corrosion resistant of the strong aluminum alloys.

Repairs are Easy in case a light of glass is broken. It is only necessary to take out the two screws on each side of the broken light, and loosen the two screws of the cap directly above, lift up the cap with the point of a chisel, remove and re-set the glass as usual. It can be done just as quickly as with the usual greenhouse glazing which is held with nails.

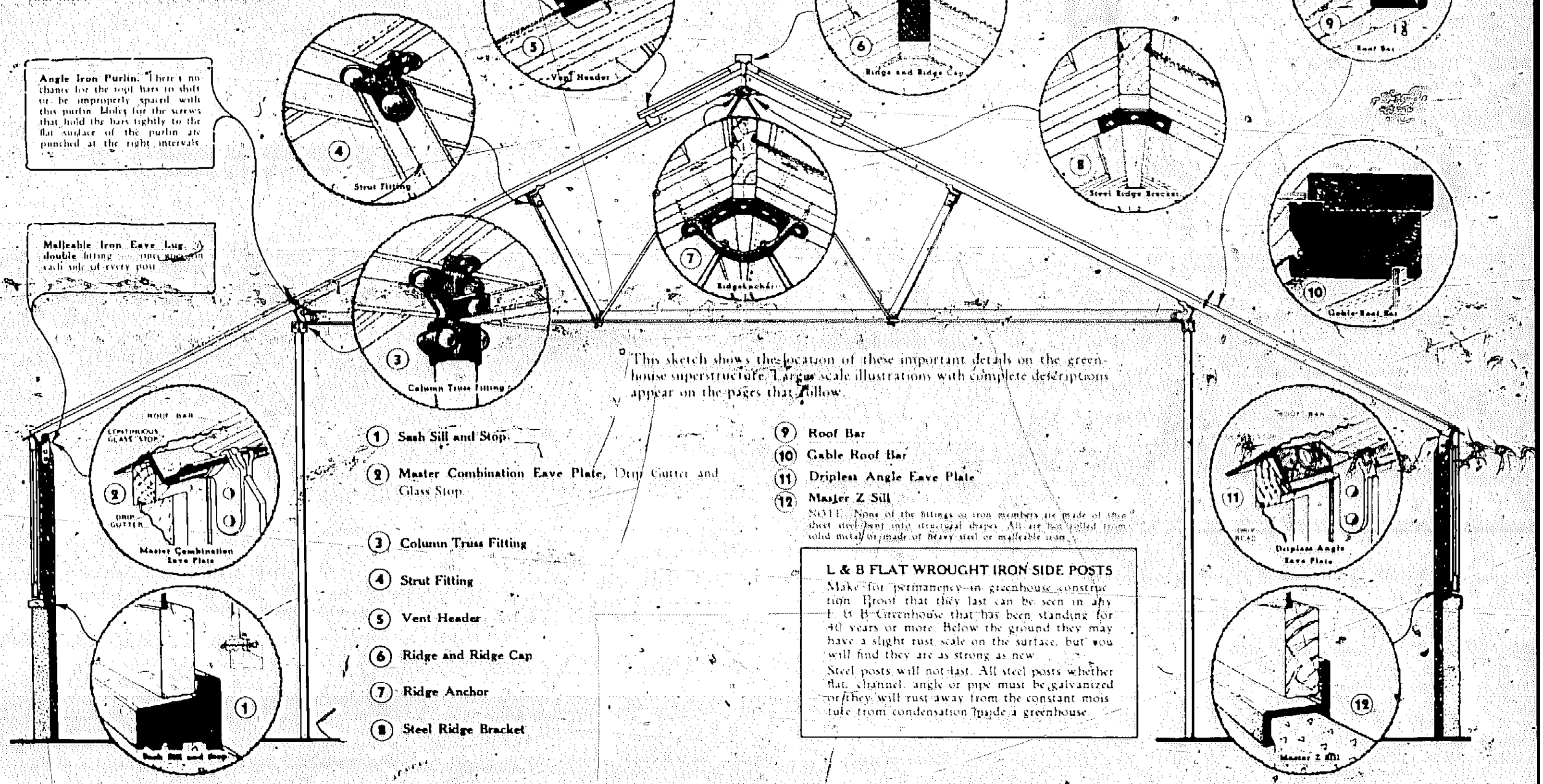
Not A Cure-all—the new Aluminum bar cap is not a restorative which can be put over existing glazing. It is only furnished with new construction and for existing greenhouses which are to be entirely reglazed.

There is no use to put a new construction over an old worn out foundation. Old putty is usually crumbly, chalking out and washing away, and it will continue to do so no matter how well it is capped on the top. Condensation is bound to keep it wet, and it will freeze and push out in cold weather. Furthermore, before caps could be put on the nails would have to be pulled out and the glass pushed up or down a little to fit the exact spacing which would be a very difficult and impractical job.

Get this new Metal-Clad Bar on your next Greenhouse - You save the additional Cost in a few years.

Details Like This Make Greenhouses LAST LONGER

The details shown here are of vital importance to maintain long life and low operating costs in any greenhouse construction. A study of these will show how carefully each is designed and manufactured in L. & B Semi-Iron construction for the big job it has to do on the glass structure. They were developed out of 82 years experience in designing and manufacturing greenhouses—your insurance of a safe investment.



Angle Iron Purlin. There's no chance for the roof bars to shift or be improperly spaced with this purlin. Holes for the screws that hold the bars tightly to the flat surface of the purlin are punched at the right intervals.

Malleable Iron Eave Lug. A double fitting — one placed on each side of every post.

This sketch shows the location of these important details on the greenhouse superstructure. Larger scale illustrations with complete descriptions appear on the pages that follow.

1. Sash Sill and Stop
2. Master Combination Eave Plate, Drip Gutter and Glass Stop
3. Column Truss Fitting
4. Strut Fitting
5. Vent Header
6. Ridge and Ridge Cap
7. Ridge Anchor
8. Steel Ridge Bracket
9. Roof Bar
10. Gable Roof Bar
11. Dripless Angle Eave Plate
12. Master Z Sill

NOTE: None of the fittings or iron members are made of thin sheet steel bent into structural shapes. All are hot rolled from solid metal or made of heavy steel or malleable iron.

L & B FLAT WROUGHT IRON SIDE POSTS

Make for permanency in greenhouse construction. Proof that they last can be seen in any L. & B Greenhouse that has been standing for 40 years or more. Below the ground they may have a slight rust scale on the surface, but you will find they are as strong as new.

Steel posts will not last. All steel posts whether flat, channel, angle or pipe must be galvanized or they will rust away from the constant moisture from condensation inside a greenhouse.

Chapter Eight: VENTILATION AND COOLING SYSTEMS

Ventilation and cooling systems in a solar greenhouse are integral to maintaining a good growing environment as well as comfortable sunspace. Cooling is the more limited topic since it relates specifically to maintaining interior temperatures below some critical level at which crop productivity drops off or plant damage occurs. Ventilation, which helps limit excessive heat buildup inside the greenhouse, satisfies a number of other needs as well: It furnishes plants with fresh air, providing the necessary CO_2 for photosynthesis; mixes greenhouse air that would otherwise stagnate around the plants; and regulates the interior relative humidity. Good ventilation also can aid in plant pollination.

Traditionally, glass greenhouses were built with numerous small, overlapping panes of glass. These greenhouses were not very airtight and the naturally leaky structures permitted substantial (and necessary) ventilation. However, the old greenhouses also permitted very significant heat losses during the heating season.

Today, heat loss is a critical problem in any structure. Solar greenhouses usually are built with maximum control over air infiltration. There is an important balance to maintain between ventilation needs and heating requirements, and ventilation systems must be designed accordingly.

Doors, windows, vents, and fans are the mechanisms that provide ventilation and cooling. Yet these same greenhouse components provide ideal locations for winter heat losses. These moving parts, designed to open and close, require considerable attention to construction detail. Installations must be well-sealed and airtight when closed. Weatherstripping and good latches that compress the weatherstripping are essential. Foamed neoprene weatherstripping, a good, long-life material, should be carefully installed where it will be out of the sun as much as possible and where it will not get damaged in everyday use.

It is wise to install screening across all windows, doors and vent openings, to keep house pests and pets out of the greenhouse and beneficial predatory insects in the greenhouse. What's more, screens will help insure that any insect problems in the greenhouse will not spread to your houseplants.

But airtight weatherstripping and effective screens are not the primary ingredients to good ventilation and cooling systems. Rather, it is the greenhouse operator's responsibility to ensure that these systems function properly. Manual systems must be monitored frequently. These tasks require a conscientious time commitment. One day of neglect could destroy a crop. During the summer, vents must be open in the morning before the sun gets very high in the sky and closed at night after the warmest part of the day. Often these operations coincide quite well with the typical working day—open the vents before you go to work and close them after returning home. But in the winter, days are shorter, and it may be dark and cold when you leave for work, and the same when you return later in the day. Hence, the venting requirements will differ from your work schedule. If someone is at home all day, these operations present no real problems; but if you are trying to operate a solar greenhouse during the winter and all house occupants are absent during the daylight hours, problems may arise. Automatic controls will help, but they are more expensive. Also, if you are using the greenhouse as a space heater, vents between the house and the greenhouse must be operated efficiently and at the appropriate times.

Information presented in this chapter will help you design an effective ventilation system. The relationship between ventilation and plant productivity is explained and alternative ways to reduce venting and cooling needs are described. The difference between natural and forced ventilation is discussed and construction details for various vents are specified. Also, opening and closing mechanisms are explained along with many other helpful tips.

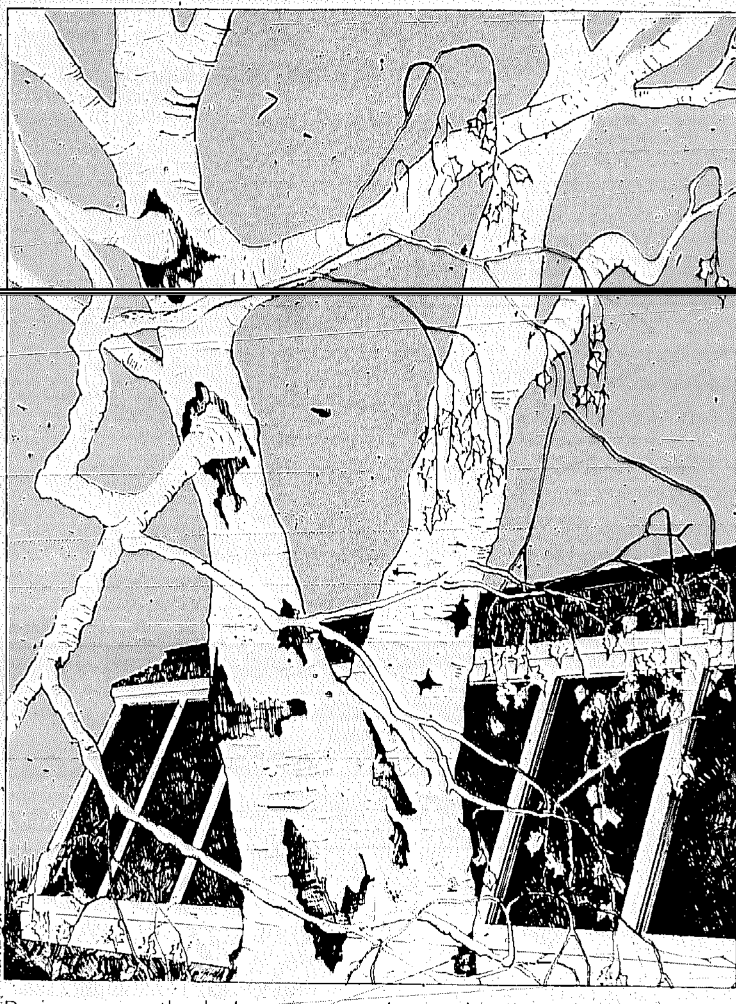
VENTILATION AND PLANTS

As mentioned above, proper ventilation and cooling are essential to obtain satisfactory plant productivity in a solar greenhouse. It is important for every greenhouse builder and owner to understand the interrelationship between ventilation functions and plant needs.

First, there is an optimum temperature range within which all plants grow well. When the interior greenhouse temperature exceeds the upper limits of this optimum growth temperature range, plant productivity starts to decline significantly. Plants become stressed, wilted or damaged, and may possibly die; or else they become more susceptible to insect and disease infestation. Thus, the ventilation system must function as the temperature guardian—reducing excessive heat buildup when necessary.

Secondly, plants need oxygen and carbon dioxide for respiration and photosynthesis, respectively. Considerable amounts of CO_2 are needed during the day, particularly on sunny days, for plant growth to occur, and air is the best source for this carbon dioxide. If the air in a greenhouse is not changed regularly, the plants deplete useable CO_2 levels to the point where their growth begins to suffer. Thus, ventilation must provide fresh air to the plants regularly. Air stagnation affects plant growth as well, because layers of CO_2-deficient air can build up around each leaf, thus retarding photosynthesis. With air movement created by ventilation, these stagnant layers are dispersed and more carbon dioxide comes into contact with the leaf surfaces.

Thirdly, most plants, except perhaps for succulents, grow best in an environment in which the air's relative humidity does not rise above 70 percent. Consistent humidities above this range create conditions in which diseases and fungi can spread. A solar greenhouse's enclosed environment, along with constant plant transpiration and water evaporation from the soil, often can result in significantly higher relative air humidities inside the greenhouse than in the outside air. Thus ventilation systems, by exchanging inside air with outside air, function to reduce the interior humidity and to maintain an adequate growing environment. On the other hand, in dry climates (where humidity is below 40 percent) greenhouse plants may dry out and wilt. In such a case, humidification techniques should be used in conjunction with



During summer, the shady trees protect the greenhouse from overheating. By winter, the leaves will be gone to let in as much sunshine as possible.

venting. One simple technique is to place open containers of water in the greenhouse.

METHODS TO REDUCE VENTILATION AND COOLING NEEDS

There are a number of ways to cut down the need for venting and cooling in your greenhouse. One alternative is to design the greenhouse so that a good deal of the summer sun is blocked from entering. Solid-roof sections or overhangs can be incorporated on the northernmost portions of the glazed roof. However, wherever there is a permanent shade inside the greenhouse, and only diffuse radiation reflecting in from the south, it is difficult to grow most plants unless you can reflect some of the light back to the shaded area. Thus, solid roof sections or other solid overhangs should be constructed to shade very little of your plant beds when the sun is highest in the sky. If you prefer more shading to further reduce solar heat gain, and you build overhangs accordingly, you should consider not planting in the shaded areas during the summer months, but rather when the sun is lower in the sky—say, from August through May. Another option is to grow crops that do not require much light in these shaded areas.

A second alternative is to shade the greenhouse with natural vegetation. If you live in an area of high solar intensity, particularly during the late spring, summer and early fall, your greenhouse interior will probably overheat a lot. In such cases, you can block out some of the sunlight before it comes in through the glazing, by locating the greenhouse where deciduous trees will partially shade it during the summer. Deciduous trees lose their leave in the fall so the winter sun is only minimally blocked out. Ideally, trees should be placed off the southeast and southwest corners of the greenhouse to block morning and afternoon summer sunshine. Such placement will help minimize shading from tree trunks and branches during winter.

As for blocking mid-day summer sunshine, you can grow vines and creepers up the outside of the glazing, preferably on trellises separated from the glazing by a foot or more. These, like the deciduous trees, will provide partial shading during the warmer months, and will lose their leaves (or you can completely remove the vines and trellises if the plants are annuals) in the fall.

Two other techniques often are used to provide some shading for greenhouses. One is to use semi-transparent blinds made of woven polyester, slatted wood, bamboo shades or some other material. The blinds can be rolled down over the glazing during hot, sunny days, and still let in enough light for plant growth. The slatted wooden and bamboo blinds will last for many years if maintained well, while plastic blinds or shades tend to deteriorate after a few years due to ultraviolet radiation exposure.

These blinds and shades are most effective if they are mounted on the outside of the glazing because they stop the sun's rays before they enter the greenhouse. Most roll-down shading systems require simple pull-cord mechanisms to operate. However, they do need to be firmly attached along the top and weighted at the bottom edge to prevent excessive flapping during windy periods. Battens and hold-down clamps along the sides and bottom also work well, although these can be fairly costly (check the Resource List for suppliers).

If you only have a few plants in the greenhouse which require shading, it may be more practical to suspend some semi-transparent material, slatted blinds or cheesecloth immediately above the plants to protect them individually from the direct sunlight.

Another shading technique is to "paint" the exterior glazing with whitewash or one of the other commercially available shading compounds. These products are easily applied to the glazing material with brushes, cloths, rollers, or brooms. Usually, they wash off gradually after a number of rains, so by late summer the glazing is clear again. Soap and water can be used before winter sets in to remove any remaining traces of these compounds. But be careful. Before using any of these paint-type shading compounds, check to see if the product contains any chemicals or chemical compounds that would damage the greenhouse glazing or caulking. Whitewash, for example, is a lime-based solution which can cause rapid deterioration of plastic film and fiber-reinforced plastic surfaces. Thus, it should not be used on these glazings. Whitewash also can react with many surface paints and various putties used to hold glass in place. Additionally, when these solutions wash off, or are washed off, they may eventually end up in some concentrated form in the soil adjacent to the greenhouse. Protect your lawn and garden. Don't use hazardous products.

THERMAL STORAGE—a hidden cooling system

It may seem odd, but one way to reduce the need for venting and cooling your greenhouse is to *add more thermal storage*. It helps, and here's how: The more thermal mass inside the greenhouse, the more excess heat it can absorb and store during the day. This excess heat is released when ambient temperatures are cooler—that is, at night.

The process is similar to that which occurs during the winter, when heat stored during the day is used to get the greenhouse through the cold nights. In summer, we don't need to worry so much about the nighttime temperatures; rather, heat storage is used to help remove excess daytime heat.

Using thermal mass will not eliminate totally the need for other venting or cooling systems. It will however, reduce the amount of venting or cooling required.

NATURAL VS. FORCED VENTILATION SYSTEMS

Venting and cooling techniques generally can be divided into two categories: **natural** and **forced** systems. Natural ventilation is perhaps the simplest and least expensive way to vent a greenhouse. Natural systems can rely on the prevailing winds surrounding your greenhouse to induce natural air movement throughout the greenhouse, or on the tendency of hot greenhouse air to rise naturally. Forced systems, on the other hand, rely on fans to move air through a greenhouse and provide adequate ventilation.

Natural Ventilation

If you build a greenhouse in an area where the wind always blows during the warm, sunny hours of the day, then windows or vent openings along the greenhouse's windward and leeward sides should provide sufficient ventilation. To take best advantage of the wind, the windward vents should be slightly smaller than the leeward vents (Figure 8.1). If, on the other hand, you build where the wind is irregular and undependable, then you will have to induce air movement by creating a "chimney effect."

To induce natural air movement, vents can be placed on the east and west ends of the greenhouse near ground level and also near the roof's peak (Figure 8.2A). If your greenhouse is more than twice as long as it is wide, you also should put some lower vents in the south wall, at or below the height of the planting beds (Figure 8.2B). An excellent variation is to install kneewall and ridge vents along as much of the greenhouse's length as is practical (Figure 8.2C). On hot, windless days, with the upper and lower vents open, the warmer, lighter greenhouse air will rise out through the higher openings while cooler ground-level air is drawn in through the lower vents. The air movement caused by this "chimney effect" is slow, but can be sufficient to maintain acceptable interior temperatures.

The total area of the upper vents should be at least one-sixth of the greenhouse floor area. There is an optimum ratio of exit to entry vent areas, as well, but the ratio depends

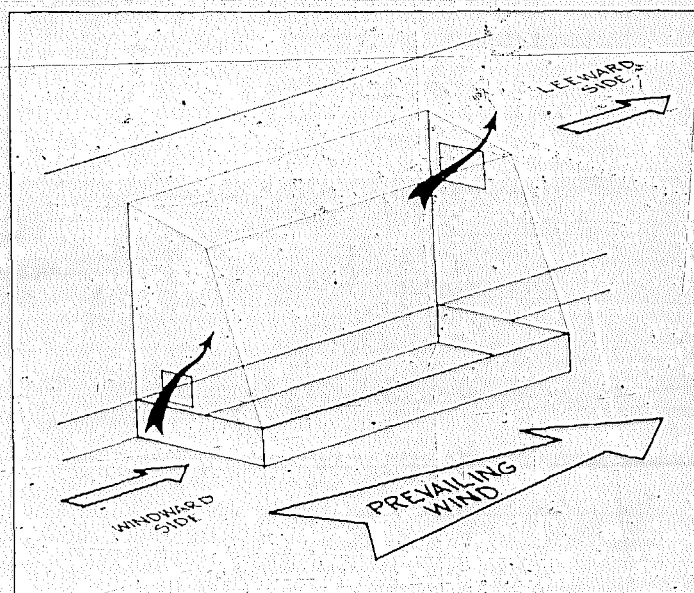
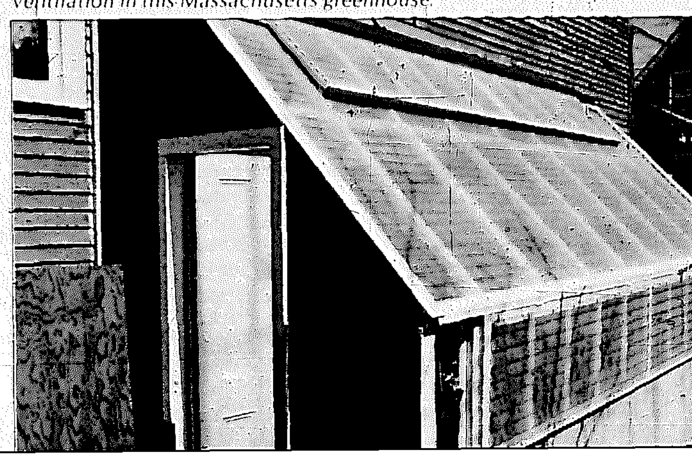


FIGURE 8.1 Taking advantage of prevailing winds—natural ventilation

A good-sized ridge vent coupled with a long lower vent that covers almost the entire kneewall provide excellent natural ventilation in this Massachusetts greenhouse.



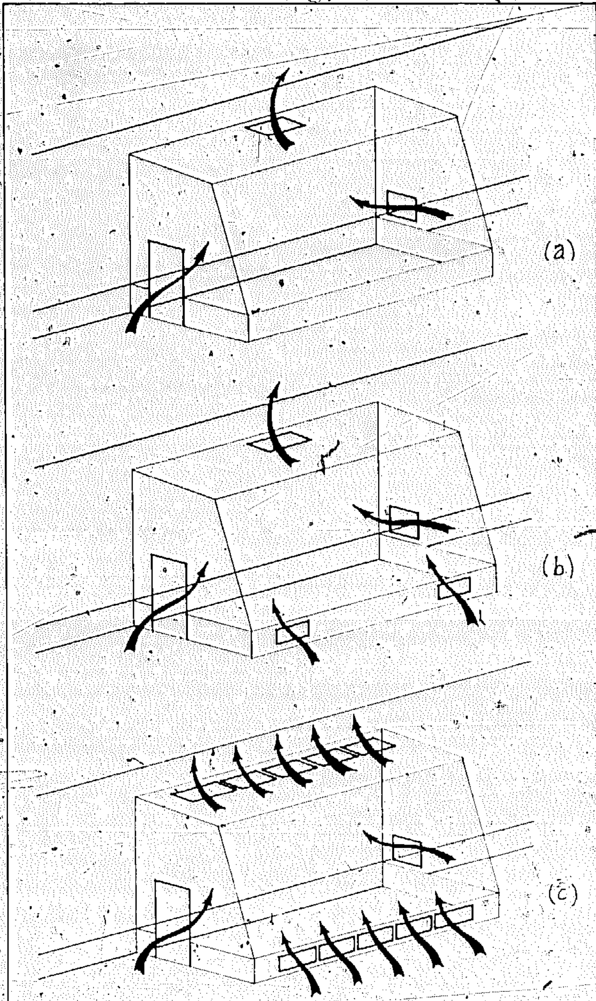


FIGURE 8.2 Three natural ventilation schemes

SOLAR CHIMNEYS

The Ecotope Group of Seattle has developed a low-energy venting system called the thermal stack or solar chimney. The chimney (Figure 8.3) rises several feet above the greenhouse peak. It is about 2 ft. square in cross-section, glazed on the south side, insulated on the other three sides, and painted black on the inside. Air in the chimney is heated by the sun, becomes more bouyant, and rises up and out. In the process, greenhouse air is drawn into the chimney base (at the greenhouse peak). With the lower greenhouse vents open, the resulting chimney effect can be quite significant, providing a ventilation rate upwards of 600 cubic feet per minute. The hotter the sun, the faster the ventilation rate. The Ecotope system is controlled automatically by a heat motor at the vent opening between the greenhouse and the chimney.

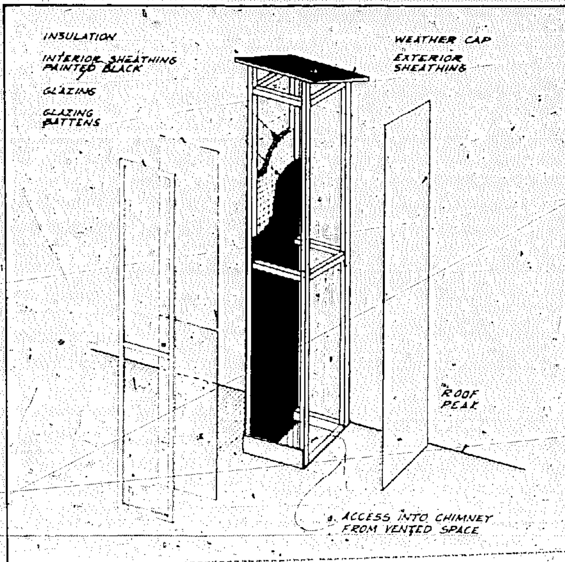


FIGURE 8.3 Solar-enhanced thermal chimney (solar chimney)

on many factors, including the height difference between the openings, the normal ambient and interior temperatures and relative humidities, ground cover, etc. A general rule of thumb, though, is to make the total area of the upper vent openings approximately 20 to 30 percent larger than the total area of the lower openings. In tall greenhouses (higher than ten feet), the greenhouse *door* can be included as part of the *lower* vents. In low greenhouses, the top third of the door can be included as part of the *upper* vents.

Forced Ventilation

Using fans to move air in and out of a solar greenhouse can be an appropriate option to natural ventilation systems. One relatively small fan and an opening on the opposite side of the greenhouse can replace a series of roof and wall vents and is less expensive to install. Building tight-closing, easy opening vents that allow natural ventilation also requires good finish-carpentry skills which may be unavailable. An associated advantage of fans is implicit: With fewer vent openings, there is less possibility of air (and heat) leakage around edges. Fans also can be fitted with an inexpensive thermostat for automatic operation.

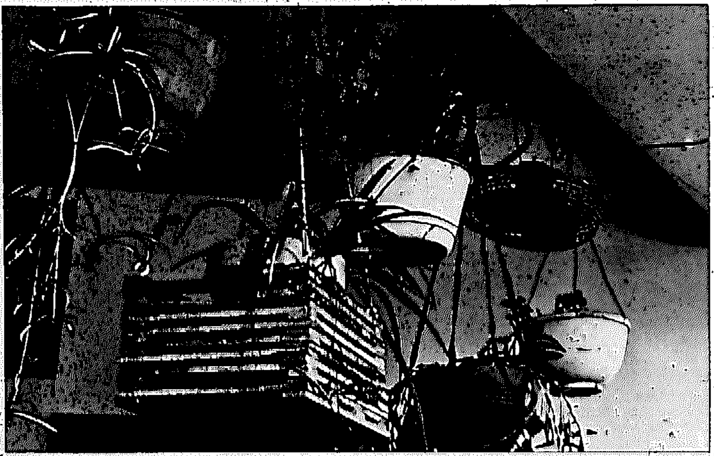
On the other hand, fans require energy to operate, and electricity can be costly as well as less reliable than is necessary. If your site is prone to even a limited number of electricity "blackouts" during the hot summer months, you might not want to rely entirely on fans to keep greenhouse temperatures within tolerable limits. Fans also make some noise, no matter how well-mounted, and the larger the fan, the more noise it will make.

The decision between natural and forced ventilation systems must be weighed carefully. For example, if you have to drive some distance to get to your greenhouse, it will be inconvenient to have to tend to vents in the morning and evening. In such a case, natural circulating vents with reliable automatic openers or an electric fan with a thermostat are good choices. You will find that automatic ventilation is by far a better energy investment than driving your car several miles to open vents.

To optimize energy use, you must use the right size electric fan for your ventilation needs. Conventional greenhouse manufacturers recommend that summer ventilation rates should be in the order of one complete air change every two to three minutes. But a solar greenhouse is not a conventional greenhouse. It is not glazed on all sides, and it has a large heat-storage mass which provides considerable cooling during the day. Couple these characteristics with some of the shading techniques outlined earlier and you have a greenhouse interior that requires less cooling than a conventional greenhouse.

You should be able to get by with a fan of one-quarter or, at most, one-half the capacity recommended for a conventional greenhouse. For solar greenhouses with little shading, one air change every *five* minutes should be adequate. For greenhouses that are at least partly shaded during hot periods, one air change every eight to ten minutes is adequate. As an example, consider a family-size greenhouse with a 200 sq. ft. floor area. If the average height of the structure is eight feet, the total interior air volume is approximately 1,600 cubic feet. If it were a conventional greenhouse, the recommended ventilation rate for a fan would be 530 to 800 cubic feet per minute (cfm). But, a well-designed solar greenhouse might only require a fan capable of moving air to 150 to 400 cfm.

The simplest arrangement for a forced-air ventilation system is an exhaust fan situated near the peak at one end of the greenhouse and a low-level wall vent at the opposite end. The exhaust fan should have shutters that are opened outward by the force of the moving air when the fan is on, and close by gravity when the fan is off. The vent opening also can be built with inside louvers that open under the suction of the exhaust fan. Small, good quality exhaust fans can be inexpensive and use little electricity. A cooling thermostat on the fan, which will turn on the fan only when it is needed, will save energy and save the trouble of turning the fan on and off. Any electrician's supply house can supply you with a fairly low-cost (less than $20) cooling thermostat which will work on the same 110 volts as the fans (called a "line voltage cooling thermostat").



This small circulating fan keeps air moving around the plants, thereby eliminating moisture and carbon dioxide buildup.

AIR PRE-WARMING, CIRCULATION, AND COOLING

Another important consideration regarding ventilation systems is the necessity to "treat" the incoming air. In winter, air must be pre-warmed so that the plants are not hit directly by a blast of cold outside air. Additionally, when the greenhouse is closed tight to conserve heat, it is important to keep interior greenhouse air moving. In summer, air must be cooled for safe ventilation when ambient temperatures are very high.

Conventional large and medium-scale greenhouses often take in ventilation air, mix it with circulating air and pass it through space heating furnaces. But for low-cost, family-sized, attached solar greenhouse, it is very difficult to economically justify such a system. For one thing, it is not so important to ventilate frequently during winter since temperature build-ups are not as great as during the summer. Also, winter days are not as long, so less photosynthetic activity takes place, and there is a reduced need for carbon dioxide. On winter days when venting is required, exchanging greenhouse air with air from the main house will satisfy the plants' needs for fresh air and will transfer heat to the main house. Subsequently, the need for an air pre-warming system is negligible.

For freestanding greenhouses, though, some minimal daily quantity of outside air is needed to replenish carbon dioxide levels, and some air pre-heating may be necessary. If cold air has to be brought directly into the greenhouse, bring it in higher up where the greenhouse air is the warmest and where cold air will not come into immediate contact with the plants. Circulating fans can mix up the warm and cold air and distribute it throughout the greenhouse. In such circumstances, these upper vents should remain open only for short periods; otherwise, heat losses can be excessive.

If your greenhouse has an entry vestibule or a potting and work room, these areas can be used to pre-heat incoming cold air. Vent openings should be situated so that when warm air is being vented out near the peak of the greenhouse, cold outside air entering to replace it is drawn through the vestibule or work room, and then into the greenhouse proper.

For attached solar greenhouses, air circulation between the greenhouse and the heated building (using doors, windows or vent openings) often is the only winter ventilation necessary. However, a **circulating fan** may be useful to keep air moving around the plants. Fans agitate and disperse localized moisture and carbon dioxide build-up around the leaves, decreasing opportunities for mold to grow and the need for ventilation with cold outside air. A small 50-150 watt fan will usually be adequate for greenhouses from 100 to 200 square feet of floor area. Fans should be hung from the ceiling, or placed in an out-of-the-way location. When the fan is turned on, air should be moving most plant leaves slightly. If the fan doesn't move the leaves, it is probably too small or not properly placed. A small polyethylene tube taped to the fan can be used as a duct to distribute the air. Generally, circulating fans are needed only in freestanding greenhouses or in attached greenhouses when air exchange is limited between the house and the greenhouse.

As for air cooling, if the shading techniques and venting sytems are not successful in reducing your summer greenhouse air temperatures to acceptable levels, there is an additional step you can take: use water to cool the greenhouse air. If water is allowed to evaporate in the greenhouse, it will absorb a lot of heat energy from the air while changing from a liquid to a vapor. Heat absorption by the water cools the air.

There are a number of ways to evaporate water. The simplest is to hose-down greenhouse walkways and storage areas around noon on a hot, sunny day. The resulting water evaporation from these surfaces will increase the humidity and decrease air temperature inside the greenhouse.

Another option is to install evaporative cooler units (purchased from greenhouse suppliers), complete with a fan, cooling pads and water recirculating systems. Smaller units, suitable for family-size greenhouses, have ¼-hp fans. On hot days, a single evaporative cooler can use over 50 gallons of water. Evaporative cooling systems are more effective in drier climates, or on days when the outside air has a reasonably low relative humidity. The systems become less effective as the ambient humidity increases because the air's moisture-holding capacity is reduced, and less water is able to evaporate from the pads or wicks.

The fact that evaporative coolers increase the air humidity in a greenhouse is a point worth noting. For drier areas of the country, higher humidities present little problem, and in fact, can provide a better climate for plant growth. But in humid regions, where evaporative cooling is less effective, any humidity increase inside a greenhouse can create a situation where disease and fungi could spread rapidly. Thus, shading and ventilating should be used extensively in very humid areas.

HOUSE VENTS FOR ATTACHED GREENHOUSES

Attached solar greenhouses require two venting systems: one through the common wall to the house, and the other to the exterior. The two systems serve different purposes. Air exchange with the house takes place predominantly during the cooler seasons of the year. Excess greenhouse heat and some humidity are transferred to the main house during the day, and (if you decide to set your backup heating system up this way) house heat is transferred to the greenhouse at night. Venting to the outdoors, on the other hand, will be necessary during the warmer months to maintain moderate greenhouse temperatures.

The easiest way to ventilate between the greenhouse and the house is to use existing doors and windows. An ideal situation is to have one or two basement windows and a main floor window (six to eight feet above the ground) enclosed within the greenhouse. In this case, cooler basement air enters the greenhouse, warms and rises inside the greenhouse, and re-enters the house through the upper window.

Generally, large venting areas are not required between the house and greenhouse because heat build-up inside the greenhouse is not that extensive during the winer, and neither is the need for fresh carbon dioxide. Total vent areas should be approximately *eight percent* of the greenhouse floor area, although larger openings will facilitate air flow somewhat. The area of the upper openings should be about *30 percent* greater than that of the lower openings.

A single door between the house and greenhouse can be a good ventilator as well. Cooler house air near the floor will pass through the open door into the greenhouse, and warmed greenhouse air will enter the house near the top of the door.

If no openings, or just one window, exist along the common wall, then you must construct some ventilation ports through the wall. When building vents, the closer you put the lower vents to the greenhouse floor, and the upper vents to the greenhouse peak, the better will be the ventilation effect. Building these ports through the common wall is a job *you* will have to decide how to do best. The construction materials used in the wall, the spacing of the studs in the frame and the aesthetics of the adjoining room are some of the variables

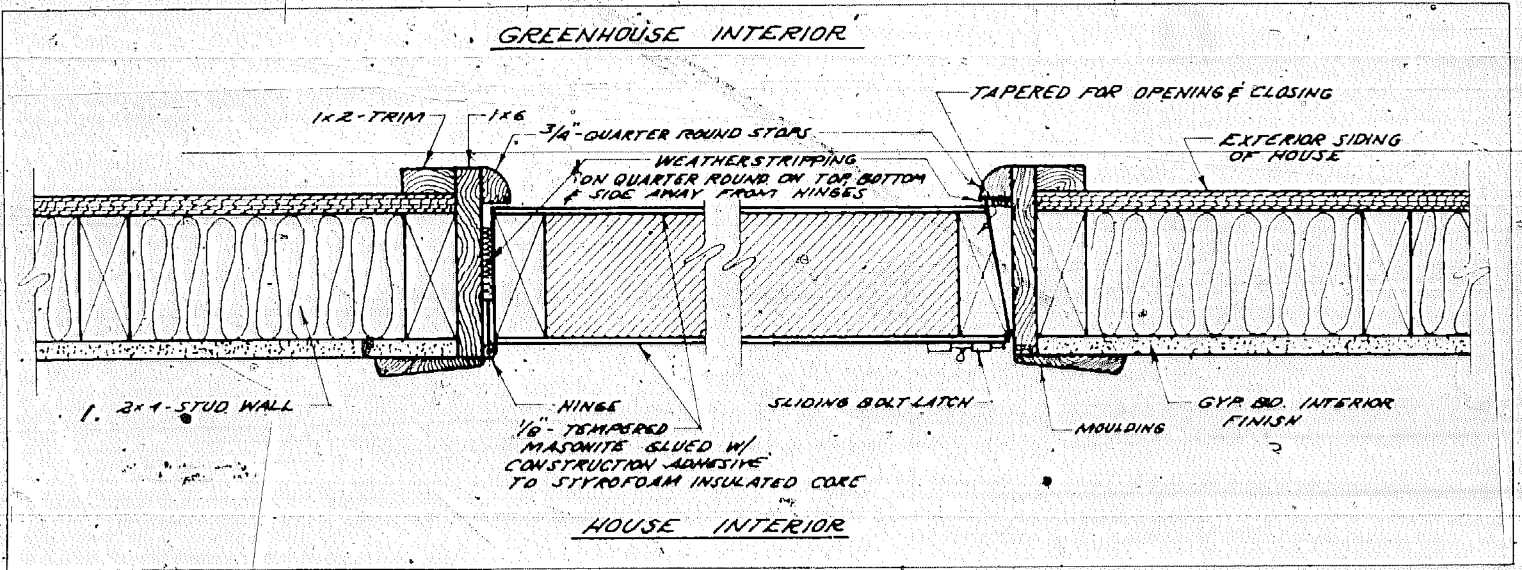


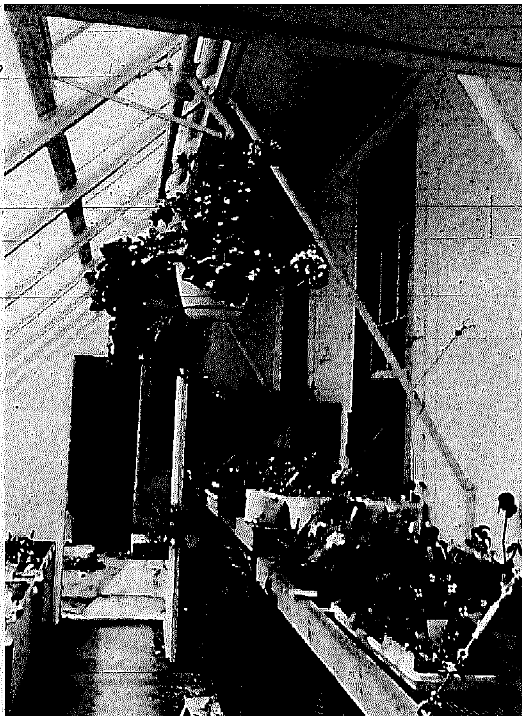
FIGURE 8.4 Horizontal wall section of side-hinged door type vent (from attached greenhouse through solid wall of house)

which make it difficult to give specific details. Wood siding is easier to work with than masonry. You can find out how to do small masonry jobs in the **Readers Digest Complete-Do-It-Yourself Manual** (Pleasantville, New York, Readers Digest Association, 1973).

For houses with wood framing you can use the studs as part of the vent frame. Since vent openings are not wide, there is no need to add a lintel to support any of the wall's weight. Details of a typical vent cut through a stud wall with wood siding are illustrated in Figure 8.4.

Cut a hole through the wall between the studs, and frame-in the opening using the studs as the sides. If the studs are 2 × 4s, use 2 × 4 blocking at the top and bottom to frame in the hole. Trim can be placed around the vent opening for good looks. Lighter 1 × 4s can be used for framing the vent door. Be sure to taper the side of the door opposite the hinges so that the door will close easily. A ¾" quarter-round nailed to the 1 × 6 which frames the inside of the opening provides a surface for the weatherstripping on these sides. On the hinged side, the weatherstripping can be placed on the same face as the hinges. Removable-pin butt hinges will make the job easier. Construct the vent door to fit snugly when closed, and hinge it at the side. A sliding bolt latch into the house interior trim will hold the door shut. Be sure that the quarter-round is securely fastened to take the pressure of the latch.

It is best to insulate the vent door. You may decide sometime in the future not to operate the greenhouse for food production in the winter, but rather to use it only as a daytime



Two windows along the common wall allow greenhouse heat to warm the adjacent Community Action Center in Gloucester, Massachusetts. Note, if there is only one window between the house and the greenhouse, it is wise to build a small wall vent (close to the floor) to promote natural air circulation and adequate venting.

space heater. In such a case, uninsulated vent doors can be serious heat-losers. Use Styrofoam insulation because fiberglass may shake loose after many openings and closings.

It is a good idea to install screening across all vent openings between the greenhouse and main house. The screening will keep greenhouse pests out of the house and household pets out of the greenhouse. If you feel that greenhouse temperature buildup becomes too high, or if it is not practical to build vents large enough for natural circulation, very small blowers placed in the upper vent leading to the house or circulating

fans can be used. These are typically units of 100 watts or less and are capable of moving up to 400 cubic feet of air per minute for a 200-300 sq. ft. greenhouse. These fans can be either thermostatically or manually controlled. A line-voltage cooling thermostat sensing the greenhouse air temperature is adequate. Manual controls will be less expensive, but will require that someone be around during the day to turn the fan on and off. These fans will be somewhat noisy, which you may find annoying.

Building a vent which operates easily and closes tightly takes good carpentry skills, a lot of patience and a fair amount of time. Well-built vents are worth the effort, though, and make a greenhouse a joy to operate. Reserve your best carpenter for this job.

TO CURB OR NOT TO CURB?

A major vent construction decision is whether to build a solid vent with a built-up "curb" (Figure 8.10) or a vent that is flush with the greenhouse surface (Figure 8.11). (Also review Figure 8.6 when considering a curbed vent in a glazed section.) Curbed vents offer much better leak protection, while flush vents improve the continuity of the insulation, which helps to minimize heat loss through the vent and vent framing.

Many people think that water leaks are not a problem in a greenhouse since the plants need water anyway. On the contrary, leaking water will rot wood, degrade insulation and destroy interior paint. In freezing climates the expansion of freezing water will push parts of the greenhouse apart.

The stiff galvanized steel flashing on the bottom and sides of flush vents will keep out much of the rain; but water from a blowing rain will probably creep in. Therefore, flush vents should not be used in very rainy areas or on shallow slopes (less than 30° from horizontal).

GLAZING VENTS

In order to achieve sufficient vent area, it is often necessary to use part of the glazed section of the greenhouse for vents. A window or glazing vent consists of a frame with glazing firmly attached, a hinge for the frame to pivot, and some mechanisms to raise, lower and hold the vent in position. Before reviewing details specific to vents made with certain types of glazing materials and used in certain installations, some general points applicable to all glazed vents are mentioned below.

The frame should be sturdy, constructed with doweled or lapped joints (see Chapter 7, Plastic Window Frames, for construction details on such joints). Weatherstripping must be installed around the entire perimeter of the vent so that all air flow is cut off once the vent is closed. Hooks and eyes or other solid latches to hold the vent closed should be used to compress the weatherstripping between the vent perimeter surfaces and the greenhouse frame.

If the greenhouse is double-glazed, all window vents should be double-glazed as well. Preferably, vents should swing open to the outside, unless there is space inside the greenhouse where an inward swing won't interfere with plant growth. In general, vents are hinged along their uppermost surface and appropriately flashed for waterproofing. Vents in vertical glazing do *not* need the raised framing or "curb" required in some slanted roof vents to keep water out. On a kneewall, vents can run the entire length of the greenhouse, at approximately the height of the planting beds.

Vent in corrugated FRP

(Figure 8.5) This vent overlaps one corrugation of the FRP on each side of the vent to keep water out. On glazing slopes of 45° or more, a four-inch overlap on the bottom edge also is required; on slopes of 30-40°, a six-inch bottom overlap is needed. The vent should be flush with the roof when shut. On shallow slopes (less than 30°), a "curb" should be used.

A flush glazing vent can be only as large as the space between the rafters, unless provisions for a larger opening was made when the rafters were designed and built. Such a provision involves omitting part of one rafter while maintaining support for the roof.

Flexible neoprene or butyl rubber (available from roofing companies) should be used at the top joint as a flexible flash-

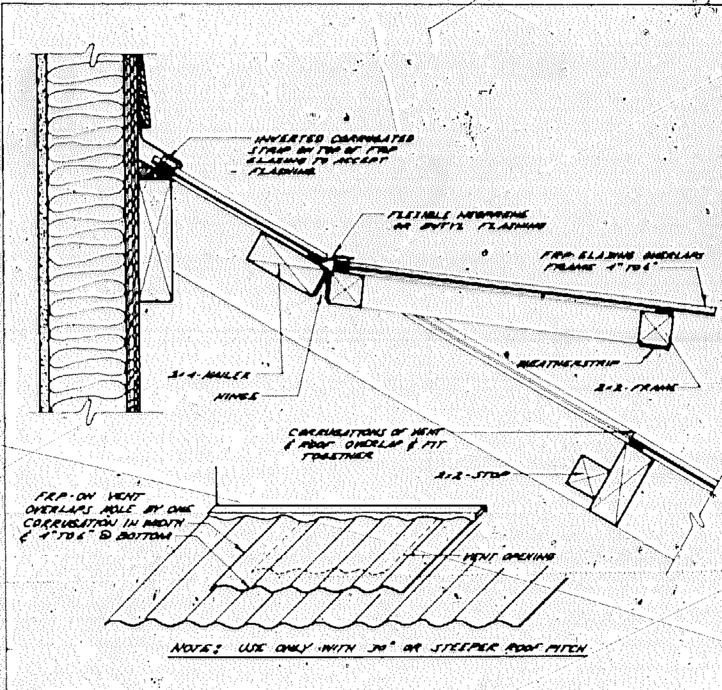


FIGURE 8.5 Vent for corrugated FRP or corrugated sheet metal

ing. If some reasonably sun-resistant, flexible material is not available, you will have to build a vent using a curb (see section on curbs).

Note in Figure 8.5 that two pieces of corrugated support strips are used at the top of the vent—one to support the corrugated FRP and one inverted on top of the FRP to support the flexible flashing. Both support strips should be fastened with one set of screws through the outer support, the glazing, the inner support and into the wood of the vent frame.

Vents in glazed roofs with flat glazing

(Figures 8.6 and 8.7) These vents protrude above the roof's surface. The "curb" can be built up by installing tall blocking between the rafters (Figure 8.6B) or by building the curb as a separate box on the ground and then placing it on top of the rafters (Figure 8.7B). The lattter method offers the advantage of more precise work. The vent frame can be built, glazed and attached to the curb before installation on the roof. The vent frame should be made of 2 × 2s unless you use a glazing such as Exolite where the aluminum extrusion will lend strength to the frame. In that case, 1 × 2s can be used. Removable pin hinges will allow you to take off the glazed vent-cover when installing the curb. This vent can be used with any nonbreakable glazing.

Flashing should be installed on all sides of the curb. As illustrated in Figure 8.8, start with the bottom piece, then attach the side pieces, and finally the top piece. In this way, the flashing pieces will shed water properly. Be sure the roof glazing goes on top of the flashing above the vent and below the flashing on the sides and bottom. Caulking or roofing tar on the corners also is needed to fill the little cracks that are left after attaching pieces of flashing together. If the vent is wider than four feet, water may not drain effectively from its upper side. Hence, the flashing on the vent's top must be sloped to the corners, thereby permitting water to drain off around the vent.

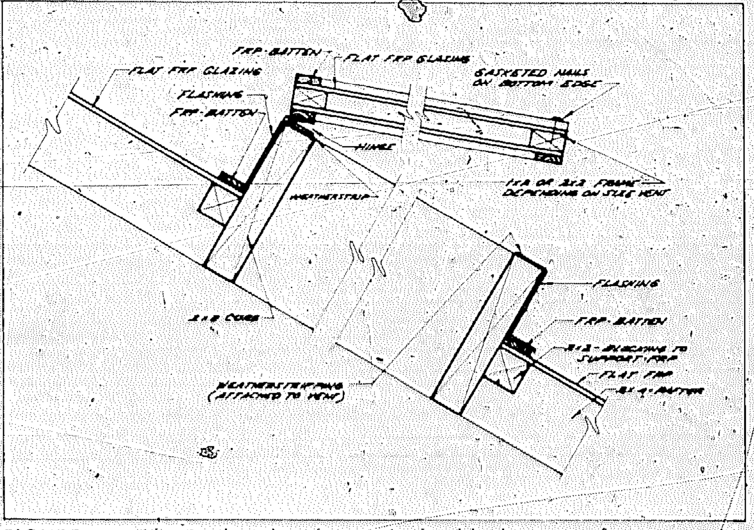


FIGURE 8.6A Vent in glazed roof — using rafter blocking as vent support (shown with flat FRP glazing)

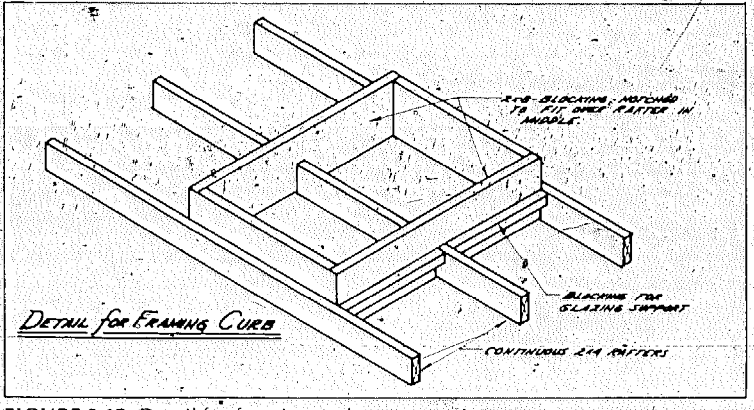


FIGURE 8.6B Detail for framing curb

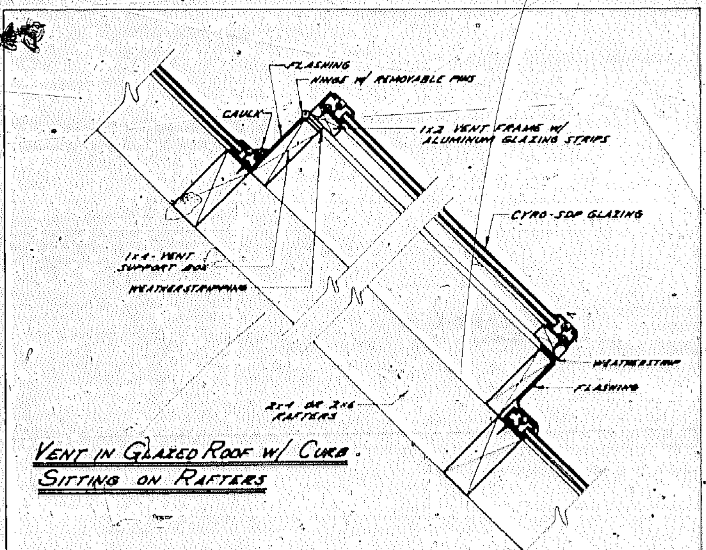


FIGURE 8.7A Vent in glazed roof with curb sitting on rafters

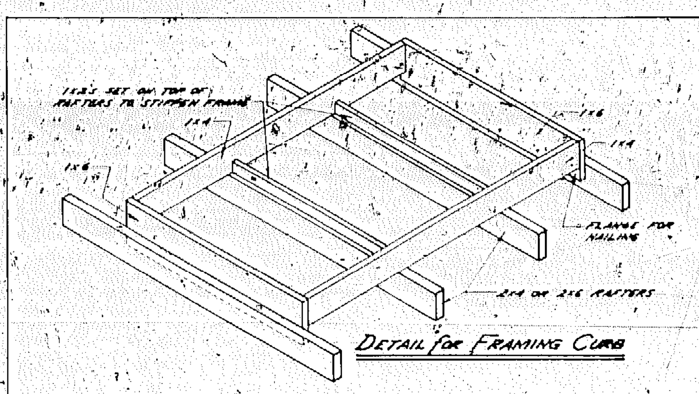


FIGURE 8.7B Detail for framing curb

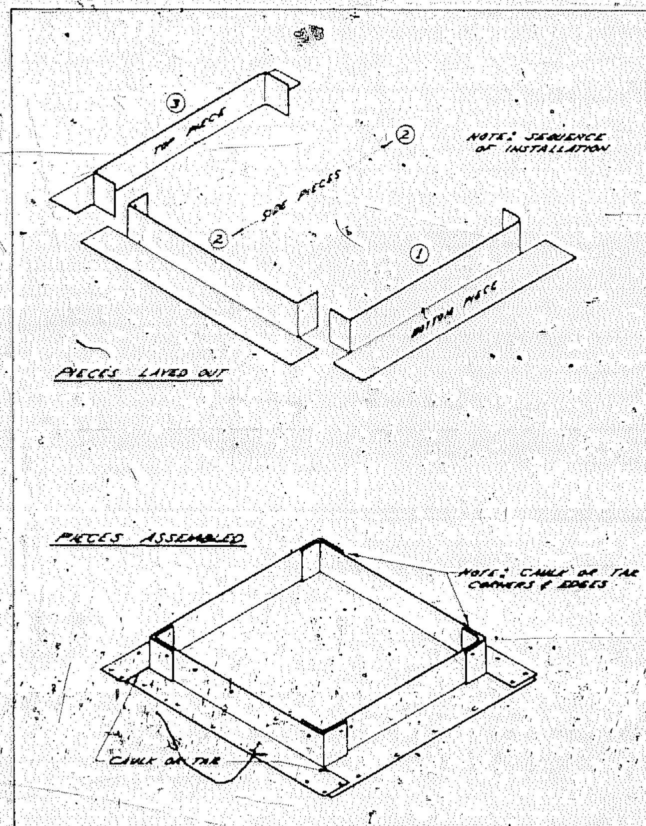


FIGURE 8.8 Flashing for curb-type vents

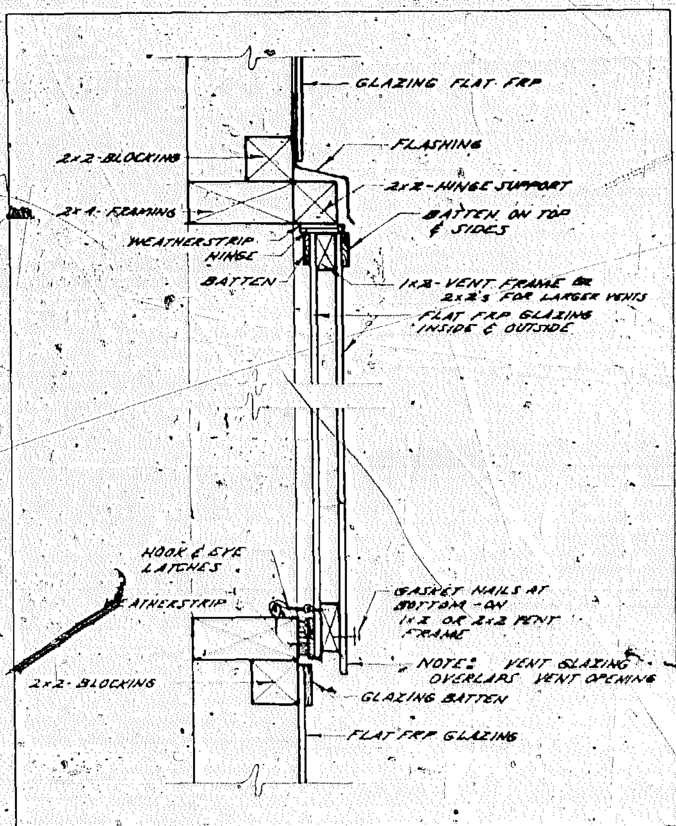


FIGURE 8.9 Vent in glazed wall

Vent in glazed walls

(Figure 8.9) The framing for this vent simply sits outside the wall framing. Each vent can be up to eight feet long if the frames are well-made, and in some cases can be made to span the entire length of the greenhouse kneewall. Placed at plant height, these vents allow excellent ventilation when combined with roof vents. A sturdy 2 × 2 frame of good quality wood should be used. As for corner fastening details, see Chapter 7 on double-glazed plastic-covered frames.

The metal flashing at the top should allow the vent to open without interference. If the top of the vent is hinged on the top plate of a kneewall, the roof glazing can be made to overhang enough to perform the flashing function.

This pit-type greenhouse uses a long ridge vent (built on a curb) with Styrofoam in each panel for insulation. The entire kneewall swings open as well to provide an excellent venting scheme.

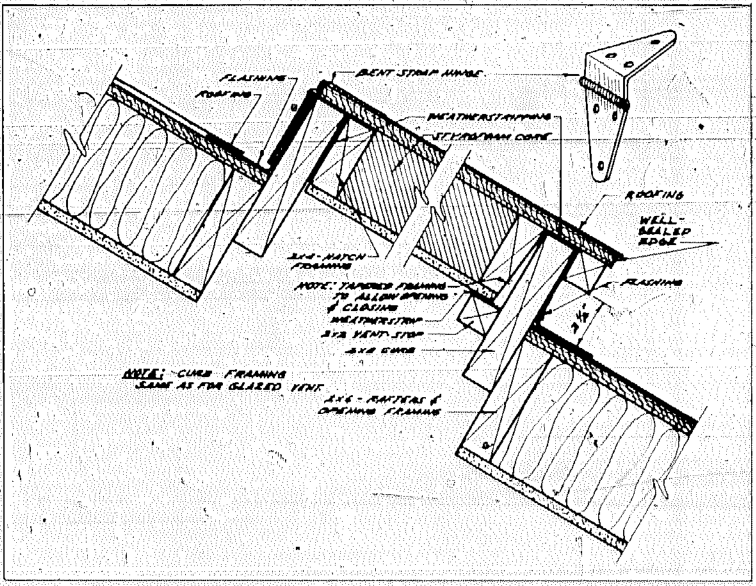


FIGURE 8.10 Solid insulated vent on a curb

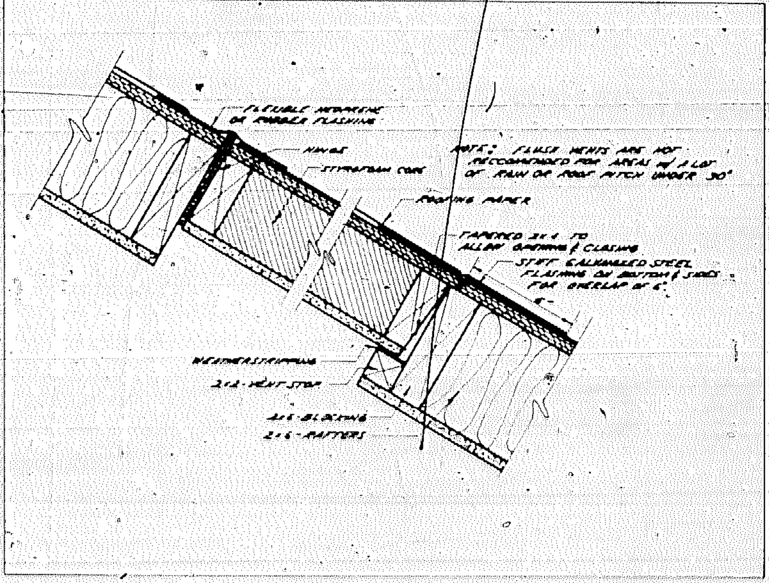


FIGURE 8.11 Flush solid vent

SOLID ROOF VENTS

(Figure 8.10 and 8.11) Vents can be built into the north-facing roof of a freestanding greenhouse or into a partially solid roof of an attached greenhouse. One advantage of solid roof vents (vs. vents in glazed sections) is that no sunlight is blocked by vent frames and blocking. Also, in some situations, solid roof vents can be placed closer to the greenhouse peak, thereby improving the chimney effect for better ventilation. Solid vents tend to be quite heavy, though, and therefore somewhat awkward to open and close.

The insulation in the vent should have about the same insulating value as the other solid roof portions. As mentioned previously, Styrofoam is a good insulation choice to withstand the repeated opening and closing. Building a curb (and flashing) for a solid roof vent is the same as for glazed vents. The vent cover should be built to fit inside the curb with at least $^1/_8$" clearance all around to compensate for swelling in wet weather. Glue and nail the plywood to the cover's frame and be sure the screws and bent strap hinge (in the curbed vent) are long enough to make a good, solid connection.

The edge opposite the hinged side needs to be tapered to allow the vent to open and close properly. On a 16"-wide vent, made of 2 × 4 framing and hinged as shown, the underside should be $^5/_8$" shorter than the opening. On a 32"-wide vent of the same thickness, the underside should be $^3/_8$" shorter than the opening. Be sure that all exposed plywood edges are sealed and painted.

SOLID WALL VENT

(Figure 8.12) Flush-mounted solid wall vents are constructed like flush solid roof vents. Weatherproofing is achieved by overlapping the siding of the building with the exterior sheathing of the vent and by a "drip mold" above the vent (the drip mold could be replaced by flashing). Removable-pin hinges will facilitate installation. With fairly thick weatherstripping at the top, hinges need not be recessed into the frame or the vent-door.

OPENING AND CLOSING MECHANISMS ("HEAT MOTORS")

All vents can be constructed to open and close manually or automatically. Manual systems can be as simple as a pole and slotted board (Figure 8.13A) or a pulley system (Figure 8.14). Other manual systems include somewhat more sophisticated rack and pinion devices, or gear and chain drives which often can be recycled from old glass greenhouses. Automatic systems, on the other hand, range from the simplest and least expensive "heat motor" vent operators (Figure 8.13B) to thermostatically-controlled electric motors driven by gears and chains.

The "heat motor" is activated by an increase or decrease in the temperature of its surroundings. In its basic form, it is a cylinder with a piston inside attached to a rod at one end. Inside the cylinder is a liquid that expands and contracts. As the air temperature around the cylinder increases, the liquid expands (its volume increases) and forces the piston rod out. The other end of this piston rod is connected to a vent door—as the piston rod moves out, the vent is pushed open. When the cylinder cools down, the liquid contracts and, presuming the vent is mounted above the cylinder, the weight of the vent door forces the piston rod back into the cylinder, thus closing the vent.

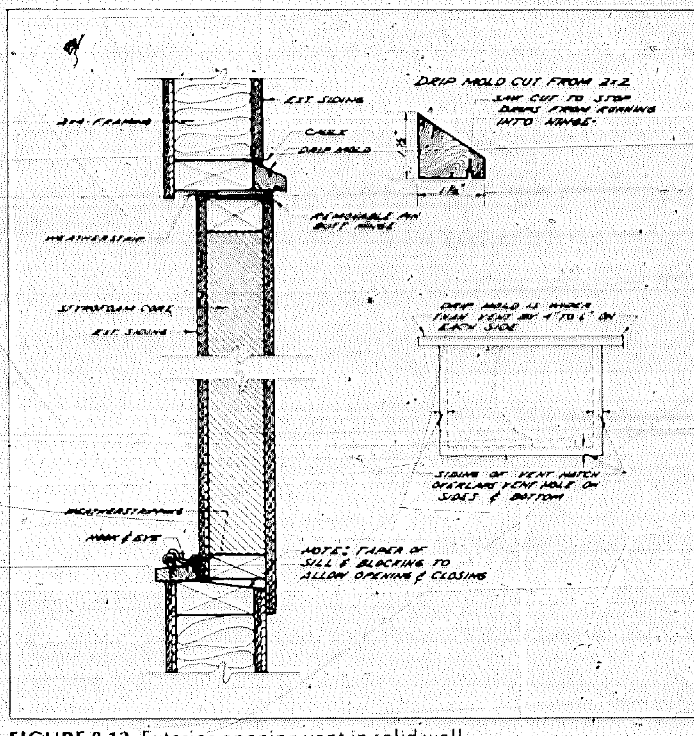


FIGURE 8.12 Exterior-opening vent in solid wall

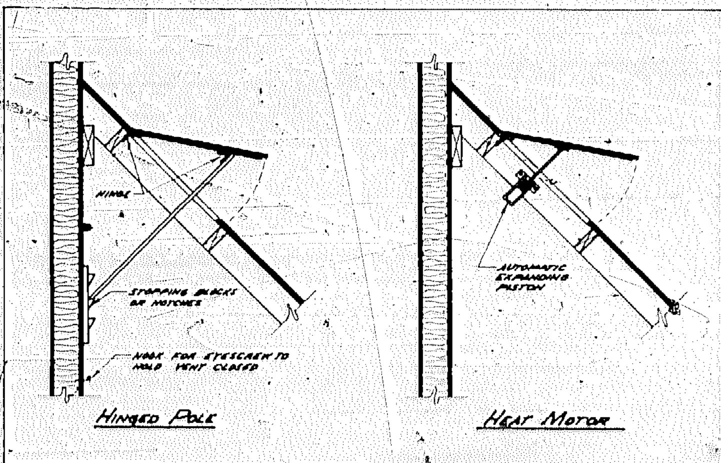


FIGURE 8.13 Vent opening and closing techniques: A. Hinged pole, B. Heat motor

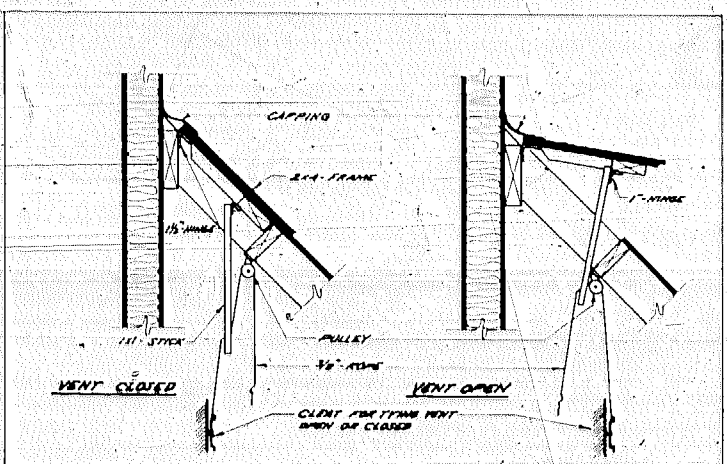


FIGURE 8.14 Pulley system for vents

Different types of heat motors are available. Some are able to move greater weights than others, and some are more suitable for mounting on vertical rather than sloping surfaces. However, the more inexpensive heat motors are not very reliable. They can only lift limited weights—10 pounds or less. Without sufficient weight, a vent will not close tightly by itself once opened. In addition, inexpensive heat motors have been known to lose their full action, that is they will not open up as far, after several months of operation. It is best to check out the various product brochures before you buy (see Resource List). Better still, try to find someone who is satisfied with a particular heat motor vent operator and see if it meets your needs. Always check with the manufacturer for installation instructions and guarantee.

For moving greater weights, say for a row of heavy ridge vents, a thermostatically-controlled electric motor can be used. The size of the motor will depend on the weight of the vents. But these motors can be quite expensive. Also, a reliable electricity source is necessary, although these systems should permit manual override in case of an electrical failure.

VENT OPENINGS WITH FANS AND LOUVERS

If you choose to construct vents with frames and louvers, you must be concerned with heat loss. The louvers, when closed, do not totally block air flow. In addition, lightweight louvers generally are made of metal, and hence have negligible resistance to conductive heat flow. Thus, heat losses through fan housings can be great unless insulation is installed when the fans are not in use.

One simple way to insulate fan-vents is to build an insulating vent cover. Generally, this cover will be mounted on the inside of the greenhouse as illustrated in Figure 8.15. Weatherstripping is essential, and a good latch is required to hold the cover against the wall and compress the weatherstripping to minimize air leakage. The fan's support frame is fitted inside the rough opening in the wall. This procedure requires accurate fan measurements and some careful carpentry.

If your fans are themostatically controlled you will have to be very careful when you close the insulated hatch covers over the fan openings at night. The thermostat, located inside the greenhouse, activates the fan whenever the interior air temperature rises above the set point. If the insulated cover is closed when the fan is activated, the fan will be trying to suck air through the insulated cover (operating uselessly and in a mode that is harmful to its motor).

One way around this potential problem is to disconnect the fan from the thermostat when the insulated vent cover is in the closed position. Another way is to raise the thermostat setting to its highest temperature (if that temperature is well above the range encountered in a greenhouse). When you want the fan on, open the insulated vent cover and reduce the thermostat setting to the desired temperature. When you want the fan turned off, increase the setting to the maximum temperature again; the fan will shut off and you can close the vent cover to prevent further heat loss.

On the other hand, if you feel that your greenhouse will need venting on sunny winter days (as is often the case with freestanding greenhouses), the thermostat must be operational and set at some comfortable upper limit. In such a case, you may want to close the insulated vent covers at night only. That way, the fan will be able to operate effectively when needed during the day. Some heat will be lost through the uninsulated fan housing during the day, but that loss is a small price to pay to avoid overheating and to know that your plants are not going to cook inside the greenhouse.

There is an underlying assumption we've made in talking about using fans for ventilation: there has to be an intake vent or door so that fresh air can enter the greenhouse when the fan is operating. An air intake vent can be treated like a fan. Automatic louvers and screen should be placed over the air intake vent and an insulating cover should be in place when it's not in use.

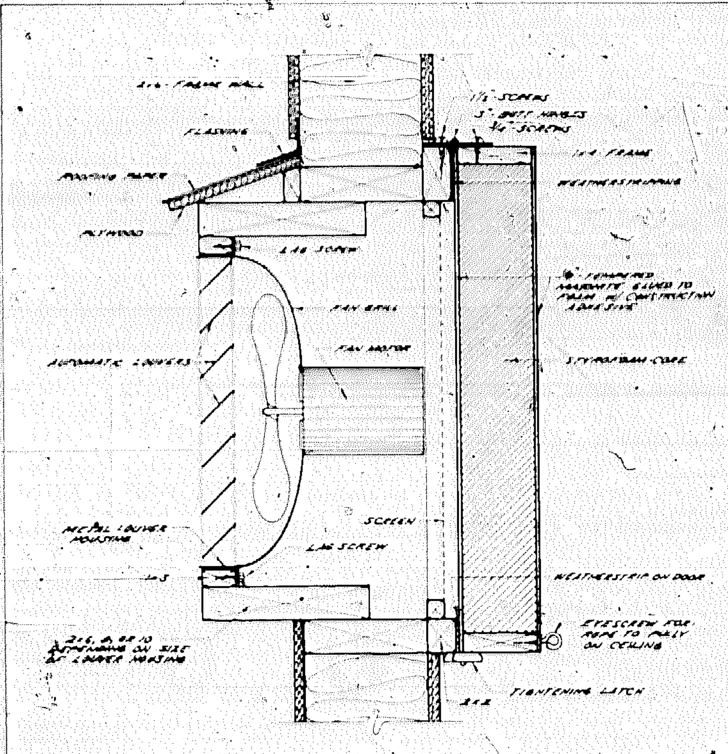


FIGURE 8.15 Fan with automatic louvers and insulating door

A rope and pulley system is used to operate the insulated vent cover in the NCAT greenhouse. The louvers let air pass to the outside automatically.

Chapter 9: HEAT STORAGE AND BACKUP

Storing solar heat for nights and cloudy days is a fundamental feature of an energy-efficient passive solar greenhouse. An effective heat storage system is an important element in solar greenhouse design. Likewise, a properly-sized backup heater and night insulation for the glazing are crucial to a greenhouse's overall efficiency.

In this chapter, we discuss the proper location and various types of heat storage. Included are suggested quanitities for the various heat storage materials as related to greenhouse design and use. In addition, we review the need for backup heat and the various systems that satisfy this need well. Finally, we will discuss the valuable contribution of night insulation in operating a solar greenhouse effectively.

HEAT STORAGE

Some kind of heat storage medium—water, rocks, dirt, etc.—is needed in a solar greenhouse to store excess solar heat when it is available. On sunny winter days, a solar greenhouse generally receives much more solar energy than is needed to provide a warm living space and a suitable growing environment for plants. The heat storage medium absorbs excess heat, helping to keep the greenhouse cool during sunny days, and more importantly, it releases that heat during the night and cloudy periods.

Heat storage requirements relate directly to how the greenhouse is used. Climate conditions and whether the greenhouse is attached or freestanding also are significant. For low-cost greenhouses enough storage for 100 percent solar heating is too costly and takes up too much space. Generally heat storage should be designed to provide about one cold day's heat requirement. That is, if the storage has been warmed up during a sunny period it should provide most of the greenhouse's heat needs for the succeeding day. During prolonged cloudy periods (more than one day) the backup heating system will probably be required at night to keep the greenhouse warm enough for plant growth.

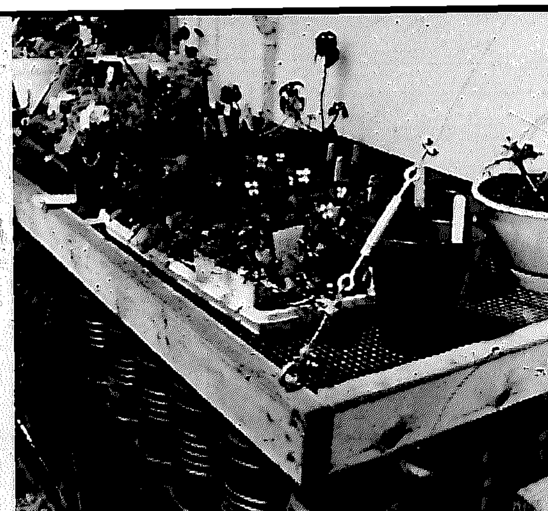
Location for Storage

Heat storage is most useful when it sits directly in the sunlight. Heat absorption by direct radiation, a form of "passive" heat storage, is efficient and economical as well as simple to build, use and maintain. Excess heat also can be forced (with fans and blowers) to a storage medium located entirely out of direct sunlight. When needed, the stored heat is pumped back to the greenhouse. But such an "active" system is more costly and more complex than passive systems, and therefore is not discussed in this manual.

Good locations for passive heat storage are directly behind the south-facing glazing and stacked up against the north wall, where winter sunlight will shine directly on the storage. *At least half of the heat storage in the greenhouse should be exposed to direct sun for at least half of the day in the winter.* All the heat storage should have some free air-space around it, so that when heat releases on cold winter nights, the warmed air adjacent to the storage medium will circulate freely to cooler areas in the greenhouse. It is particularly important to maintain air flows around heat storage that is exposed to very little sunlight. For example, if some of your heat storage is under the planting beds, leave air-spaces between the storage and beds as well as between the storage and the floor to facilitate air movement. Benches that cover heat storage should be made of wood slats, heavy screen or other open construction.

Heat storage that is located where it is exposed to direct sun for little or none of the day is still useful, although not as useful as directly exposed storage. Warmed air moved about by natural convection or by circulating fans will warm up such storage somewhat, contributing to the overall heat storage. Storage heated indirectly will be most useful when the greenhouse is very cold, because the temperature difference between the storage and the air will be large enough to cause significant heat transfer from the storage to the surrounding air.

There are various types of heat storage. The most common are rock, water, masonry and soil. Generally, the various types are combined; for example, water barrels, a brick footpath, and deep soil beds. Since water storage is perhaps the easiest to handle and the cheapest in most situations, we will discuss it first.



A screen bench over heat storage containers (recycled Navy Sonar-Buoy containers) lets warm air circulate more freely to cooler areas in the greenhouse.

Water Storage

Water is the most compact, low-cost heat storage. It stores one Btu of heat per pound per degree Fahrenheit of temperature rise—about three times the heat storage capacity of rock or masonry, and two to four times that of moist soil. Water storage in a passive solar greenhouse may rise 10°F on a sunny day.

Almost any container can be used to hold the water. You should use whatever is available at the lowest cost. Fifty-five-gallon oil or chemical drums have become the most commonly used containers for water storage. They are usually easy to find, relatively cheap (used drums cost $3 to $10 each), easy to handle and fill, and strong enough to support beds or benches. To some people, an oil drum in a solar greenhouse is an interesting symbol of the transition from oil to solar energy. Oil dealers, car dealers and, in large cities, drum-

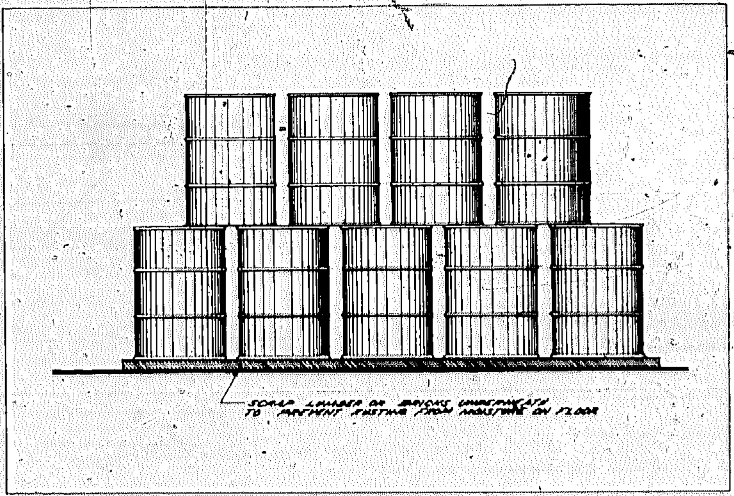


FIGURE 9.1 Technique for stacking recycled drums

reprocessing plants are all good sources for drums. If at all possible, get drums that still have the plugs or "bungs." Smaller 35-gallon oil or grease drums can sometimes be found. They fit nicely in tight places and can be quite useful.

The main problem with 55-gallon drums is rust. If you are not going to drain the drums in winter, a rust inhibitor must be used in the water. The inihibitor can be bought from Zomeworks in Albuquerque, New Mexico (see Resource List), or from plumbing suppliers. A small quantity of the Zomeworks inhibitor is required—about three ounces of powder for a 55-gallon drum. Another precaution against rust is to add a quarter cup or so of old oil after the drum is filled with water. This oil film on top slows water evaporation and lowers the water's oxygen content, thereby retarding rust. If the drums formerly contained motor oil, leave the residue in them. But if the drums contained an unknown or toxic chemical, rinse them out with a small amount of kerosene. Be sure to dump the kerosene somewhere safe, and then rinse the drum again with water. Finally, when you place the drums in the greenhouse, put scrap wood, old bricks or something else under them so that ground moisture doesn't rust the drums from the outside (Figure 9.1). A fresh coat of paint also will increase a drum's lifespan.

Drums should be placed and stacked securely before filling—when full, each weighs about 450 pounds. Leave an inch of air in the top and the bung slightly loose (on barrels standing straight) to accommodate water expansion and contraction. Add the rust inhibitor before filling—it will mix well with the water as the drum is filled.

Smaller containers can provide satisfactory storage as well, especially in spaces not exposed to direct sunlight. In fact, smaller containers transfer heat (by convection) more efficiently than the larger drums. Smaller containers expose more surface area to the air, in relation to the amount of water in them—as air moves across these surfaces, it picks up heat more effectively.

Five-gallon honey or frying-oil cans can sometimes be obtained from food stores or fast-food restaurants. Easy to wash and handle, small containers are not as strong as drums and cannot be used as bed or bench supports. Stacks of oil or honey cans should be secured to the wall so they don't fall. Cleaning and rust-proofing procedures are the same as for oil drums, but these cans also require priming and painting. Wipe the surface off with paint thinner before priming. Check with your paint dealer for a primer that is compatible with the plating on the cans.

Any darkish color is fine for painting heat-storage containers. The difference in heat absorption by different colors—as long as the colors are not very light—is too little to bother with. Some people use blue or red because they reflect a part of the spectrum that plants need for flowering and fruiting. If summer light levels in the rear of the greenhouse are too low—indicated by the plants leaning toward the glazing—light-colored paper or cloth can be draped over the rear heat-storage barrels or cans to reflect more light onto the plants.

Even smaller water containers, such as gallon jugs, two-liter soda bottles, or cans also are fine to use. Don't use glass containers, though, because they will break if the water freezes. Plastic jugs can take freezing without damage. These smaller containers do require shelves or some other placement structure. Stack them so that air can move around them if possible. More effort goes into installing these small containers, but their easy availability may make them worth the trouble. Small containers make heat-storage areas out of otherwise unusable nooks and corners in the greenhouse.

Water freezing should not be a problem if you have enough heat storage and if the greenhouse is airtight. Since water releases a tremendous amount of heat as it changes from a liquid to a solid, the air temperature must stay below freezing for quite some time before the water will freeze solid. Usually, no damage is done to containers until the whole mass freezes and expands. Larger containers have the advantage of losing heat more slowly and hence being less prone to freezing solid. Anti-freeze is too expensive for the large volume of water in even a small greenhouse.

In cold climates, if you are only using the greenhouse for extending the growing season and not using it in the winter, consider draining the water in the cold months.

In attached greenhouses, some heat from the main house can be released into the greenhouse at night to keep temperatures above freezing. A back-up heater in the greenhouse, too, will always bail you out and keep the storage from freezing. The amount of time and money that backup heating can save you—both in burst containers and frozen crops—is well worth the cost. But if your greenhouse uses more back-up heat than you can afford, then it may not be worth the expense to operate the greenhouse in winter.

Masonry

Masonry stores about one-third as much heat as the same volume of water and, generally, is fairly expensive to install. Solid, dense concrete block (not cinder blocks), dense bricks, concrete or stone walls all are good heat stores. Adobe also is good, although it does not hold as much heat as the more dense materials. Costs will vary, so check local prices.

Gallon jugs placed in tight corners and under growing beds increase a greenhouse's heat storage capacity.

Although it is expensive, masonry is a good heat storage because it doesn't freeze. It is discussed here because there are many adobe, stone, concrete-block, concrete and brick-clad houses to which greenhouses may be attached. In such cases, masonry storage may be an appropriate option. Use Table 9.1 to determine what portion of the suggested heat storage can be supplied by the volume of masonry contained

		For Season Extension		For Year-Round Growing	
		WATER gallons/ft.² glazing	**MASONRY** ft³/ft² glazing	**WATER** gallons/ft² glazing	**MASONRY** ft³/ft² glazing
ATTACHED GREENHOUSES	COLD	2½	5/6	4	1 1/3
	TEMPERATE	2	2/3	3	1
	WARM	1	1/3	2	2/3
FREESTANDING GREENHOUSES	COLD	3	1	5	1 2/3
	TEMPERATE	2½	5/6	4	1 1/3
	WARM	2	2/3	3	1

The quantities are expressed in terms of gallons of water or cubic feet of masonry per square foot of glazing area, since the glazing is the main area of heat loss, and of course, heat gain;

"Season Extension" means that the greenhouse is not used for growing during the coldest winter months;

"Cold" climate means that winters are longer than the summers; "temperate" means equal summer and winter; "warm" means that freezing only occurs during two or three months.

Masonry is assumed to be of moderate to high density, such as stone, concrete or heavy bricks; masonry is also assumed to be eight inches or less in thickness;

Chart assumes at least half the storage is exposed to direct sunlight for at least half the day;

Chart assumes that the greenhouse is insulated (as suggested in this manual), tightly built, and double glazed, except in warm climates.

TABLE 9.1 Suggested quantities of heat storage materials for passive solar greenhouses in the greenhouse. In colder climates, some water containers will probably have to be added to the greenhouse if there is not enough masonry.

Crushed Rock or River Rock

Many people have put one, two or even three feet of rock on the floor of their greenhouse to act as heat storage. But unless air is blown through the rocks, only the top few inches are useful storage. Individual rocks touch each other only at a few small points and very little heat is transferred by conduction from one rock to the next, above or below. Also, warm air rises, and as the upper rock layers warm up, the resulting warmed air does not move down to warm the lower rock layers.

Fans or blowers, and the associated ductwork and controls, are necessary to force the warm air around the rocks. Such an active storage system can be shown to be cost-effective, but the initial installation expense tends to be rather high. For this reason, such systems are not considered in this manual. Nonetheless, under-floor heat storage systems do save greenhouse space.

Soil and Earth

The heat storage capacity of a volume of soil in greenhouse growing beds is half to a quarter that of water, depending mostly on the soil's moisture content. Deep soil beds will increase the greenhouse's heat storage capacity and may contribute up to 20 percent of the total storage. Deep soil beds also minimize waterings and provide more root space for your crops.

The earth floor within the greenhouse's insulated perimeter also functions as heat storage. Since the floor generally sees very little sunlight, and since warm air tends to rise, relatively little heat is stored or released by the floor compared to sun-exposed water storage. One advantage earth has over a crushed rock floor is the ability to conduct heat downward, particularly if the earth is moist and compacted. Should the greenhouse get quite cold, the heat stored in the floor will tend to warm the greenhouse a bit.

How Much Storage Is Enough?

A key tradeoff in a passive solar greenhouse is between more storage—hence less backup heating—and more growing space. The storage quantities suggested in Table 9.1 are a compromise between these two factors. But you need to evaluate your particular situation before you make a decision. For example, if backup heat is quite expensive, you may wish to increase the quantity of heat storage. On the other hand, if food production is the main purpose of the greenhouse, you may wish to increase the planting area and thereby minimize storage.

An attached greenhouse needs less heat storage than a freestanding greenhouse, since excess heat captured by the greenhouse during the day can be vented and used in the home instead of absorbed in storage. Also, if the greenhouse is *not* used for growing plants during mid-winter, less heat storage is required. With less storage, there is more growing space, and the extra growing space can result in increased yields during spring, summer and fall. Due to higher light levels and warmer temperatures, the greenhouse is more productive during these three seasons than in winter, anyway. Thus, you may obtain greater total annual yields without a winter crop and with less storage. But again, the storage decision must be evaluated carefully. Produce is more expensive in the winter than summer. Thus, food needs and gardening habits must be balanced against monetary benefits.

The following assumptions have been made regarding the heat storage quantities for passive-solar greenhouses suggested in Table 9.1: Some backup heat will be needed, although not a lot; the greenhouse is tightly built—no big cracks allowing infiltration; the walls and foundation are insulated; there is double glazing (except in climates where freezing seldom occurs); there is *no* night insulation for the glazing; half or more of the heat storage is exposed to direct sunlight for at least half the day; and there is additional heat storage in some soil beds. The use of night insulation *decreases* the need for heat storage. But we suggest that you use enough storage to keep the greenhouse warm even without glazing insulation, to compensate for those inevitable nights when you forget to close the curtain. Using the suggested heat storage quantities in Table 9.1 *plus* night insulation, then, will decrease backup heat use and increase an attached greenhouse's heat contribution to the main house.

Remember, Table 9.1 represented approximate rules of thumb—storage should be added or removed as needed. An indication of needing more storage is excessively high temperatures (approaching 85°F) in the greenhouse during a cold, sunny day accompanied by low interior temperatures (approaching freezing) at night. But be sure to monitor both day and nighttime temperatures closely. Excessive daytime temperatures accompanied by adequate night temperatures often indicates a problem with ventilation rather than storage.

BACKUP HEAT

A dependable backup heating system is just about essential for a solar greenhouse. Even if you are designing the greenhouse to be 100 percent solar heated—an expensive option which is not covered in this manual—a backup heater is good insurance for those long, cold, cloudy periods. The backup heat must complement the design of the greenhouse as well as the lifestyles of the owners. A manually controlled wood heater may be the cheapest solution in some cases, but it requires careful attention during cold weather. Additionally, you must ensure that the greenhouse is airtight whenever costly backup heat is used. Many operators caulk or tape all the vents closed during the coldest part of winter.

Given the heat storage quanitities suggested in Table 9.1, backup heat will be needed frequently during mid-winter and occasionally during the spring and fall. Backup heaters also are used by many growers in the spring, directly under wire-screen shelves to speed seedling germination.

Almost any type of backup heat will work in the greenhouse—you should use whatever is most available. The operational tasks will vary for each type, though, so make your decision accordingly. Backup heaters with thermostats have a distinct advantage over those without thermostats. Besides saving fuel, a thermostat makes backup heating somewhat automatic. The greenhouse can be left unattended during cold periods if a thermostat is set to turn on the heater when the interior temperature drops too low. Generally, the coldest periods of the day occur just before dawn, when it is the least convenient to get out of bed and turn on a heater. Of course, heaters without thermostat controls can be left on a low setting all night if you think the early morning hours are going to be cold. But such a system involves guesswork, worrying, and probably occasional mistakes in using too little or too much backup heat. In any case, a thermostat is a definite necessity if you plan to be away from the greenhouse for more than a day during early spring, late fall or winter.

If you choose to use the main building's heating system to supply backup heat to an attached greenhouse, you must remember to open doors, windows or vents between the house and the greenhouse. You must decide each night if there is a chance that the greenhouse temperature will drop to the minimum temperature you wish to maintain, and open vents accordingly. Only experience will tell you how far to open the windows, vents or doors in order to keep the greenhouse at a reasonable temperature. Also, you must make sure the house's heating system is capable of handling the extra load of the greenhouse. If the house heater cannot keep the rooms adjacent to the greenhouse very warm, chances are it will not be able to heat the greenhouse.

Thus, the appropriate backup heat system for your greenhouse is a function of availability, expense, and personal commitment. Make sure the system you employ is consistent with what you can afford and manage well.

Wood Heat Backup

In some rural areas, wood is a low-cost fuel that may be a good backup heat source. A small, airtight stove can heat up to 1,000 square feet of greenhouse space. But a good-quality stove that will keep a fire burning slowly throughout the night can be expensive. Additionally, chimney installation costs, availability of wood and the inconvenience of tending to a

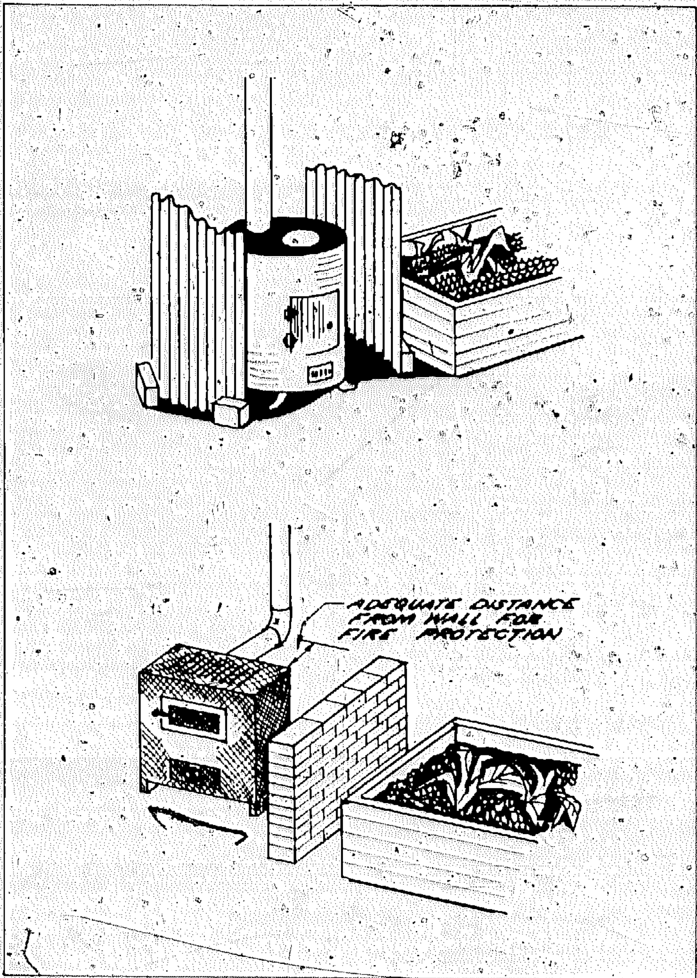


FIGURE 9.2 Radiation shielding of wood heaters in greenhouses

fire must be weighed in the decision to use wood as the back-up heat source.

The stove and stovepipe should be at least three feet from plants to avoid burning the leaves. This distance can be cut in half if the stove and pipe are shielded from the plants with sheet metal, bricks, aluminum foil, or other non-flammable material (Figure 9.2). Also, all chimneys must be vented to the *outside* of a greenhouse, because no matter which fuel you are using (wood, kerosene, fuel oil, gas or propane), the carbon monoxide and other toxic chemicals released by incomplete combustion can harm the plants or people inside the greenhouse. Venting the noxious gases out is particularly important for attached greenhouses where they might otherwise find their way into the home.

The decision to use wood heat is a major one. The option may be practical in terms of actual fuel costs, but it may also be expensive in terms of the personal time commitment.

IS WOOD CHEAPER THAN OIL?

A rule of thumb often used to answer this question is: Dollars per cord equals cents per gallon. For example: If a cord of hardwood costs $75 and oil is 75¢/gallon, the heat from the two sources costs about the same. If a cord costs $55 and a gallon fuel oil costs 80¢, wood heat is cheaper. On the other hand, if a cord costs $100, and fuel oil is 80¢/gallon, fuel-oil heat is cheaper. In any case, the decision between the two should be based, as well, on installation costs, convenience and fuel availability.

Also, note that softwoods have about two-thirds the heat capacity of hardwoods per cord. The formula above assumes a 60 percent efficient oil burner and a 50 percent efficient wood stove.

Electric Backup Heat

Low installation costs and easy, automatic operation make electric heaters a common choice among greenhouse owners. Electric heaters often are used in attached greenhouses on very cold nights to supplement heat vented from the house.

The main disadvantage are the high cost of electricity in most areas, and the problems associated with increased electricity use in general. Nonetheless, if the greenhouse is well-designed and built, little electricity will be needed.

Most electric heaters have built-in thermostats, or inexpensive thermostats can be brought from electrical supply houses for about ten dollars. Table 9.2 will help you choose the right size electric heater for your greenhouse. The table assumes that the greenhouse is airtight and was built according to the insulation, glazing and heat storage details suggested in this manual. For attached greenhouses, in particular, the chart assumes that vents between the house and the greenhouse are closed and that *no* night insulation for glazing is used. The location of an electric (or any other) backup heater is not critical if a fan is used. Electric heaters without fans are not recommended. Locate the heater as centrally as is convenient. If the heater ends up in a corner, that shouldn't be a problem unless your greenhouse has many air leaks. The size of the heater, as with heat storage quantity, relates to the area of greenhouse glazing, due to the fact that the glazing is the major area of heat loss. The table gives the minimum number of watts of electric heat needed per square foot of greenhouse glazing.

		FOR SEASON EXTENSION	FOR YEAR-ROUND GROWING
FREE-STANDING	COLD CLIMATE	10W	12W
	TEMPERATE	8W	10W
	WARM CLIMATE	6W	6W
ATTACHED	COLD CLIMATE	8W	10W
	TEMPERATE	6W	8W
	WARM CLIMATE	5W	5W

EXAMPLE A: A freestanding greenhouse with 200 sq. ft. of glazing in a cold climate:

1) For season extension — 200 X 10W = 2000W heater.

2) For year-round growing — 200 X 12W = 2400W heater.

EXAMPLE B: An attached greenhouse with 100 sq. ft. of glazing in a temperate climate:

1) For season extension — 100 X 6W = 600W heater.

2) For year-round growing — 100 X 8W = 800W heater.

TABLE 9.2 Minimum capacity of electric heaters for passive solar greenhouses

Other Backup Heaters

Gas, propane, or kerosene heaters also may be used in greenhouses. The main advantage of these fossil fuels are that they generally are cheaper than electricity and easier to handle than wood. The main disadvantage is that they all require chimneys to vent the combustion gases out of the greenhouse. Also, heaters using these fuels generally do not have thermostats.

To determine the capacity needed for a gas or oil-burning stove, use the electric heater-sizing chart (Table 9.2). Because gas and oil heat is expressed in Btu's per hour, you need to translate the appropriate wattage number (from Table 9.2) into Btus. Approximately 3.4 Btu/hr are equivalent to one watt, so you need to multiply the number from the chart that fits your greenhouse by 3.4.

In addition, the efficiency of the heater must be considered, since some of the heat goes up the chimney. Fossil-fuel-burning heaters can range from 40 to 70 percent efficient. If you don't know the efficiency of your heater, assume it to be 50 percent. Thus, half the fuel's heat value goes up the chimney, which means that the capacity of the fuel-burning heater for your greenhouse should be double that of the electric heater.

For example, let's say that you have a freestanding greenhouse with 200 sq. ft. of glazing, that you plan to use it year-round in a cold climate, and that you want to install a gas heater. The heater should have a capacity of at least 16,320 Btu/hr ($200 \times 12 \times 3.4 \times 2$). (Glazing is 200 sq. ft.; 12 is the number of watts required per sq. ft. of glazing; there are 3.4 Btu/hr/watt; and 2 Btu of gas must be burned to deliver 1 Btu of heat.)

A small electric heater can be used when solar heat stored in the water barrels is depleted.

NIGHT INSULATION

Night insulation is used in many solar greenhouses to cut heat loss through the glazing. It reduces backup heat bills somewhat and, for attached greenhouses, can increase the amount of heat delivered to the main house.

On the other hand, night insulation requires evening and morning operation—a time commitment from the greenhouse owner. In addition, night insulation may take up space that otherwise would be used for growing; and in the case of roll-up curtains, the insulation may reduce light admission during the day. Thus, unless a system can be installed at a low cost, backup fuel savings from night insulation may not justify its cost.

A very simple and inexpensive alternative is to insulate the individual beds instead of the entire greenhouse. Small plants can be covered with an old sheet, tarp, or blanket. This method is particularly effective if there is heat storage under the bed, or bench and the cover is large enough to overlap that heat storage. A simple wood frame (Figure 9.3) also can be used, made of thin wood pieces, to avoid shading the plants. Instead of a wood frame, a wire attached

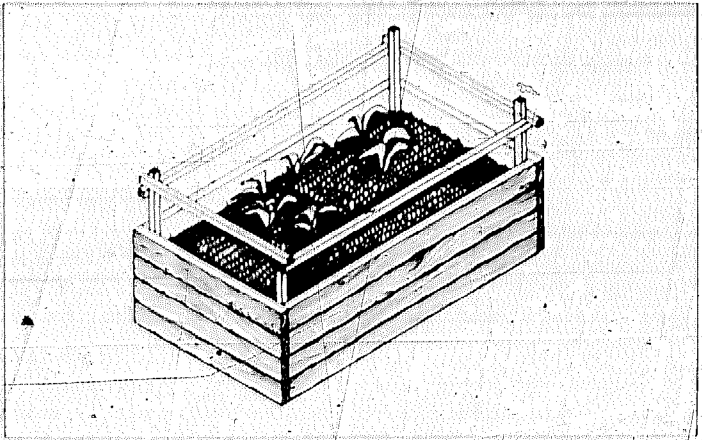


FIGURE 9.3 Planting bed covers

firmly to the greenhouse walls can be strung over the beds to support a blanket. Seedlings can be kept warmer this way even if the greenhouse is maintaining adequate temperatures.

Another low-cost insulation scheme is to use Styrofoam sheets directly against the inside of the glazing (Figure 9.4) Zomeworks (see Resource List) sells inexpensive magnetic clips — trade name, Nightwall, about 30¢ each — to hold the sheets in place. One clip is needed for every 18 inches of Styrofoam perimeter. Two-inch Styrofoam can be used and is relatively inexpensive as well — about 30¢ per square foot.

The advantage of placing the insulation directly next to the glazing is that there is no room for heat-robbing air movement between the glazing and the insulation. The clips can't be used with plastic films, but are suitable on glass and rigid plastic glazings. If your inner glazing is polyethylene, the clips can be attached to the edge of the batten that holds the polyethylene in place, but only if the surface of the batten is smooth. This installation (clips on battens) does not provide quite as good insulation, though, since there is an air gap between the insulation and the glazing.

One consideration with any rigid removable insulation is storage. The pieces must be stacked somewhere convenient when they are not in use, such as under a bench. With the Nightwall clips, large Styrofoam sheets can be used — as large as the spaces between glazing supports. But larger pieces are more awkward to handle and store, particularly if the greenhouse is filled with vegetation.

Another concern with the Styrofoam is that it is rather delicate — the corners tend to flake off and pieces break easily. Covering the edges and corners with a sturdy tape will alleviate the flaking somewhat.

A third night insulation scheme is curtains (Figure 9.5). Roll-up curtains for the inside of the glazing can be made using two layers of water-proof fabric with garment or quilt-type insulation in between. These curtains are expensive, relative to the schemes outlined above, but are more convenient to operate.

A roll-up curtain built at NCAT cost $1 per square foot (materials only for a 186 ft. glazed area), using vinyl-coated nylon fabrics (Duratuff, made by Curacote Corp.) and Polarguard insulation (a continuous filament polyester garment insulation made by Celanese Fibers Corp.). This curtain was found to cut backup heat used in the NCAT greenhouse by

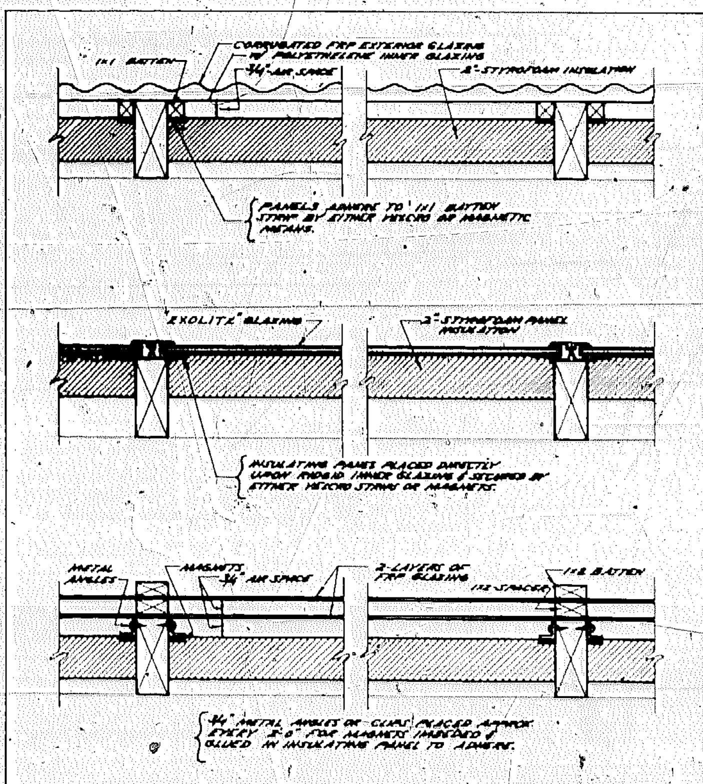


FIGURE 9.4 Three methods of installing night insulating panels in greenhouse

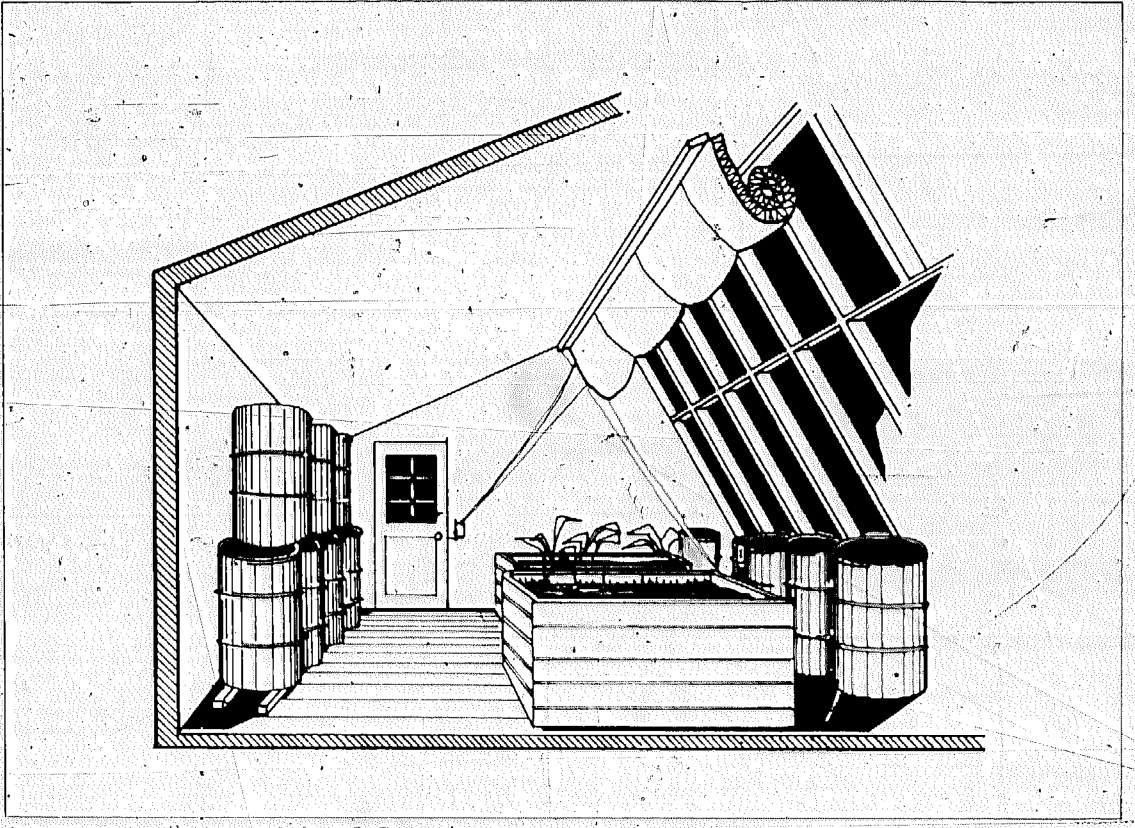
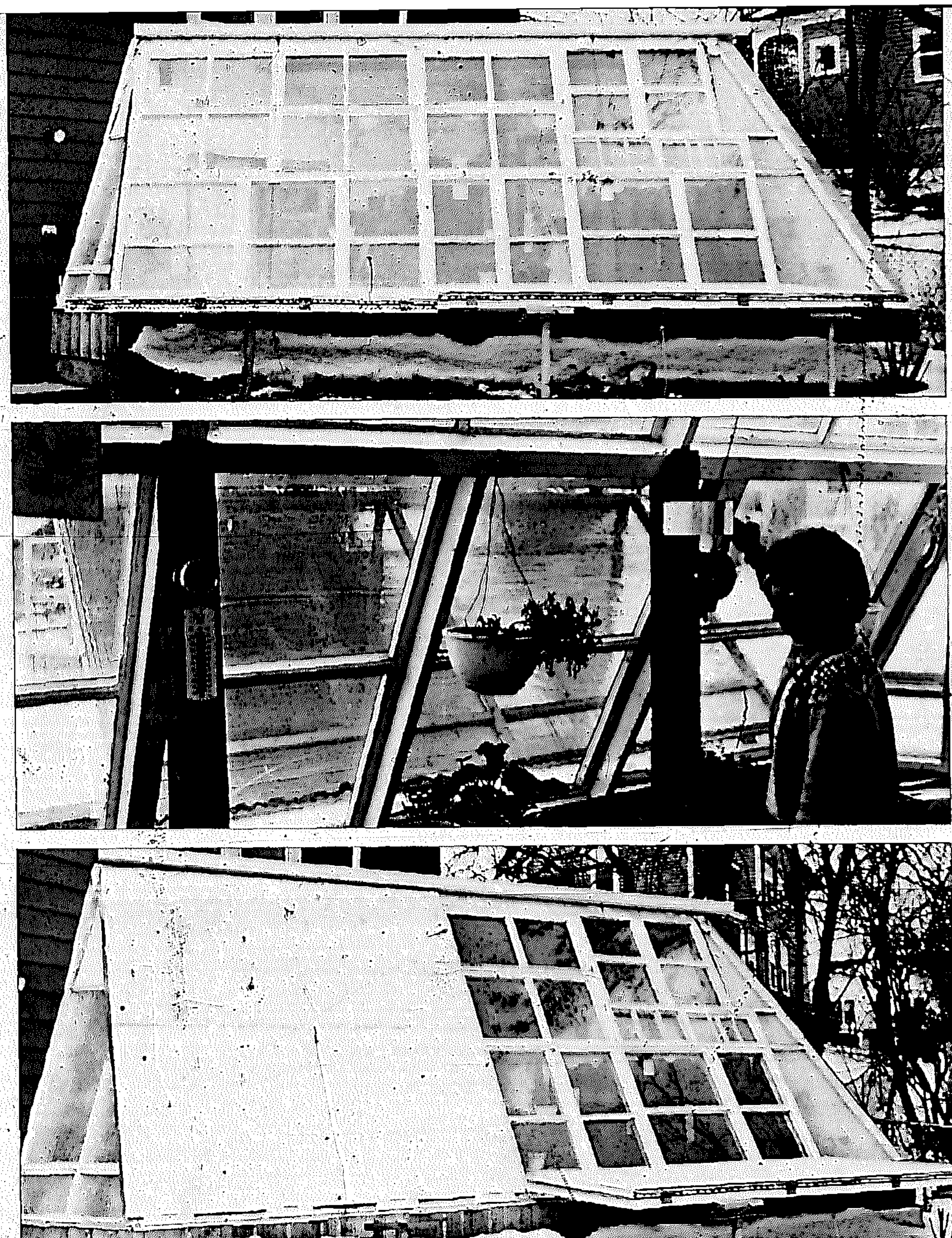


FIGURE 9.5 Insulating curtain for NCAT greenhouse

50 percent. But, since so little backup heat was used in this extremely heat-conserving, freestanding greenhouse, total savings only amounted to $20 for the year. A paper outlining the curtain construction and detailing the experiment and results is available from NCAT (**Comparison of NCAT Passive Solar Greenhouse Performance With and Without a Night-Insulating Curtain**, $0.90, NCAT, P.O. Box 3838, Butte, Montana 59701.

There are several commercially-made insulating curtains and shades on the market, but since they tend to be rather expensive—from $3 to $6 per square foot—they are not discussed in this manual.



Covering the glazing at night conserves heat and helps maintain moderate temperatures for a more stable growing environment. Linda Nelson in Madison, Wisconsin uses a simple cable and pulley system to close her exterior insulating panels from the inside.

DOMESTIC HOT WATER PREHEATING IN ATTACHED GREENHOUSES

A simple solar hot water heater may be added to the greenhouse by running the cold water supply for your existing hot water heater through a preheat tank that sits in the greenhouse sun. Such an installation requires some experience with plumbing, but is fairly easy and simple. The greenhouse provides the "glazing" for this tank, and heat storage keeps it from freezing. If the greenhouse is not used during the winter, the preheat portion of the system can be drained.

As always, conservation measures should be taken before installing any kind of solar system. Insulate your conventional hot water tank and pipes. Set the temperature on the heater to approximately 120°F—few household uses require hotter water. Then, and only then, add a solar preheater.

Use a good quality, 30-50 gallon tank, such as a glass-lined or galvanized one. Be sure to use di-electric fittings between copper and galvanized metal to avoid corrosion. Mount the greenhouse preheat tank on or next to the warm house wall to help protect the tank from freezing. Choose a spot in the greenhouse that sees direct sun all year (Figure 9.6).

Cold water is introduced into the bottom of the preheat tank. The solar-heated hot water is drawn off the top and routed into the cold water supply for your conventional hot water heater. Mounting the preheat tank vertically will assist in separating the hot water from the cold. Stratification (the separating of hot and cold water) occurs simply because the hot water is lighter than the cold. In a vertical tank, the turbulence caused by introducing more cold water (when you use hot water in the house) is localized in the bottom. With horizontal tanks, cold water mixing seems to take place throughout a greater volume of water. When the cold and hot water mix, the preheater's efficiency decreases because warm instead of hot water is drawn off. The existing hot water heater then uses more energy to boost the water to a usable temperature. Another heat-saving step is to insulate the hot water outlet of the preheat tank all the way to the existing hot water heater. Also, in cold climates, an additional layer of glazing—perhaps even two—over the tank will increase water temperatures and give additional protection from freezing.

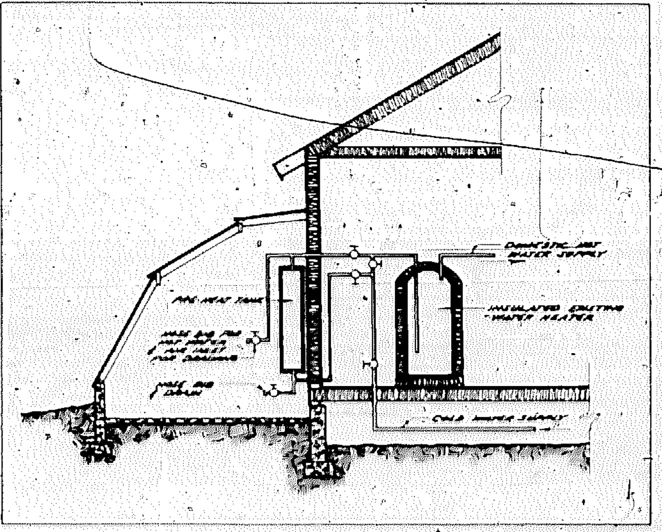


FIGURE 9.6 Greenhouse preheat tank for domestic hot water use

A solar preheater also provides easy access to an inexpensive supply of warm water for plants. Cold water is a shock to plants and retards growth somewhat. In winter, sun-warmed water can be a great benefit.

Chapter 10:

INTERIOR MANAGEMENT DETAILS

As a greenhouse grower, you will be interested in efficient and convenient plant production. Thus, it is necessary to design the various production details to optimize plant growth and to satisfy your individual needs as well.

This chapter reviews some general construction guidelines for beds, benches and troughs, as well as various watering systems that are appropriate for greenhouses. While this review is not an exhaustive compilation of existing techniques, the information should help you design components that suit your needs well.

(A helpful references on other aspects of greenhouse operation is **Biological Management of Passive Solar Greenhouses**, a 16-page bibliography and resource list, available for $.70 from NCAT, P.O. Box 3838, Butte, Montana 59701.)

BEDS AND BENCHES

The growing area inside the greenhouse can be arranged in many ways. You need to make the appropriate tradeoffs between storage space, pathways and growing areas, and then design a suitable floor plan. The most common planting arrangements utilize benches, beds or troughs, or some combination of the three.

Benches are used frequently by commercial producers for ornamental plant production, and also can be used for starting seedlings. Plants placed on raised benches benefit from the warmer air at that level. The air is usually colder at floor level. In addition, benches are very convenient when pots are used for containers—pots can be moved in and out quickly. On the other hand, pots are not suitable for growing most vegetables because extra time for transplanting operations is required and the space for healthy root growth may not be adequate. For growing vegetables, beds and troughs are more suitable.

Benches can be as simple as a few scraps of wood lying across the top of heat-storage barrels, or they can be good-looking open tables of 1 × 2 wood nailed together—resting on top of the heat storage or built with legs. The benches should be of open construction, as shown in Figure 10.1. Thus, air can circulate easily around the plants, for their health an'

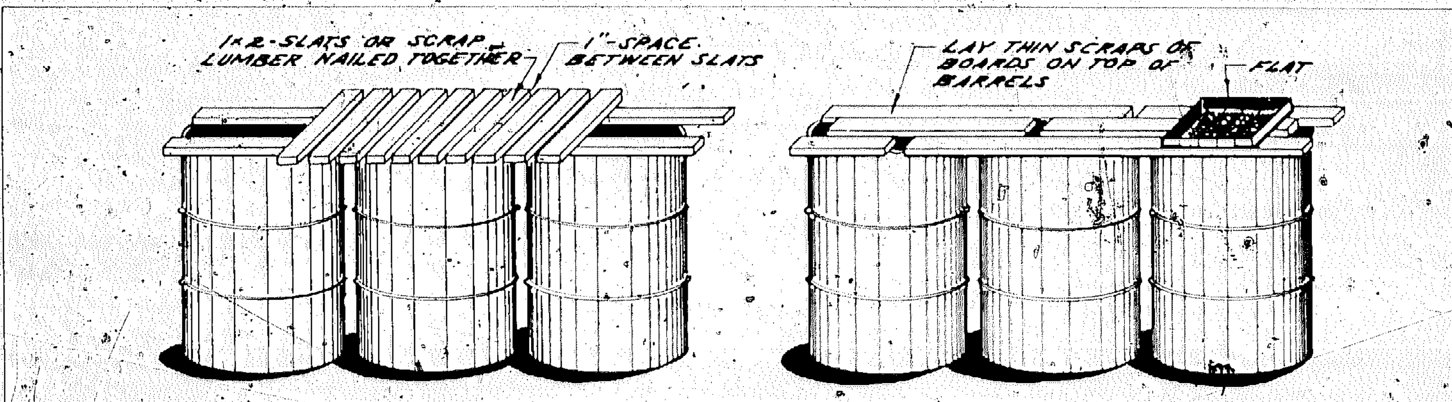


FIGURE 10.1 Benches for top of barrels

growth, and around the heat storage to increase the flow of heat in and out of storage.

Beds and troughs are the most common systems for vegetable production in an organically managed greenhouse. A bed is simply a large container with some kind of drainage. Usually, it is made of wood and can sit either directly on the greenhouse floor or on a series of legs or supports (Figure 10.2). Different growers have different preferences for bed design. Some people are content to build beds that hold only 8" to 12" of soil while others prefer deeper containers. As a general rule of thumb, though, beds under organic management should be at least two feet deep and contain at least 20" of soil, plus a little sand and gravel underneath for drainage. This depth allows ample room for root development.

It is almost impossible to provide for too much drainage in a bed; more often, drainage is insufficient and problems for the plants and the grower arise. Inadequate drainage keeps the lower soil too wet and prevents the lower plant roots from getting the oxygen they need. (Old gardeners say that certain plants don't like their feet wet.)

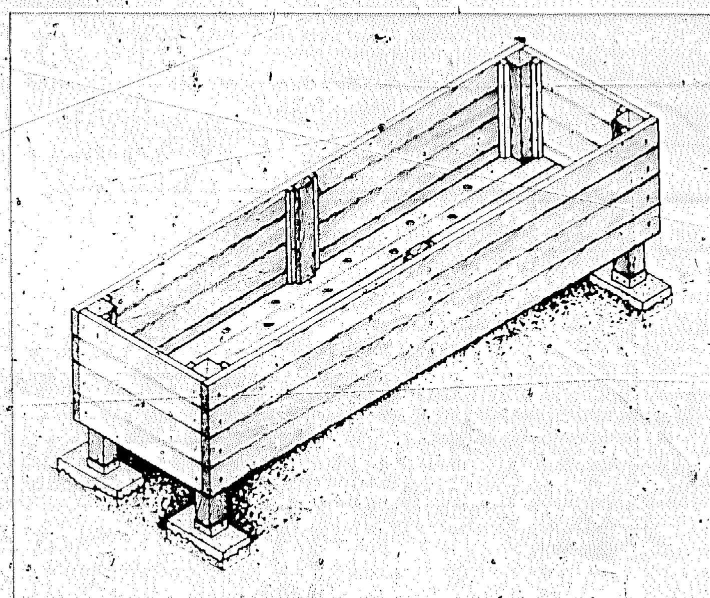


FIGURE 10.2 Raised planting bed

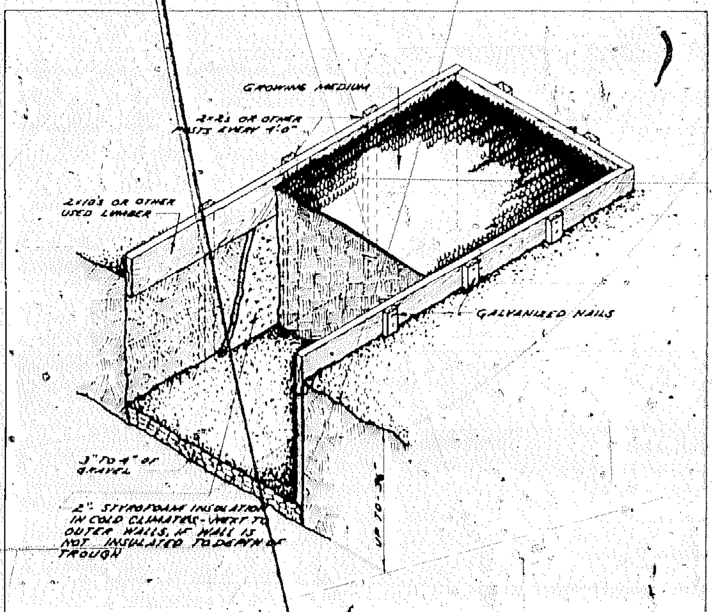


FIGURE 10.3 Trough-type growing bed

Drainage can be provided by drilling large holes — ¾" — into the bottom bed boards at frequent (6") intervals. Because they are so large, it is wise to cover these holes with nylon screening so that sand, gravel or soil does not fall out. You can drill the holes in rows and staple strips of screening over each row.

If your bed has a slat bottom, you can simply leave spaces between the bottom boards, and then screen over the bottom. Leave ½" spaces between the boards, as they will swell when wet and tend to close up the spaces.

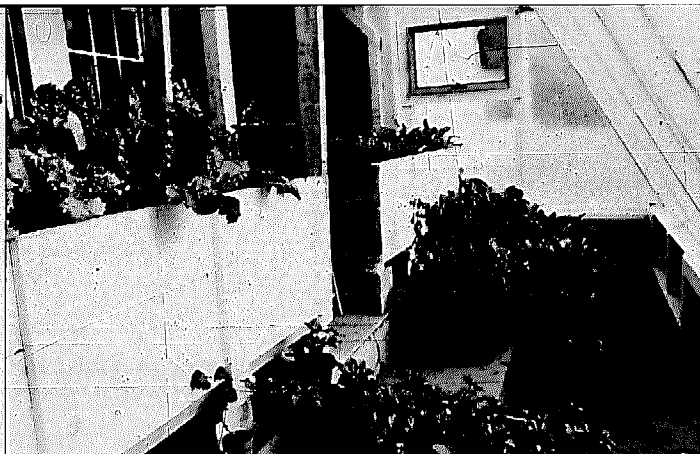
A trough is a bed that is dug directly into the floor of the greenhouse (Figure 10.3). Unless the earth below the greenhouse is exceptionally well drained, some sort of drainage must be provided in troughs, too. Some people construct troughs by excavating down about three feet; adding three or four inches of washed gravel on the bottom; lining the sides with boards held in place with 2 × 2s or other posts that extend at least 6" above the level of the floor; and then filling the trough with a soil mixture. Concrete blocks, bricks or stones also can be used for edging the trough-bed. Troughs hold in the soil mixture to a certain extent but also allow earthworms and other soil organisms relatively free access to the soil. Other people simply dig out a predetermined area and fill the hole with a soil mix. It is important to add your own soil mix, even if you are building the greenhouse on top of old garden soil.

A trough system has the advantage of giving more overhead space, but should not be used when the greenhouse glazing does not extend down to the ground or in areas where there are problems with the native soil (such as metals contamination or destructive nematodes). In addition, some warmth-loving plants may not survive at floor level during the winter in cold climates. The trough wall next to the foundation should be insulated from the frozen ground outside if the foundation itself is not insulated to the trough's depth (Figure 10.3). Troughs built directly against continuous foundations can utilize the foundation as one wall.

Using a trough near the south glazing and a raised bed on the north side of the greenhouse is a good growing area combination (Figure 10.4). Tall plants in the front trough won't shade crops in the rear planting bed. Also, the excavation already done for the foundation wall will save some digging.

PRESERVATIVES: Wherever wood comes in contact with moisture and rot-producing soil organisms, it must be preserved, and wood used in planting beds must be especially safe to plants.

Most wood preservatives are toxic to plants because they contain phenolic compounds. There are a few safe ones, including oil-base paints free of asphalt, mercury and lead; Varathane; and copper naphthanate. Copper naphthanate actually kills some beneficial soil fungi and bacteria when it



This converted Massachusetts greenhouse utilizes the old concrete porch floor and steps to provide an excellent growing arrangement. The lower front beds and raised rear beds complement incoming light effectively.

is new, and also releases toxic fumes as it dries. If it is necessary to use this preservative, it would be safer to leave the treated beds outside to weather for a few months. (Incidentally, if you used copper naphthanate on the greenhouse structure, the perservative should be applied long before the plants are in.)

Another way to protect your beds is to line the sides with plastic film. Use small scraps of wood to attach the plastic. Don't cover the bottom of the bed this way because it will interfere with drainage.

A third alternative is to use rot-resistant wood, such as cedar or redwood. However, these wood types are expensive and scarce natural resources in most parts of the United States.

WATERING

As with other components, you have several options when selecting a water system. The range is wide, from the simplest hand methods to the more elaborate automated systems. Once again you must determine and prioritize your needs and desires, as well as consider the limiting factors in your particular situation. Then you can determine which watering system will be best for your greenhouse.

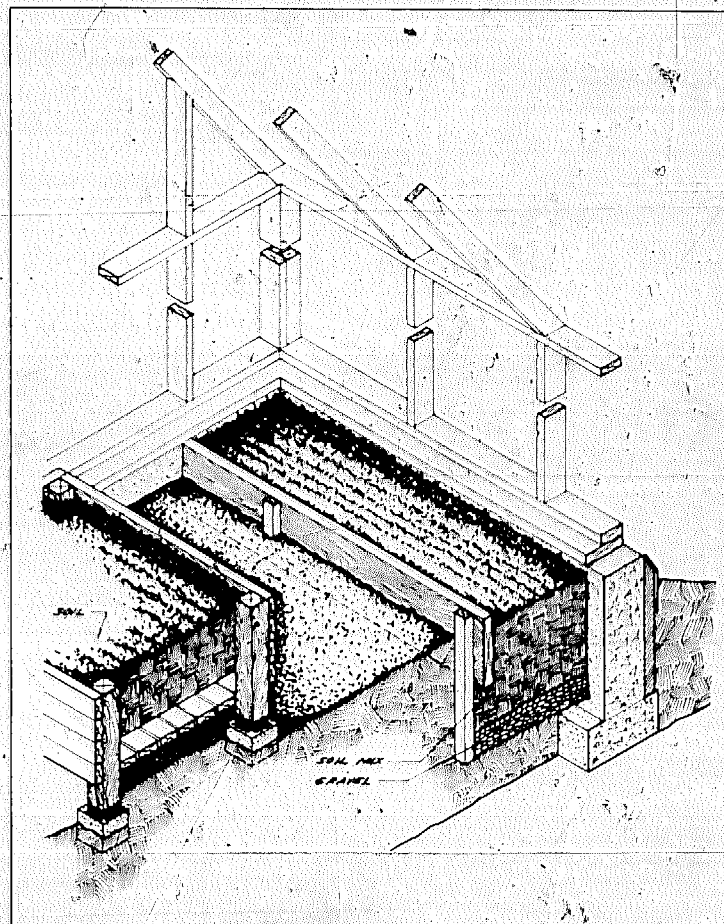


FIGURE 10.4 Soil bed placed in greenhouse

Limiting factors to consider include the type of crops being produced, the size of your growing space, the climatic conditions of your environment, your personal time allotment, cost, materials available and maintenance requirements. Obviously you must set your own priorities. Is time more important to you than money?

Choice of crops and area of growing space are two primary considerations. Plants have differing water needs. Certain plants do not take kindly to having their foliage wet (violets, gloxinias) and would obviously not do well with an overhead spray or mist system. Some combinations of plants cannot be grown under the same conditions using a system which waters all the crops equally. Likewise, pots (if you use them instead of beds) of varying sizes will have different water needs. On the other hand, if you are dealing with a large growing area, the amount of labor and time involved in hand watering each individual crop or plant may not be justified. Remember, it does not rain inside the greenhouse. Plants are entirely dependent upon the greenhouse operator and the watering system for their livelihood.

HAND METHODS: Hand watering is the simplest and the least costly, but also the most time consuming. There are several hand watering methods. The oldest and most basic method is the **watering bucket**. It involves numerous trips from the water source to the plants. Changeable "roses" or nozzle heads may be obtainable for your bucket that permit a variety of patterns and force with which to water.

Another method is **watering from below** by setting your pots in tubs. These tubs should be filled with water to a depth of about one-half the height of the pot. This approach allows for a thorough watering. But be sure to use soil that drains well. This method is useful in greenhouses with plants that react negatively to getting their foliage wet. However, watering from below is messy and time consuming. Also, it might lead to a buildup of salts on the soil and pot surfaces, noticeable by a white film. When and if salt buildup occurs, a good leaching of the soil by watering from above will be necessary.

A third hand method, the **wick system**, is somewhat similar to watering from below. It utilizes the principle of capillary action which allows the soil to take up the amount of water that the plant needs. The wick (a piece of absorbent woven nylon) runs from the soil in the bottom of the pot to the water source. When the soil dries, it pulls more water from the wick, maintaining an equilibrium between the water available and the plant's needs. An appealing advantage of the wick system is that the plants can be left unattended for long periods of time. As long as the water source is plentiful, plants can take care of their own water needs. It is also a useful system for plants that dislike getting wet. Among the problems, though, are the set-up cost for this system, and the possible unattractive appearance. Also, salt buildup is likely and should be dealt with as mentioned above.

The most common hand watering system is the **hose**. As with the watering bucket, various heads or nozzles can be utilized for different patterns, force and quantity effects. Some of the available nozzles include mist heads, spray heads, jets and guns which allow the water to be controlled right at your hand. The hose is inexpensive, labor-intensive system which can be set up to reach all areas of your greenhouse. *Be sure to keep the nozzle off the ground at all times:* Bacteria, fungi and other pathogens can be spread to all areas of your greenhouse if the nozzle is infected. Additionally, a hose is a handy tool around the greenhouse regardless of the irrigation system in use. It can be helpful for watering pots before they are taken from the greenhouse or for other singular situations—for example, to wet down the floor of the greenhouse in order to raise the humidity.

SOPHISTICATED SYSTEMS: More sophisticated irrigation systems generally require increased costs and, in terms of initial installation and maintenance time, more labor. Many of these systems can be automated, which could justify the labor of initial installation and maintenance. On the other hand, your decision will depend partly on the size of the growing area. It might be hard to justfiy an automated, sophisticated system if your growing space is minimal.

Drip Systems: Drip systems (Figure 10.5) often are used in greenhouses set up to produce potted plants, and can be especially useful in areas of the country where water scarcity is a serious problem. They are designed to provide water to the plants through a series of plastic or metal pipes and small "spaghetti" tubes. Designed to drip the water into the soil, these spaghetti tubes are fitted with plastic end pieces which are poked into or laid on the soil beside the plant. Although very thorough and efficient, this watering method requires that all the plants on any particular portion of the drip system have the same watering needs. The water is run until all the pots show signs of drainage throughout.

When functioning properly, the drip system saves time and water. The ability to keep the foilage dry is another plus. One problem with drip irrigation is mechanical: sometimes the tubes pop out of the pipes due to fluctuating pressures. Water pressure also can be a problem where the pipes are extremely long, causing variations from one end of the system to the other. Thus, the plants furthest from the water inlet may not receive the same quantitiy of water. Another problem is the tendency of the small individual tubes to clog up with debris. Pots must be checked regularly to insure that they are all getting water from their tubes.

Misting: Misting is excellent for the production of starts, seedlings and cuttings. This type of production requires moist air space around the leaves to maintain turgor and promote rapid root development and plant growth.

The foundation piping of the mist system can be similar to that for drip irrigation (Figure 10.6). Plastic or metal pipes run the length of the bed or bench. From these pipes, upright piping with mist heads are attached. These are designed to cover a specific area evenly and will vary according to the

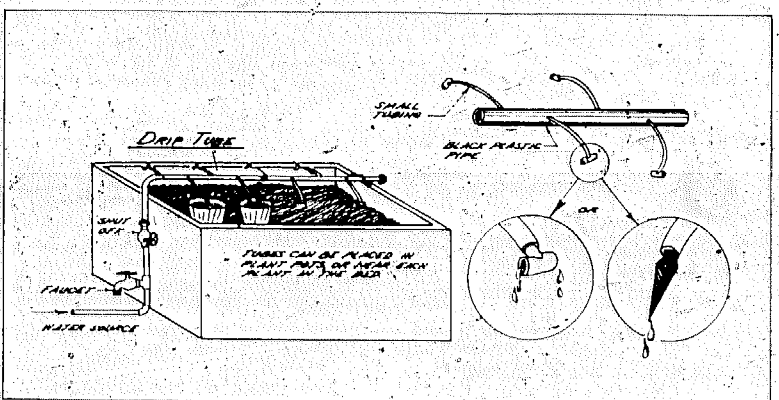


FIGURE 10.5 Drip tube irrigation system

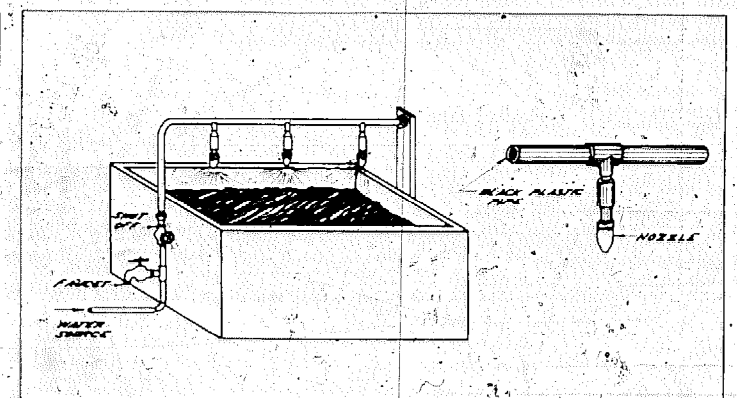


FIGURE 10.6 Mist spray nozzle irrigation system

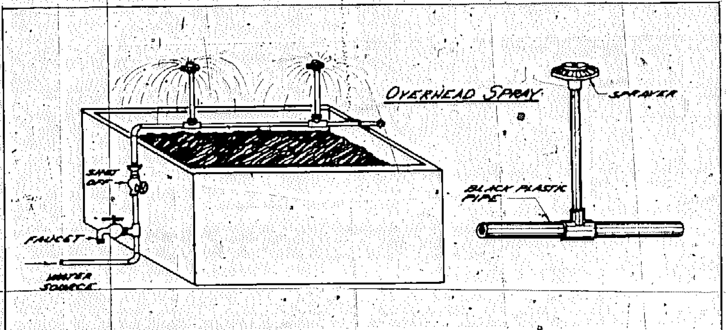


FIGURE 10.7 Overhead spray irrigation system

type of head, size of piping and water pressure. Mist heads cover from a 180° to 360° area and usually can be set for the desired patterns. Your mist head choice will influence how you lay out your piping: If the mist nozzle only covers a 180° area, your piping will be laid out along one edge of the bed or bench; with a 360° nozzle, however, the piping can go down the center of the growing structure.

With misting, your plants' water needs again must be similar for every area covered by specific portions of the system. A timer can be used to automate your mist. Misting should not be used to meet normal watering needs because it only covers foliage and surface areas with a light spray to prevent wilting and drying out of the soil. Again, it is a good option if you are only producing starts or doing propagation of cuttings, seedlings, etc. But for thorough watering of larger plants and pots, misting is inadequate.

Overhead Irrigation: The overhead irrigation approach (Figure 10.7) is similar in structure to the mist system. The only real difference is the type of nozzle or head, which provides a more forceful watering. Therefore, an overhead watering system is adequate for larger plants needing less frequent yet more thorough watering than starts, cuttings, or seed beds.

GREYWATER: Greywater refers to wastewater from the kitchen, bathroom sink and tub which are not contaminated by human wastes. Using greywater for greenhouse irrigation is a recycling system which deserves some attention and further research. In the greywater system, the water is generally run through a rough filter such as gravel, which screens out large particles and debris such as hair, food scraps, lint, etc. The greenhouse beds are used as leaching fields for greywater purification. In theory, a greywater system serves two purposes: 1) it provides water and nutrients to the plants in the greenhouse, and 2) it purifies wastewater before it is recycled back into the groundwater table. (Research is being done by Abby Rockefeller and Carl Linstrom, in Cambridge, Mass.; they plan to publish a manual of design criteria for greywater use in a greenhouse.)

HYDROPONICS: Probably the ultimate "watering" method is hydroponics—a total approach of supplying all the plants' nutritional needs through the water. With hydroponics, the root structure is supported in various media other than soil: sand, vermiculite, perlite or gravel. The nutrient mix supplied through this watering procedure usually is fed into the root structure medium on a frequent basis.

Generally, hydroponics is not recommended for the beginner, since it requires a delicate balance of water, nutrients and air—something not easily understood by the neophyte greenhouse grower. Using hydroponics requires practice and study to grasp the concepts. It also is an intensive system which demands constant monitoring and adjustment. One drawback to hydroponics is the possible dependence on chemical fertilizers which are derived from fossil fuels. But there are proven organic methods of hydroponic growing: see Jim DeKorne's work, described in his book **The Survival Greenhouse** (Resource List). Another consideration is purely tactile: Working with perlite or gravel just isn't as satisfying to many folks as digging into a rich humic soil.

The positive aspects of hydroponic production include generally higher yields and less weight of materials (perlite, versus soil) which could be appealing in a rooftop situation. The frequent waterings can be automated too.

WATER TEMPERATURE

The temperature of your irrigation water is critical. Plants cannot stand extreme water temperatures. Water within a range of 60-80° is best. If you are operating your greenhouse on a year-round basis, some water heating might be necessary. If your water source is from the attached structure and you can control the temperature there, you're in good shape. If not, you may want to consider one of several options.

One simple solution is to fill a garbage can (or 55-gallon drum) with water. The container should be stored in the greenhouse and its contents allowed to warm up to greenhouse temperatures. The water could take 12-24 hours or longer to warm, so you will have to think ahead. The can must be covered at night to prevent evaporative heat loss, especially in cold months or when you plan to water in the morning. If the water reserve is set up on a platform above the bench or bed level, a hose can be used to drain the water conveniently.

A related option is to use one of your upper thermal storage barrels (if your greenhouse is set up this way) as your water preheater. The principle is the same as the first option. Use a hose to drain off the necessary water. If you choose this method, though, there are a few things to consider. Is 55 gallons enough to meet your watering needs? Can you afford (thermally) to give up that mass storage? Are you willing to replace the barrel as necessary, since you won't be using rust inhibitors in that drum? If you answered "yes" to these three questions, this option may be a very practical solution.

An even more elaborate system carries this principle one

In this hydroponic growing system, PVC irrigation tubes are placed eight inches below the gravel (surface) line. The tubes are drilled every four inches. An "organic tea" solution (water, manure tea, seaweed, fish emulsion) circulates from the tubes up through the gravel to the plant roots by capillary action. The gravel is sloped to one corner and the nutrient solution is recycled to the tubes.

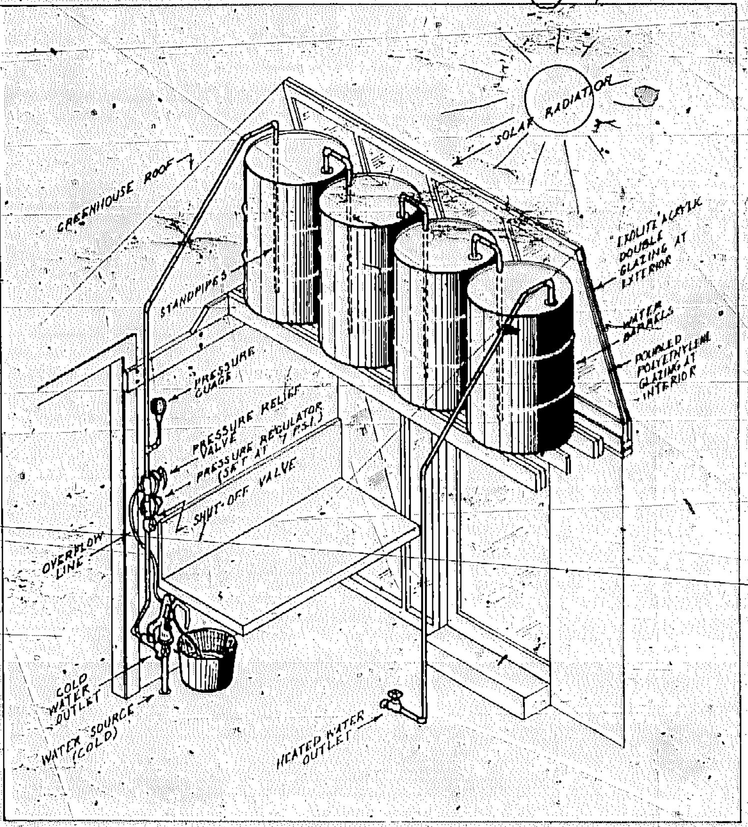
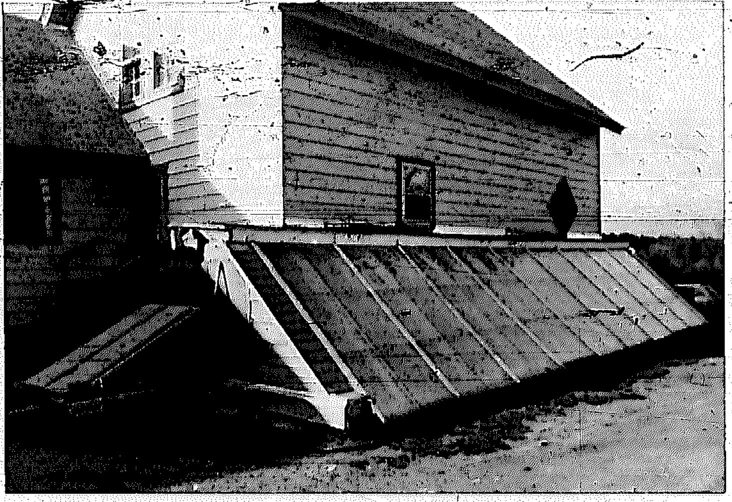
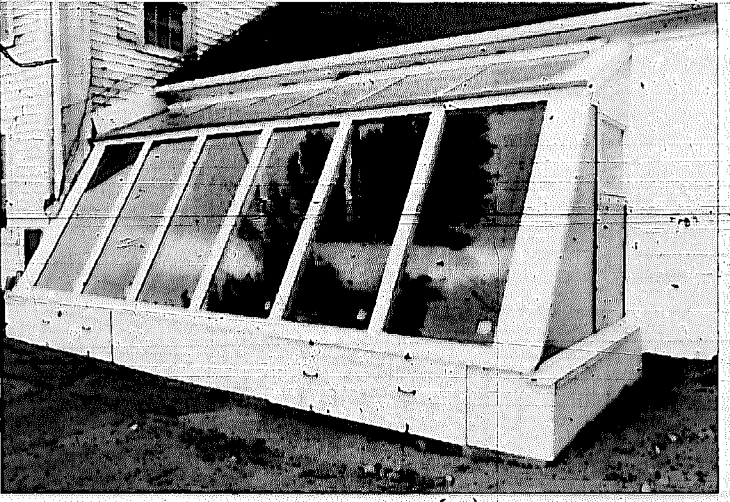
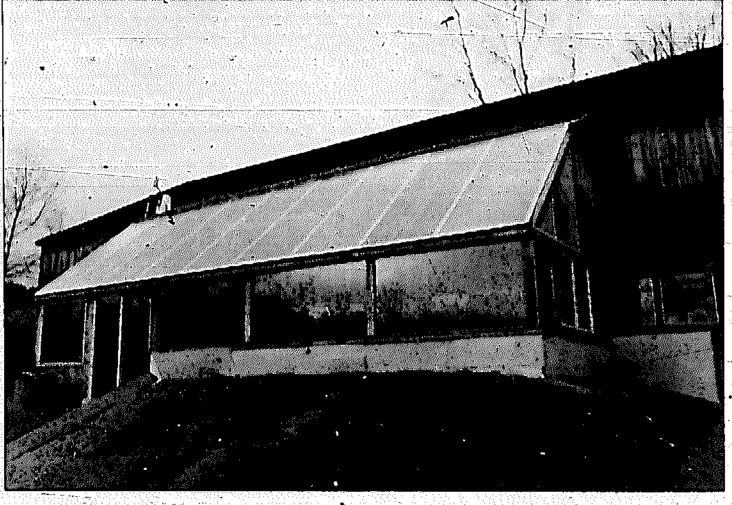


FIGURE 10.8 Water heating system for NCAT solar greenhouse

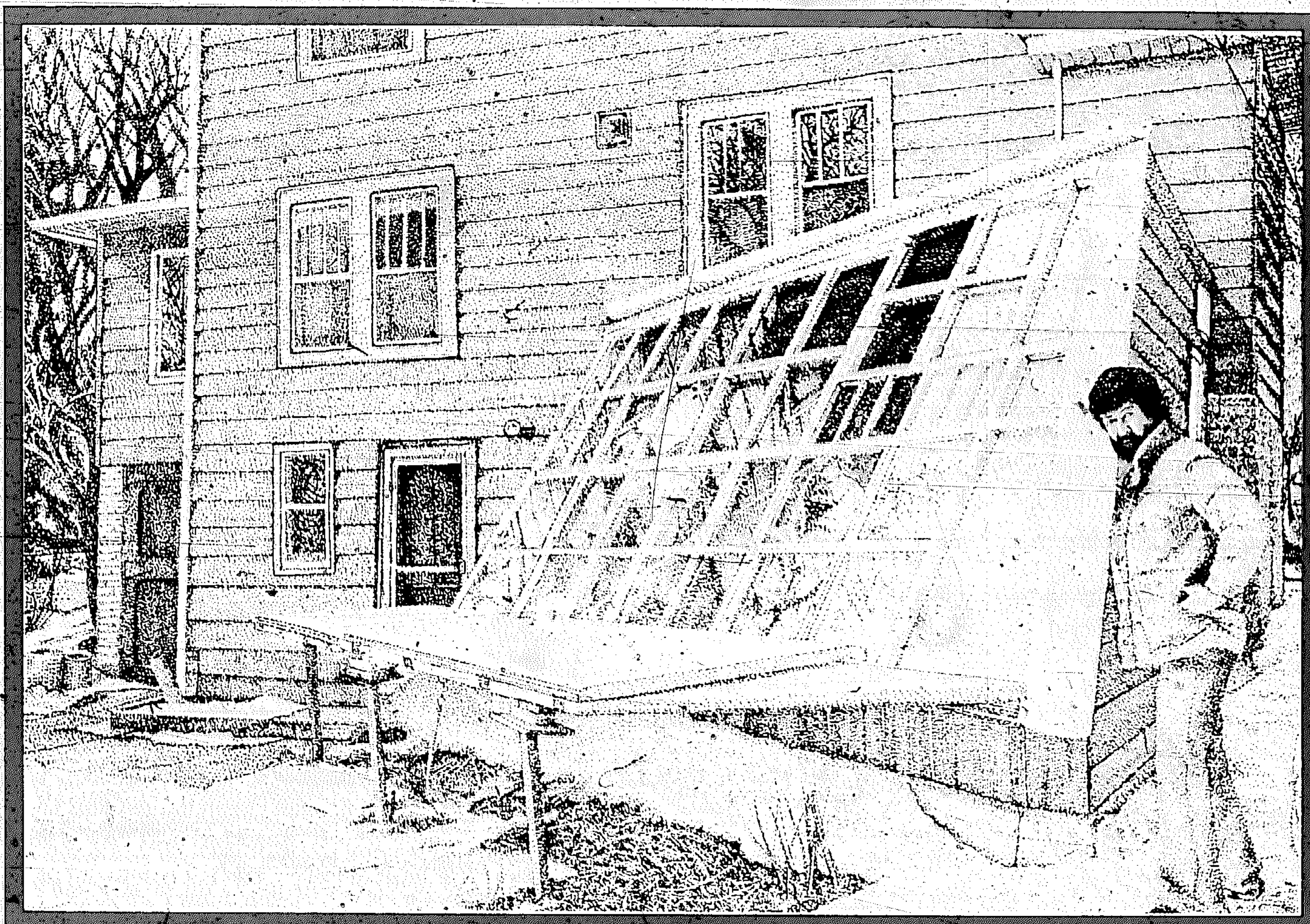
step further. In operation at the NCAT greenhouse in Butte, Montana, this system (Figure 10.8) utilizes four 55-gallon drums in the greenhouse vestibule. The sun entering the vestibule keeps the irrigation water heated. Natural convection/circulation (based on the fact that warm water rises) takes place within each of the four barrels. Water is piped into the first barrel at low pressure. As it is warmed by the sun, the warmer water rises from the bottom to the top and the cooler water sinks. The warm water at the top is forced to the bottom of the next barrel each time water is withdrawn from the hose. During periods of the year when 50 gallons of irrigation water are used per day, the water spends about four days in the drums, allowing it to warm considerably—about 10°F each sunny day. The NCAT greenhouse has a growing area of about 250 square feet, and irrigation needs have not exceeded 75 gallons per day. Approximately half (110 gallons) of the total warm water storage (220 gallons) is suitable for watering at any given time. Thus, there is some "backup" warm water in the case of a series of cold, cloudy days. Quadruple glazing is used at the NCAT greenhouse on the south side in front of the barrels. The barrels are not insulated, as they help to warm the vestibule in which they are located. Water from this system averages about 55° in winter and 80° in summer. In contrast, tap water is about 35° in winter and 50° in summer.







An attached solar greenhouse is one of the most popular solar retrofit options. With combined benefits of heat and food, it is an attractive investment. Choose a good design that will satisfy your individual needs. Take your time during construction to ensure quality craftmanship. Plan your effort carefully and good luck.



Part IV

RESOURCE DIRECTORY/BIBLIOGRAPHY

RESOURCE LIST OF GROUPS AND INDIVIDUALS

These organizations can help you design and construct a solar greenhouse that is appropriate for your specific site and climate. As mentioned several times in this book, greenhouse designs and construction techniques that work well in one area of the country may not be suitable in another. Advice from someone who has greenhouse building experience in your immediate locale can minimize problems.

The organizations are listed by federal region (as shown on the map) and under each listing is a letter(s) which indicates the kind of assistance each group can provide:

"C" — construction help

"D" — design assistance (usually for a fee)

"I" — information (library and/or questions answered, often free)

"W" — workshops (courses and "hands-on" instruction on design, construction and management)

CSA Regions

With the exception of south Florida and Hawaii, where greenhouses are seldom used, there are several operating greenhouses in the United States, and at least a few groups and individuals in most areas prepared to offer assistance. While this list is by no means exhaustive, it should lead you to someone who can help.

In addition to this Resource List, there are other sources of assistance that you should investigate:

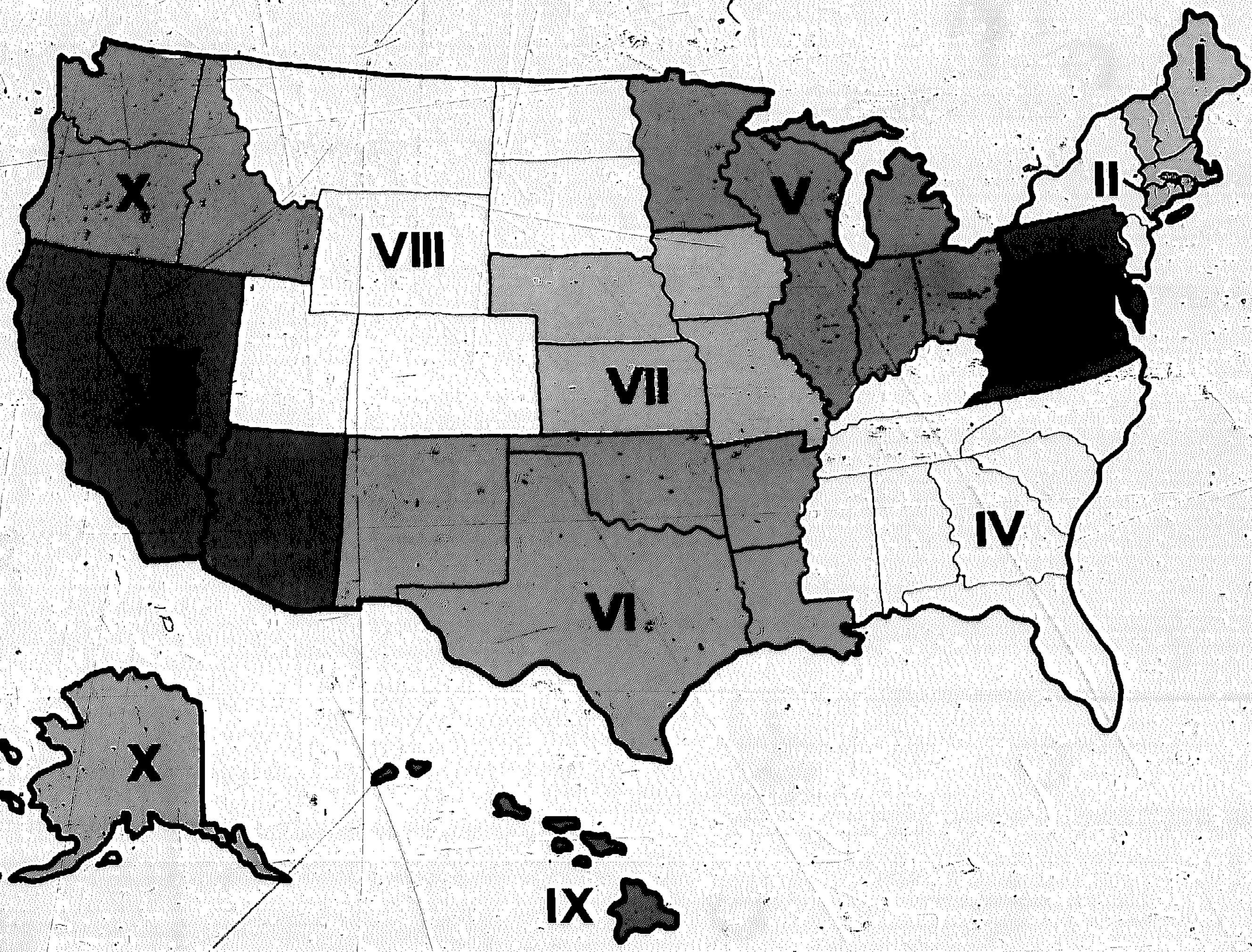
State (and sometimes county) energy offices: Usually there is someone on the staff that is familiar with local greenhouse projects. Many agencies offer publications, workshops, and energy libraries on the subject, and some may have compiled their own directories of people using solar greenhouses in their area.

State and local associations: Programs, workshops, and access to books and plans for greenhouses are available through solar energy associations in many parts of the country. Your state energy office will have addresses for such groups. Gardening and greenhouse associations also may be sources for workshops on greenhouse management. Check with your local botanical garden for workshops as well.

Educational institutions. In some areas, courses and workshops on solar greenhouse planning and construction are conducted by vocational-technical schools, small colleges, and universities.

Design/construction firms. Firms that can provide planning help or a complete custom design are available in many areas. Professional architects and engineers, design/build construction companies, and individual consultants with a background in solar greenhouses are becoming increasingly common. Try to find one with experience in your climate.

** Although an attempt was made in our survey to identify the most active and reputable people in each locale, NCAT cannot endorse any of the groups or individuals listed in this directory.


I
II
IV
V
VI
VII
VIII
IX
X
X

REGION I
(New England: ME, CT, VT, NH, RI, MA)

CANDUWIT
R.D. #1
Brooksfield, VT 05036
(802) 276-3061
Contact: Jim Lacillade
(D)

CENTER FOR ECOLOGICAL TECHNOLOGY
74 North Street
Pittsfield, MA 01201
(413) 445-4556
Contact: Ned Nissau
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JEREMY COLEMAN
Box 45
Marlboro, VT 05344
(802) 257-0735

CORNERSTONES
54 Cumberland Street
Brunswick, ME 04011
(207) 729-0540
Contact: Jonathan Gorham
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GREENHOUSE, ETC.
396 Cambridge Turnpike
Concord, MA 01742
(617) 369-1354
Contact: Mark Ward
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HEARTWOOD
Johnson Road
Washington, MA 02135
(413) 623-6677
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HOBBY GREENHOUSE ASSOCIATION
45 Shady Drive
Wallingford, CT 06492
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HARVEY LORBER
Room 110, Bangor Hall
University of Maine
Bangor, ME 04401
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MEMPHRAMAGOG GROUP
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Newport, VT 05855
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Contact: Miriam Klein
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NEW ALCHEMY INSTITUTE
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Contact: Denise Backus
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NORTHEAST CARRY
P.O. Box 187
Hallowell, ME 04347
(207) 623-1667
Contact: Ron Poitras
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PARAL[illegible], INC.
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Contact: Doug Taff
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RHODE ISLAND GOVERNOR'S ENERGY OFFICE
80 Dean St.
Providence, RI 02903
(401) 277-3773
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ABBY ROCKEFELLER
14A Elliot Street
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SHELTER INSTITUTE
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Bath, ME 04530
(207) 443-9084
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SOLSEARCH ARCHITECTS
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SUNPLACE CORP.
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(New York, New Jersey)

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(609) 924-9576
Contact: Tom Swartz
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RAMAPO ALTERNATE ENERGY CENTER
505 Ramapo Valley Rd.
Mahwah, NJ 07430
(201) 825-2800
Contact: Pete Savio
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RARITAN VALLEY COMMUNITY CO-OP
182 Hamilton St.
New Brunswick, NJ 08901
(201) 247-8246
Contact: Laurel King, Alice Borsody
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SOUTH END SOLAR
196 Morton Ave.
Albany, NY 12202
(518) 465-6462
Contact: Herb Hugh
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YOUTH DEVELOPMENT SOCIETY
P.O. Box 1127
New Brunswick, NJ 08903
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Contact: Maurice M. Sampson
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REGION III
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Oxford, PA 19363
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Contact: Kent Vendrick
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ENERGY INFORMATION CENTER
State Office of Emergency and Energy Services
310 Turner Rd.
Richmond, VA 23225
(804) 745-3245
(800) 552-3831 in Virginia
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MID-ATLANTIC SOLAR ENERGY ASSOCIATION
2233 Grays Ferry Avenue
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PENNSYLVANIA DEPARTMENT OF COMMUNITY AFFAIRS
Office of Community Energy
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Harrisburg, PA 17120
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SCOTT COUNTY RURAL AREAS DEVELOPMENT ASSOCIATION
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(703) 386-6441
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SHADES OF WEST VIRGINIA
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THE SOLAR PROJECT
c/o C.A.P. of Lancaster County
630 Rockland Street
Lancaster, PA 17602
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TECHNOLOGY EDUCATION DEPARTMENT
W.V. University
Suite 609 Allen Hall
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(304) 293-3803
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REGION IV.
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APPALACHIA SCIENCE IN THE PUBLIC INTEREST
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(606) 453-4121
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AQUATIC-AGRICULTURAL INSTITUTE FOR RESEARCH
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EAST TENNESSEE COMMUNITY DESIGN CENTER
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(218) 847-1341
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3302 Chicago
Minneapolis, MN 55407
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CENTER FOR NEIGHBORHOOD TECHNOLOGY
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Chicago, IL 60606
(312) 454-0126
Contact: Paige Chapel
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1282 Jackson Ave.
Lakewood, OH 44107
(216) 221-6319
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ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN
P.O. Box 8618
Ann Arbor, MI 48107
(313) 994-1200
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INGHAM COUNTY ENERGY OFFICE
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(517) 676-3550
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M13 SYSTEMS
417 Superior Street
Rossford, OH 43460
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SUNSPACE DESIGN AND CONSTRUCTION
1251 Johnson
Madison, WI 53704
(608) 257-1743
Contact: Bob Forrer
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REGION VI
(Southwest: NM, TX, OK, AK, LA)

ALTERNATIVE ENERGY SYSTEMS
P.O. Box 117
Beaver, AR 72613
(501) 253-7393
Contact: Steve J. LaFontaine
(C, D, I, W)

LOUISIANA DEPARTMENT OF NATURAL RESOURCES
Division of Research and Development
P.O. Box 44156
Baton Rouge, LA 70804
(504) 342-4592
Contact: Keith Overdyke
(I, W)

MAXIMUM POTENTIAL BUILDING SYSTEMS
8604 F.M. Road 969
Austin, TX 78724
(512) 928-4786
Contact: Pliny Fisk
(D, I, W)

NEW MEXICO SOLAR ENERGY ASSOCIATION
P.O. Box 2004
Santa Fe, NM 87501
(505) 983-5338
(505) 983-2861
(C,D,I,W)

OZARK INSTITUTE
Box 549
Eureka Springs, AR 72632
(501) 253-7384
Contact: Ed Jeffords
(D, I, W)

SUNSPACE, INC.
P.O. Box 1792
Ada, OK 74820
(405) 332-0106
Contact: Bill Zoellick
(D, W)

TEXAS SOLAR ENERGY SOCIETY
600 W. 28th No. 101
Austin, TX 78705
(512) 472-1252
(W,I)

REGION VII

(Plains: KS, MO, IA, NE)

BETA FOUNDATION PROJECT
Stevens College
Columbia, MO 65201
(314) 442-2211
Contact: Wallace Wells
(I,C,W)

CENTER FOR RURAL AFFAIRS
P.O. Box 405
Walthill, NE 68067
(402) 846-5428
Contact: Donald Ralston
(I,D,C,W)

ENEGRY RESOURCE SYSTEM ANALYST
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Wichita Div. of Energy
1602 McLean Blvd.
Wichita, KS 67213
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Contact: Terry Behrendt
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IOWA CENTER FOR SELF-RELIANCE
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Des Moines, IA 50311
(515) 277-0968
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KANSAS ENERGY OFFICE
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Topeka, KS 66603
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Contact: David Martin
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MIDLAND ENERGY INSTITUTE
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Kansas City, MO 64106
(816) 842-2459
Contact: George L. Sasser
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MISSOURI SOLAR OFFICE
Department of Natural Resources
1014 Madison Street
Jefferson City, MO 65101
(314) 751-4000
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NEBRASKA SOLAR OFFICE
W 191 Nebraska Hall
Lincoln, NE 68588
(402) 472-3414
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SIOUXLAND SOLAR ENERGY ASSOCIATION
2606 Jones St.
Sioux City, IA 51101
(712) 258-6790
Contact: Mac A. Lewis
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SOLAR GREENHOUSE ASSOCIATION
34 N. Gore Avenue
Webster Grove, MO 63119
(314) 962-4176
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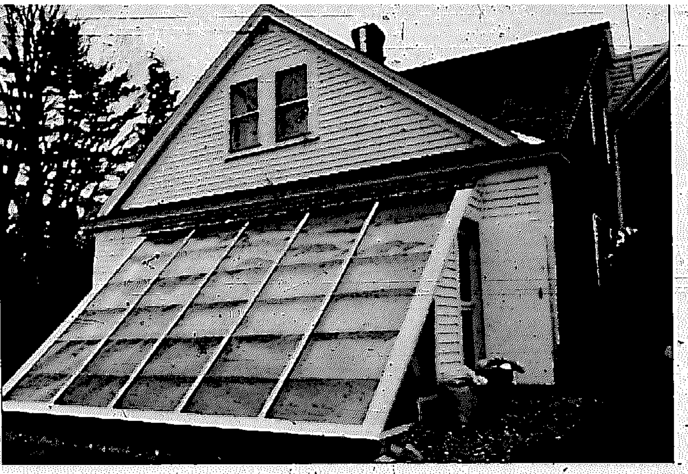
(D, I, W)

UNIVERSITY FOR MAN
1221 Thurston
Manhatten, KS 66501
(913) 532-5953
Contact: Sue Maes
(I,C,D,W)



REGION VIII

(Rocky Mountains: UT, CO, WY, MT, ND, SD)

AERO - ALTERNATIVE ENERGY RESOURCE ORGANIZATION
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Billings, MT 59101
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Contact: Monique Mandali
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JIM BAERG
Box 1146
Bozeman, MT 59715
(406) 587-0567
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NORM BARNES
1159 E. Stratford Avenue
Salt Lake City, UT 94106
(801) 485-8648
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COLORADO MOUNTAIN COLLEGE, A.T. PROGRAM
3000 County Rd. 114
Glenwood Springs, CO 81601
(303) 945-7481
Contact: Larry Puleo
(I)

COMMUNITY ACTION OF LARAMIE COUNTY
1603 Central
Suite 400
Cheyenne, WY 82001
(307) 635-9291
Contact: Gary Garber
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CUSTOM SOLAR APPLICATIONS
P.O. Box 641
Crowheart, WY 82512
(307) 486-2224
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DAKOTA SUN
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Grand Forks, ND 58201
(701) 252-8060
Contact: Dave Haley
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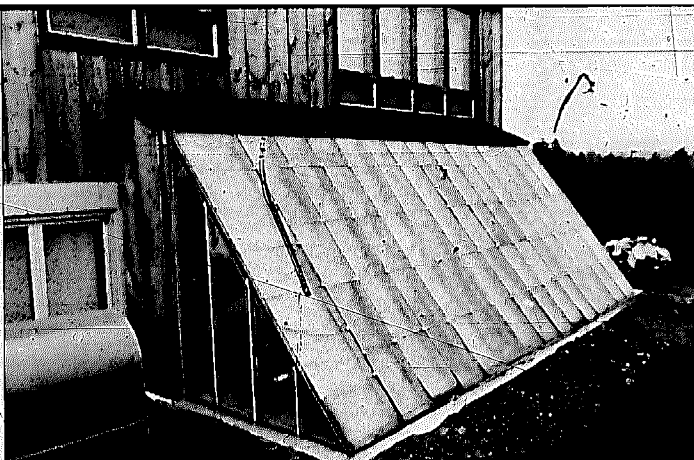
DOMESTIC TECHNOLOGY INSTITUTE
12520 West Cedar Drive
Lakewood, CO 80228
(303) 998-3054
Contact: Malcolm Lillywhite
(D, I, W)



DAVID ELFRING
384 So. Humboldt
Denver, CO 80209
(303) 777-1132
(D)

GRAND JUNCTION PUBLIC ENERGY INFORMATION OFFICE
250 North 5th Street
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Circle, MT 59215
(406) 485-2180
Contact: John Brown
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NEW WESTERN ENERGY SHOW
226 Power Block Building
Helena, MT 59601
(406) 443-7272
Contact: Jon Derry
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PEOPLE'S ALTERNATIVE ENERGY SERVICE
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San Luis, CO 81152
(303) 672-3602
Contact: Arnie & Maria Valdez
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PONDERA SOLAR ALLIANCE
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Conrad, MT 59425
(406) 278-5330
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REGION 9 COMMUNITY SERVICES AGENCY
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Contact: Bud Evans
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SAN LUIS VALLEY SOLAR ENERGY ASSOCIATION
P.O. Box 1284
Alamosa, CO 81101
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Contact: Bob Dunsmore
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SOUTH DAKOTA OFFICE OF ENERGY AND POLICY
Capitol Lake Plaza
Pierre, SD 57501
(605) 773-3603
Contact: Steve Wegman
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SUN'S RIGHT GREENHOUSES
Box 370
Huntington, UT 84528
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c/o Flagstaff Center for Appropriate Technology
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CALIFORNIA OFFICE OF APPROPRIATE TECHNOLOGY LOCAL ASSISTANCE GROUP
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Sacramento, CA 95814
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HABITAT CENTER
162 Christen Dr.
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FARALLONES INSTITUTE
15290 Coleman Valley Road
Occidental, CA 95465
(707) 874-3060
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SANTA BARBARA COMMUNITY ACTION COMMISSION
5689 Hollister
Goleta, CA 93110
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SUN MOUNTAIN DESIGN
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Flagstaff, AZ 86001
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Contact: Joe Costion
(C,D,I,W)

REGION X

(Northwest: OR, WA, ID, AK)

ALASKA ALTERNATE ENERGY RESOURCE CENTER
1069 W. 6th Street
Anchorage, AK 99501
(907) 274-3621
Contact: Nancy Lee
(I, W)

ALASKA FEDERATION FOR COMMUNITY SELF-RELIANCE
Box 73488
Fairbanks, AK 99707
(907) 456-7674
Contact: Alex Scala
(I, W)

ALTERNATE ENERGY SYSTEMS
Box 187
Twisp, WA 98856
(509) 996-2490
Contact: Aileen Jeffries, Peter Morrison
(C,D)

ECOTOPE GROUP
2332 East Madison
Seattle, WA 98112
(202) 332-3753
(D,I)

KITTITAS VALLEY ALTERNATIVE ENERGY ASSOCIATION
ENERGY RESOURCE CENTER
Washington Energy Extension Service
109½ W. 6th
P.O. Box 282
Ellensburg, WA 98926
(509) 962-9863 Ext. 255
(I,D,C,W)

NEWACT - NORTH EAST WASHINGTON APPROPRIATE & CREATIVE TECHNOLOGY
P.O. Box 385
Republic, WA 99166
(509) 775-3865
(509) 775-3341
Contact: Mike Nelson
(I,C,D,W)

OREGON APPROPRIATE TECHNOLOGY
Box 1525
Eugene, OR 97440
(503) 683-1613
Contact: Don Williams, Larry Parker
(C,D,I)

OREGON SOLAR ENERGY SOCIETY
P.O. Box 142
Willamette University
Salem, OR 97308
(503) 363-3298
Contact: Jeff Michael

OREGON SOLAR INDUSTRIES ASSOCIATION
7642 SW Capitol Hwy.
Portland, OR 97219
(503) 244-2143
Contact: Steve Barrett
(I)

PORTLAND SUN
628 S.E. Mill
Portland, OR 97214
(503) 239-7470
Contact: Lynn Youngbar
(D,I,C,W)

PROJECT
Box 777
Soaplake, WA 98851
(509) 246-0261
Contact: Greg Higgins or
(206) 445-2473
Contact: Graham Hubenthal
(D)

RAINSHADOW
3237 East Lake Ave. E.
Seattle, WA 98102
(206) 323-2377
Contact: Tim McGee
(C,W,D)

SOLAR ENERGY ASSOCIATION OF IDAHO
Box 2761
Boise, ID 83701
(208) 336-1526
Contact: Dan Smith
(D,I,W)

SOUTHERN PUGET SOUND SOLAR ENERGY ASSOCIATION
P.O. Box 454
1620 E. 4th
Olympia, WA 98506
(206) 943-4595
Contact: David Haskill
(I,D,C,W)

SOLAR STUDY GROUP
P.O. Box 1241
Corvallis, OR 97330
(503) 753-0334
Contact: D.R. Knapp
(C, D, I, W)

WASHINGTON SOLAR TRADES COUNCIL
1916 Pike Place, No. 22A
Seattle, WA 98101
(206) 622-7171
Contact: Jeanie Taylor
(I,W)

CANADA

BRACE RESEARCH INSTITUTE
Macdonald College of McGill University
St. Ann de Bellevue, Quebec
H9X 1C0
(514) 457-2000 Ext. 255
Contact: Andy Skelton
(D,I)

CONSERVER SOCIETY CO-OP
P.O. Box 4377
Station E
Ottowa, Ontario
(613) 233-0928
(W)

THE DRAWING ROOM GRAPHICS SERVICES, LTD.
P.O. Box 86627
N. Vancouver, BC V7L 4L2
Contact: Richard Kadulski
(D,I)

ECOLOGY HOUSE
12 Madison Ave.
Toronto, Ontario M5R 2S1
(416) 967-0577
(I)

RICHARD KERR
RR 3
Dalkeith, Ontario K0B 1E0
(613) 874-2293
(C,D)

MEMPHRAMAGOG COMMUNITY TECHNOLOGY GROUP
RR 4
Mansonville, Quebec J0E 1X0
(514) 292-5663
Contact: Ron Alward
(D)

PASSIVE SOLAR DESIGN, LTD.
Office No. 204
10830 107th Ave.
Edmonton, Alberta T5H 0X3
(403) 426-3857
Contact: John Huges
(I,D,W)

SOLAR APPLICATIONS
3356 West 13th Avenue
Vancouver, B.C., Canada
(706) 733-5631

SUN HOUSE HOMES, LTD.
5 - 1945 Scarth St.
Regina, Sask. S4P 2H2
(306) 352-4433
Contact: Henry Lorenzen
(D,I)

SYNERGY SYSTEMS
Michael Keifoot
Seebe, Alberta
Canada, T0L 1X0
(403) 673-3858

THE WOODEN EWE
P.O. Box 1387
Fairview, Alberta T0H 1L0
(D,W,I)

BOOKS

An Assessment of Controlled Environmental Agricultural Technology

Prepared by:
Lawrence H. deBivort
Sponsored by:
National Science Foundation
Available from:
National Technical Information Service
U.S. Dept. of Commerce
Springfield, Virginia 22161

1978	462 pages	$15.00

This report represents an overview of "Controlled Environmental Agriculture," its use today and its potential. Reviews of operating commercial food greenhouses, analysis of the elements of greenhouse plant growth, a description of current growing space construction technology, and a look at economics and social impacts are included in the volume. This is a valuable publication, especially for experienced growers interested in technical assessments of large-scale greenhouse vegetable production.

Building and Using a Solar Heated Geodesic Greenhouse

Prepared by:
John Fontanetta and Al Heller
Published by:
Garden Way Publishing
Charlotte, VT 05445

1979	194 pages	$8.95

Fontanetta and Heller describe a geodesic dome greenhouse (25 ft. diameter) developed by their research group at New York's Fordham University. The 416 square foot structure was built for less than $480 in materials (in 1976). This low cost was achieved through the use of reinforced polyethylene for inner and outer skins, and because the dome's inherent strength allowed 2 × 2 framing. Although the prototype had endured two years of operations with no major problems since the book was written, the materials used would suggest a fairly short lifetime for the structure. One would expect moisture trapped in the fiberglass insulation (which is enclosed between two layers of polyethylene) to reduce efficiency. Nonetheless, the authors present an exciting example of low-cost, energy-efficient greenhouse design.

Building and Using Our Sun-Heated Greenhouse

Prepared by:
Helen and Scott Nearing
Published by:
Garden Way Publishing Company
Charlotte, VT 05445

1977	148 pages	$6.95

This is the Nearings' account of the building and operation of their home-built solar greenhouse in coastal Maine. It is expressly aimed at fellow homesteaders, and about half the book is taken up with pictures and quotes. They offer useful information and some interesting suggestions concernings the practicability of growing cold-hardy vegetables in a sun-heated (no back-up system) greenhouse in the North Temperate Zone. General low-cost construction advice along with details on pouring stone-faced concrete walls with movable forms is presented. The Nearings' book is a good inspiration source for the individual that wants to build a greenhouse with minimal dollar investment.

Coal Ash Utilization: Fly Ash, Bottom Ash, and Slag.

Edited by:
S. Torrey
Published by:
Noyes Data Corporation
Mill Road at Grand Avenue
Park Ridge, New Jersey 07656

1978	370 pages	$8.95

Fly ash, the fine residue resulting from the combustion of coal, is a good substitute for Portland cement in concrete. In fact, due to its very small particle size, fly ash concrete is actually superior to conventional cement concretes for applications where resistance to water flow is important. This volume outlines the many techniques for using fly ash in concrete, a resource that is becoming increasingly available due to greater use of coal for electricity generation and in industrial processes. Proportions for mixing such concrete for a variety of uses, test results, fly ash mineral recovery (mainly silica & alumina), and other uses for fly ash are treated in detail in the book. This is the most comprehensive guide available for engineering and building fly ash concrete structures.

The Complete Greenhouse Book: Building and Using Greenhouses from Cold Frames to Solar Structures

Prepared by:
Peter Clegg & Derry Watkins
Published by:
Garden Way Publishing Company
Charlotte, Vermont 05445

1978	280 pages	$8.95

A guide for the design, construction, and management of solar greenhouses. A diversity of project reviews along with good general construction guidelines makes this a valuable resource to the greenhouse builder. Primary greenhouse components are thoroughly discussed as to advantages and limitations. Many construction details are discussed and illustrated although a few outside references may be needed by the builder in this area. A thorough introduction and working guide for all people interested in solar greenhouses.

Construction Manual: Concrete and Formwork
Prepared by:
T.W. Love
Published by:
Craftsman Book Company
542 Stevens Avenue
Solana Beach, California 92075

1977 | 169 pages | $4.25

Mixing, excavation, forms, piers, beams, arched openings, finishing and reinforcing of concrete are comprehensively examined in the book. One of the better references available on the subject for beginners or experienced builders.

Construction Manual: Rough Carpentry
Prepared by:
T.W. Love
Published by:
Craftsman Book Company
542 Stevens Avenue
Solana Beach, California 92075

1976 | 286 pages | $7.95

Lumber selection, sills, girders, columns, joists, underlayment, wall framing, wall sheathing, trusses, and several types of roof framing are detailed in the book. All the reference material necessary to frame practically any kind of greenhouse is clearly presented. A clear guide to the "bones" of the matter for professional or beginner.

A Fish and Vegetable Grower for All Seasons
Prepared by:
Robert E. Huke and Robert W. Sherwin, Jr.
Published by:
Norwich Publications
Box F
Norwich, VT 05055

1977 | 125 pages | $4.95

Citing increasing energy prices, escalating shipping costs, shrinking productive agricultural acreage and a growing population, the authors argue that raising food near home using small amounts of energy will soon be imperative. Their book discusses intensive vegetable and fish production inside energy efficient solar greenhouses (built on a family or community scale). The construction and management of Mr. Huke's dome greenhouse (17 ft. diameter) which breeds catfish, trout, and vegetables is examined. Although not recommended as a complete construction guide, the book clearly presents certain greenhouse and aquaculture system design details.

Fish Farming and Your Solar Greenhouse
Prepared by:
William Head and Jon Splane
Published by:
Amity Foundation
Box 7066
Eugene, OR 97401

1979 | 43 pages | $5.00

The yield of a solar greenhouse can be enhanced significantly by making dual use of the water heat storage tank(s). The 70°F to 90°F temperatures (considered normal for sun-tempered water) are ideal for rapid growth of some varieties of fish. This book, an excellent introduction to the subject, describes what kinds of fish work best and how to grow them successfully. Examples of different approaches to greenhouse fish production are presented in the text.

The Food and Heat Producing Solar Greenhouse: Design, Construction, Operation
Prepared by:
Rick Fisher and Bill Yanda
Published by:
John Muir Publications
P.O. Box 613
Santa Fe, New Mexico 87501
Distributed by: Bookpeople
2940 Seventh Street
Berkeley, California 94710

1980 (6th Printing, Revised and Expanded) | 208 pages | $9.00

This book was originally published in 1976 as a chronicle of the Solar Sustenance Team who had built a number of solar greenhouses in the Southwest. Now in its 6th printing, the manual has been substantially revised and expanded to become one of the best solar greenhouse publications available. It provides a good variety of proven design and construction details plus step-by-step instructions for planting, maintenance and harvesting. It is very complete and highly recommended as a first book to read on the subject.

Handbook for Building Homes of Earth
Prepared by:
Lyle A. Wolfskill and others
Sponsored by:
Agency for International Development
Available from:
National Technical Information Service
U.S. Department of Commerce
Springfield, Virginia 22161

1978 | 159 pages | $8.00

Tells how to make adobe and pressed earth blocks and rammed earth walls. Soil stabilizers, site preparation, foundations, roofs, floors, and surface treatments are given detailed treatment in the publication. With lots of good how-to details, this volume is recommended as a good construction reference for anyone interested in using earth construction techniques.

Lighting for Plant Growth
Prepared by:
Elwood D. Brikford and Stuart Dunn
Published by:
Kent State University Press
Kent, Ohio 44242

1978 — $16.75

From definitions and descriptions of the behavior of light through an examination of the photochemistry of plants and specific lighting recommendations for various plants, this volume is a thorough exposition of the relationship of plant growth and light. This rather technical discussion of both sunlight and artificial light's place in the growth cycle should be of value to the serious greenhouse builder and manager.

Modern Carpentry: Building Construction Details in Easy-To-Understand Form
Prepared by:
Willis H. Wagner
Published by:
Goodheart-Williox Company
South Holland, Illinois 60473

1976 — 480 pages — $14.95

A detailed guide to construction details that is clear enough for the beginner and comprehensive enough for the full-time thumb-pounder ... most of the detail that you'll need for any greenhouse should be here somewhere. This is one of the best over-all carpentry guides available.

Passive Solar Design: An Extensive Bibliography
Prepared by:
AIA Research Corporation
Washington, D.C.
Available from:
N.T.I.S.
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

1978 — 199 pages — $9.25

A thorough listing of books and pamphlets relating to passive solar design. Beyond detailing sources of data on greenhouse passive design; economics, climatic human comfort, glazing, heat storage, insulation, and hybrid systems references are catalogued. Passive cooling by ventilation, convection, evaporation, radiation, absorption, and shading is also covered. This is a valuable aid to the passive greenhouse designer.

The Passive Solar Energy Book
Prepared by:
Edward Mazria
Published by:
Rodale Press
Emmaus, Pennsylvania 18049

1979 — 435 pages — Trade Edition $10.95
548 pages Professional — Hard Cover $24.95

This passive design text provides all the numbers necessary to design a passive solar building. Rules-of-thumb for developing passive attached or freestanding greenhouses, direct gain systems, thermal storage walls of masonry or water, and roof pond systems are clearly presented. ... the most comprehensive guide to the subject now available. The general guidelines on greenhouse energy design will be very helpful to any reader. The hard cover professional edition with 100 extra pages provides more technical data for the professional designer or more serious layman.

The Solar Greenhouse Book
Edited by:
James C. McCullagh
Published by:
Trade Sales Department
Rodale Press
Emmaus, Pennsylvania 18049

1978 — 328 pages — $10.95

This comprehensive publication details the design, building, and use of a variety of solar-reliant greenhouses. Reviews of a wide spectrum of approaches to the problem for different climates and situations is one of the strongest points of the book. The ample illustrations help to give the reader insight into how to lay out his own growing space. Generally good construction how-to along with excellent horticultural advice make this one of the most complete guides available for people planning their first solar greenhouse.

A Solar Greenhouse Guide for the Northwest
Prepared and
Published by:
Ecotope Group
2332 East Madison
Seattle, Washington 98112

1979	92 pages	$5.00

This guidebook summarizes Ecotope's considerable experience with solar reliant growing structures in the Northwest. Feasibility, siting, designing, foundations, framing, glazing, insulating, sheathing, thermal mass and finishing are outlined in the text with generous charts and diagrams accompanying. The "How to Put On a Workshop" chapter will be especially useful to many. Pacific Northwest insulation and heat loss data concludes the book. Recommended for both the novice and the experienced greenhouse builder.

Sun Angles for Design
Prepared by:
Robert Bennett
Published by:
Robert Bennett
6 Snowden Road
Bala Cynwyd, Pennsylvania 19004

1978	77 pages	$5.00

Mr. Bennett tells how to prepare a solar site plan for a solar collecting building or other collector system. Orientation, solar time, shadow mapping. Sun-control devices, overhangs, skylights, and the use of south vertical fins are analyzed in the text. Sun-angle charts for 0° through 60° N. Latitude by 20 increments are provided. A good introduction to the subject.

CONFERENCE PROCEEDINGS

Great Lakes Solar Greenhouse Conference Proceedings
October 6 and 7, 1978, Midland, Michigan
Edited by:
C.G. Currin
Sponsored by:
Chippewa Nature Center
Availabe from:
Chippewa Nature Center
400 S. Badour Rd., Route #9
Midland, MI 48460

1978	148 pages	$7.00

Papers ranging from general overviews of the construction and operation of several working solar greenhouses through technical presentations on heat storage in salts and wet sand and active versus passive economics and efficiencies are printed in this volume. These proceedings offer a good summary of diverse approaches to solar heating both large and small growing structures.

New England Conference on Energy in Agriculture
May 3 and 4, 1976, Durham, New Hampshire
Edited by:
R.G. Light
Sponsored by:
New England Farm Electrification Institute and five other groups
Published by:
Massachusetts Cooperative Extension Service
Available from:
The Bulletin Center
213 Stockbridge Hall
University of Massachusetts
Amherst, MA 01003

1976	161 pages	$2.00

Data on wind, solar, wood, hydroelectric, methane and power stations waste heat energy use on the farm and in greenhouses. Although emphasis is on relatively costly active solar heating systems, the technical papers on other means of heating are worth the price of admission.

Passive Solar State of the Art: Proceedings of the 2nd National Passive Solar Conference
March 16 and 18, Philadelphia, Pennsylvania
Edited by:
Don Prowler
Sponsored by:
International Solar Energy Society
Available from:
Mid-Atlantic Solar Energy Association
2233 Grays Ferry Avenue
Philadelphia, Pennsylvania 19146

1978	951 pages (3 volumes)	$20.00

As the name states — these volumes represent the state-of-the-art through Spring of '78. Case studies of passive greenhouses, direct gain systems, mass walls, mass roofs, passive combinations, and hybrid systems are presented in Volume I. Volume II covers simulation and testing of components. Volume III reviews policy, education, and econimics. The section on greenhouses consists of seven semi-technical reports on planned and already-built units employing a variety of passive heating techniques. A worthwhile source book.

Proceedings: A Conference on Solar Energy for Heating Greenhouses and Greenhouse-Residential Combinations
May 20 through 23, 1977; Cleveland, Ohio
Compiled by:
Ted H. Short
Sponsored by:
Ohio Agricultural R & D Center and Energy Research and Development Administration
Available from:
Department of Agricultural Engineering
O.A.R.D.C.
Wooster, OH 44691

1977	344 pages	$5.00

This volume summarizes primarily government-funded greenhouse and other agricultural solar heating projects and studies. Reports on active solar systems and energy conservation in greenhouses are included in the papers. The highly-technical discussions of cutting energy use in the plant house will be of use to some greenhouse designers.

Proceedings of the Conference on Energy-Conserving Solar-Heated Greenhouses
November 19 and 29, 1976; Marlboro, Vermont
Edited by:
John Hayes and Drew Gillett
Sponsored by:
Total Environmental Action and seven other groups
Available from:
Marlboro College
Marlboro, Vermont 05344

1977	282 pages	$9.00

Papers by many of the ground-breakers in passive solar greenhouse design and construction make this one of the best proceedings documents on the subjects. Many case histories from all parts of the country, economic data, horticultural information, aquaculture, along with reports on all significant greenhouse components are included. A mix of technical summaries and projections, general papers, and socio-economic data is presented. A good reference book.

Proceedings of the International Symposium on Controlled-Environment Agriculture
April 7 and 8, 1977, Tucson, Arizona
Edited by:
Merle H. Jensen
Sponsored by:
Environmental Research Laboratory
University of Arizona
Available from:
Environmental Research Laboratory
Tucson International Airport
Tucson, Arizona 85706

1976	413 pages	$15.00

Commercial greenhouse: background and situation, economics, cultivars, intercropping, energy alternatives, transplanting, mineral nutrition and CO_2, insect and disease control, and energy alternatives are examined in reports included in this volume. Active solar heating and power plant waste heat utilization are the main energy sources considered. The presentations included are generally quite technical.

Proceedings of the 1978 Annual Meeting
Prepared by:
Karl W. Boer, Gregory E. Franta
Sponsored by:
American Section of the International Solar Energy Society
Available from:
A.S. of I.S.E.S.
American Technological University
P.O. Box 1416
Killeen, TX 76541

1978	1033 & 759 pages (2 volumes)	$26.50 ISES member $61.50 Non-member

This somewhat overwhelming collection represents solar heating state-of-the-art through early 1978. Reports on a large passive solar greenhouse, modeling and reports on attached solar greenhouses, and papers on solar food drying will be of interest to the greenhouse grower. All the papers are relatively technical.

Proceedings of the Third National Passive Solar Conference
January 11 through 13, 1979; San Jose, California
Prepared by:
Harry Miller, Michael Riordan, David Richards
Sponsored by:
U.S. Department of Energy
International Solar Energy Society
Available from:
A.S. of I.S.E.S.
American Technological University
P.O. Box 1416
Killeen, TX 76541

1979	943 pages	$26.50 ISES Member $66.50 Non-members

The quality of ISES passive conference proceedings' presentations is improving each year as the field matures. The 1979 event included a wealth of technical data on passive solar greenhouse monitoring, thermal modeling, materials and products. Reports on sessions on domestic and commercial scale greenhouses, and on greenhouse/dwelling combinations are part of the proceedings document. This is an essential design aid for the serious energy self-sufficient greenhouse builder.

Proceedings: Third Annual Conference on Solar Energy for Heating of Greenhouses and Greenhouse-Residence Combinations
April 2 through 5, 1978; Fort Collins, Colorado
Edited by:
Charles C. Smith
Sponsored by:
U.S. Department of Energy
U.S. Department of Agriculture
American Society of Agricultural Engineers
Available from:
Solar Energy Applications Laboratory
Colorado State University
Fort Collins, CO 80523

1978 — 117 pages — $7.50

Papers dealing with greenhouse heat loss reduction through night insulation and multiple glazing and with solar heating of a variety of greenhouses are included. Active solar air and water heaters, solar ponds, fluid roof, and direct gain passive heating systems are detailed in the reports. The majority of the projects summarized are for commercial size growing spaces, although several smaller attached and freestanding units are referenced.

PERIODICALS

Alternative Sources of Energy
Published by:
A.S.E.
Route 2
Milaca, MN 56353

Subscription Price: $15/year

A bi-monthly magazine concerned with energy production from natural sources and energy conservation. Issue #36 is a special on solar greenhouses.

New Mexico Solar Energy Association Newsletter
Published by:
N.M.S.E.A.
P.O. Box 2004
Santa Fe, NM 87501

Subscription Price: $10/year

This monthly newsletter is one of the better sources around for information on new developments in low-technology solar in general and especially on solar greenhouses.

New Roots
Published by:
New England Appropriate Technology Network
P.O. Box 459
Amherst, MA 01003

Subscription Price: $8/year

A bi-monthly magazine focusing on developments in appropriate technology in the Northeastern states. Frequent articles on solar greenhouses.

Organic Gardening
Published by:
Rodale Press
Emmaus, PA 18049

Subscription Price: $9/year
$16.50/two years

Frequent articles on construction and management of solar greenhouses.

Solar Age
Published by:
Solar Vision, Inc.
Church Hill
Harrisville, NH 03450

Subscription Price: $20/year

This monthly journal of developments in the solar industry carries articles on solar greenhouses a few times a year. October 1976 and November 1977 are special greenhouse issues.

Solar Greenhouse Digest
Published by:
Solar Greenhouse Digest
P.O. Box 2626
Flagstaff, AZ 86003

Subscription Price: $7/year.
$12/two years.

Bi-monthly magazine focusing on the design, construction and management of solar greenhouses of all sizes.

Transitional Network for Appropriate/Alternative Technologies
Published by:
TRANET
P.O. Box 567
Rangeley, NE 04970

Membership Price: $15/year.

A quarterly newsletter-directory of people involved in appropriate technology. A good solar greenhouse design/research project reference.

PLANS AND PAMPHLETS

An Attached Solar Greenhouse
Prepared by:
Bill and Susan Yanda
Published by:
The Lightning Tree
P.O. Box 1837
Santa Fe, NM 87501

1977 | 17 pages | $1.75

Instructions for the design, construction and management of a solar greenhouse. Each step is presented in English and Spanish. The manual tells how to build a low-cost unit in a simple, understandable style.

Beadwall System Window and Greenhouse Plans
Prepared and
Published by:
Zomeworks Corporation
P.O. Box 712
Albuquerque, NM 87103

1977 | 7 pages | $15.00

Complete blueprints and instructions for a "Bead Wall" movable insulation system and a greenhouse. A license to build a 140 sq. ft. Bead Wall is included. Such a movable insulation system typically costs about $8 to $10 per square foot to build.

Construction with Surface Bonding
Agriculture Information Bulletin #374
Prepared by:
B. Carl Haynes, J. W. Simons
Published by:
U.S. Department of Agriculture
Agriculture Research Service
Distributed by:
Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

1974 | 18 pages | $.45

Describes concrete block wall construction in which blocks are stacked dry, then trowelled on both surfaces with a cement-glass fiber mixture. A stronger wall than a conventional mortar-joint block wall is the result, with a considerable time savings. This technique is especially useful for an inexperienced block-layer.

Noti Solar Greenhouse Performance and Analysis
Prepared by:
Eric Hoff, David Jenkins, Jim Van Duyn
Published by:
University of Oregon
Department of Agriculture
Eugene, OR 97403

1977 | 32 pages | $2.00

A low-cost fir pole, post and beam greenhouse designed and built by University of Oregon students is detailed in the booklet. Specification and schematics revealing the back wall and gravel floor heat storage; sod roof; and frame construction are presented, very clearly. A detailed thermal analysis of the building's performance in all seasons is presented.

Plastic Greenhouse Manual: Planning, Construction and Operation
Prepared by:
Raymond Sheldrake, Jr., Robert M. Sayles
Published by:
Department of Vegetable Crops
New York State College of Agricultural and Life Sciences
Cornell University
Ithaca, New York, 14850

1977 | 21 pages | $2.00

This design guide details useful techniques for use in commercial greenhouses glazed with plastic films. General data on plastics and specific instructions on building the Cornell Exterior Plywood Gussett Design (for 86¢ per sq. ft. of building floor area) make up most of the book. While this design isn't for an energy efficient unit, some useful construction procedures are presented.

Solar Frame Plans
Prepared and
Published by:
Solar Survival
P.O. Box 119
Harrisville, NH 03450

1978 | 5 pages | $6.00

Blueprints for building a cold frame with water drum heat storage and a manual beadwall/cover movable insulation system. Solar Survival offers these plans as a very low-cost alternative to building a complete greenhouse.

Solar Greenhouse Construction Drawings
Prepared by:
Farallones Institute
Available from:
Farallones Institute
1916 5th Street
Berkeley, CA 97710

1977 | 9 pages | $1.25

Plans for a low-cost, woodframe polyethylene covered greenhouse. The freestanding unit defined in the plans should be buildable for under $5 per square foot in materials. A materials list and clear construction detail drawings are included for the 8' × 16' structure.

A Solar Greenhouse for Mesa College
Prepared by:
Joyce Jenkins
Published by:
Grand Junction Public Energy Information Office
250 North 5th
Grand Junction, CO 81501

1978 | 51 pages | $3.00

A workshop manual prepared for a solar greenhouse construction workshop held at Mesa College in fall of 1978. Contains heat production basics, food production basics, construction details and plant management information. The greenhouse presented is buildable for about $5 per square foot in materials.

Solar Greenhouse Concepts
Prepared by:
Maine Audubon Society
Available from:
Cornerstones Foundation
54 Cumberland Street
Brunswick, ME 04011

1979 | 12 pages | $1.50

A general introduction to solar greenhouses including treatments of units employing direct gain, water walls, and remote heat storage. Rule of thumb for Maine greenhouses and a bibliography are included. Useful for explaining the basics to someone with no knowledge of solar-reliant greenhouses.

Solar Reliant Greenhouse Plans
Prepared by:
Domestic Technology Corporation
Published by:
Solstice Publications
P.O. Box 2043
Evergreen, CO 80439

1978 | 5 pages | $7.50

Some of the more complete blueprints availalbe for a freestanding solar-reliant greenhouse. Water drum heat storage and movable night insulation panels are featured.

Two Solar Aquaculture Greenhouses for Western Washington: A Preliminary Report
Prepared by:
Woody and Becky Deryckx
Published by:
Southfork Press
Available from:
Hunter Action Center
Evergreen State College
Olympia, WA 98505

1976 | 49 pages | $2.00

A description of a solar-heated greenhouse with an aquaculture tank built into the base of the parabolic back wall and a circular dome greenhouse built around a central, circular aquaculture tank. The booklet contains lots of information on aquaculture. A good source for design concepts—very limited construction details.

Vocational Region 10 Solar Greenhouse
Prepared by:
Jonathan Gorham
Published by:
Maine Audubon Society
118 Old Route One
Falmouth, ME 04105

1978 | 38 pages | $5.00

A curriculum booklet developed to help vocational schools become involved in alternate energy projects. Greenhouse design fundamentals, construction instructions, and materials concerning the development of a renewable energy curriculum in trade schools is included in the book.

GREENHOUSE SUPPLIES AND COMPONENTS

This source list provides access to some materials of value in greenhouse construction, maintenance, and management that may not be available in some areas. Supplies that are normally stocked in most building stores such as lumber, caulk, and insulation are not included here. Prices are quoted, where available, for purposes of comparison only . . the rapid price increases being experienced with many building materials preclude accurate cost data in this index. These prices represent suggested retail prices in May of 1979.

GLAZINGS

Bio-Energy Systems

Mountaindale Road
Spring Glen, NY 12483 (914) 434-7858

"Sola Roll" synthetic rubber (EPDM) glazing extrusion systems for greenhouses .025" to .125" flexible or rigid glazing material can be installed, water-tight with Bio Energy's System. Cost is a little under $2.00 per lineal foot for GF-1 flush glazing extrusion with a L-1 locking strip.

Brother Sun

Rt. 1, Box 107AA
Santa Fe, NM 87501 (505) 455-7550

Greenhouses glazings including Acrylite SDP, Lascolite, and Lexan.

Chave and Early, Inc.

1460 Broadway
New York, NY 10019 (212) 391-1010

"Loretex" polyethylene strand reinforced poly film manufacturer. Tear strength and lifetime of Loretex are increased by the addition of the fiber reinforcing and UV inhibitors over the values for untreated polyethylene. Two to three year replacement is typical for Loretex. Available direct from Chave and Early in 72" widths by any length for 8¢/sq. ft. plus shipping.

Chemplast, Inc.

150 Dey Road
Wayne, NJ 07470 (201) 696-4700

Distributor for Martin Processing's "Llumar" UV inhibited polyester film. The material, is designed as a long-life (about 15 years) outer glazing for greenhouses and solar collectors. 5 mil Llumar comes in 26", 38", 50", and 60" widths in 50 or 100 foot rolls. 7 mil thickness comes in 48" width by 50 or 100 foot lengths. Price ranges from 48 to 58¢ per sq. ft. for 5 mil, and from .81 to $1.20 per sq. ft. for the 7 mil thickness, depending on quantity (FOB Wayne, NJ).

Cyro Industries

W. Main Street
Bound Brook, NJ 08805 (201) 356-2000

"Exolite" double-skinned acrylic or polycarbonate sheet and glazing bars manufacturer. Exolite comes in 5/8" thick panels, 47¼ wide by 8, 10, 12 or 16 foot lengths. Available through dealers nationwide; contact (CYRO) for a dealer list.

Filon Corporation

12333 Van Ness Avenue
Hawthorne, CA 90250 (213) 757-5141

"Filon" Fiberglass and nylon reinforced acrylic-fortified polyester resin panel manufacturer. Poly vinyl floride (Dupont's Tedlar) coated Filon will last ten to fifteen years when used as an outer greenhouse glazing. Corrugated sheets of the material come in a 51 1/8" width with 8, 19, 12, 14'4", and 16' lengths available. Rolls of flat Filon come in 50, 100, and 110 foot lengths with 34, 36, and 48" widths. Prices range around $1.00 per sq. ft. (depending on quantity). Contact Filon for a dealer list.

General Electric Company

Appliance Part
Louisville, KY 40225 (502) 452-4021

"Lexan" polycarbonate sheet and film manufacturer. 60 mil 4' × 8' Lexan sheet makes a long-lived outer glazing (or $1.00 per sq. ft.) 5 and 20 mil Lexan film is good for inner glazings (15 and 50¢ per sq. ft., respectively). The film comes in 4' wide rolls of various lengths. Check with G.E. for local dealer.

Kalwall Corporation

88 Pine Street
Manchester, NH 03013 (603) 668-8186

"Sunlite" fiberglass glazing manufacturer. Sunlite comes in 4 and 5 foot wide rolls in lengths to 1200 feet. Prices are 59¢/sq. ft. for .025", 73¢/sq. ft. for .040" and 97¢/sq. ft. for the .060" thickness. Double-glazed panels that are bonded to an extruded aluminum frame are available to fit 2 × 8 foot, 3 × 8 foot and 4 × 8, 10, 12, or 14 foot openings for $3.00/sq. ft. All prices are plus shipping. Check with Kalwall for a distributor in your state. . .if there is none, they will sell direct.

Lasco Industries

3255 E. Miraloma Avenue
Anaheim, CA 92806 (714) 993-1220

"Crystalite" fiberglass glazing manufacturer. The corrugated panels are available to cover 2 and 4 foot widths; lengths of 8, 10, 12, feet are standard. Prices are obtainable from distributors—contact Lasco for a local source.

Rohm and Haas Company

Independence Mall West
Philadelphia, PA 19105 (215) 592-3000

"Tuffak-Twinwal" polycarbonate and "Plexiglass" acrylic sheet manufacturer. "Tuffak-Twinwal" is cast with an ½" square internal airspace to reduce heat-loss through the glazing. Cost is $1.95/sq. ft. (comes in 4 foot by 8 foot by .220" thick sheets). Plexiglass in 4 × 6 foot and longer sheets costs $1.47 in 1/8" thickness and $2.43 for a sq. ft. of ¼" material. Contact Rohm and Haas or check your yellow pages for a dealer.

3M Company

3M Center Bldg. 223-2-2W
St. Paul, MN 55101 (612) 733-0306

"Flexiguard" polyester/acrylic film manufacturer. The material is available from 3M for $228 for a 4' × 150' roll (38¢ ft.) or $36.00 for a 4' × 10' sample roll. All prices are FOB shipping point.

Norman B. Saunders

15 Ellis Rd.
Weston, MA 02193 (617) 894-4748

Supplies glazing extrusions

Maxi Seal
Lane Maxwell Enterprises

4303 Rawhide Road
Pueblo, CO 81008 (303) 542-9806

This EPDM rubber seal holds promise for use in site-built collectors and solar greenhouses which use fiberglass reinforced plastic (FRP) glazing. The assembly assumes the use of flat FRP, (e.g. Kalwall); which is wide enough to provide a 1½-inch overlap on rafters, absorber mounts, etc. This is normally done by spanning 49½-inch FRP over rafters which are 24 inches on center and using Maxi-Seal on every other rafter. The Maxi-Seal is covered by a 1X2 or molding secured with rustproof fasteners. Double-glazed installations use Maxi-Seal on the outer layers only, with the inner layer simply overlapped and held with 1X2 spacers over the rafters.

U-shaped molding is available for use at the edge of the glazing surface.

KITS-SUPPLY CATALOGS

Charley's Greenhouse Supply

12815 NE 124th Street
Kirkland, WA 98033 (206) 823-1616

Greenhouse supplies and accessories catalog; $1.00 (refundable on purchase). . .dealer for Thermofor vent operators.

Domestic Grower's Supply, Inc.

P.O. Box 809
Cave Junction, OR 97523 (503) 592-3615

Greenhouse supplies and instruments, catalog for $1.00 (refundable on purchase).

The Exchange

286 Congress Street
Boston, MA 02210 (617) 482-2727

Recycled industrial equipment and surplus material marketer. Fly ash (for low cost cement) and other industrial waste-products along with all kinds of new and used machinery at considerable savings—usually in bulk. Get in touch with the Exchange for information on a specific need... chances are they'll be able to fill it.

Friends of the Sun

210 Main Street
Brattlebore, VT 05301 (802) 254-4208

Greenhouse components, growing, and maintenance supplies... ask for their descriptive brochure to be available by fall of '79.

Guard'n Gro Cloche Company

61 Cromary Way
Inverness, CA 94937

"Guard'n Gro" poly-proplene cloche manufacturers. These 42"×18"×21" mini-greenhouses weigh under five pounds. $19.95 plus $3.00 postage from Guard'n Gro.

Lacillade Lumber

Williamstown, VT 05679 (802) 433-5311

Greenhouse components and free advice on energy-efficient house and greenhouse design to customers.

Don Lewis Associates

105 Rockwood Drive
Grass Valley, CA 95945 (916) 272-2077

"Solar Site Selector" is a valuable tool for determining if a potential building site will have enough winter sunlight for a solar greenhouse or other solar system. A curved, transparent sun-chart mounted on a metal base-plated is designed to be attached to a tripod for direct sighting of obstacles/shade sources on the site... really simplifies the site planning process!

Mellinger's, Inc.

North Lina, OH 44452 (216) 549-9861

Free greenhouse supplies catalog... dealer for Thermofor vent operators.

J.A. Nearing Company

9930 Davis Avenue
Laurel, MD 20810 (301) 498-5700

Greenhouse kit catalog, $1.50. Their glass/pipe frame greenhouses are available as attached houses—easily solarized although not specifically designed as a solar-reliant greenhouse.

Pacific Coast Greenhouse Mfg. Co.

8360 Industrial Avenue
Cotati, CA 94928 (707) 795-2164

Solar greenhouse kits including compost privy and aquaculture components—also thermally massed window greenhouses and cold frames. No data was available on PCG's solar greenhouse kits at this writing—these will be available by the end of 1979. Conventional, redwood frame, fiberglass and glass greenhouses in all sizes are currently manufactured and marketed. Send for a free catalog.

Solar Room Company

P.O. Box 1377
Taos, NM 87571 (505) 758-9344

Greenhouse kit—designed to be added to the south side of a building to function as a solar heater. The UV inhibiter polyethylene skin/galvanized steel frame kits are warranted for 3 years. Contact Solar Room for a brochure and prices.

Solar Survival

Cherry Hill Road
P.O. Box 119
Harrisville, NH 03450

Kits for solar "pods" and "cones" as well as plans and materials for a "Trisol" add-on solar greenhouse are offered (for sale) from Solar Survival. Solar cones are made from a single piece of flat fiberglass glazing, bolted into a 15 inch or 30 inch cone. These mini-greenhouses cost $8.00 for the smaller design and $16.00 for the 30 inch model. Solar pods, like cones, are suitable for extending growing seasons, but are larger. Glazed with fiberglass, solar pod kits cost $160. Even larger is the "Trisol" solar greenhouse—a triple-glazed growing structure with integrated masonry heat storage/structure. The Trisol Kit costs $2500.

Solar Technology Corporation

2160 Clay Street
Denver, CO 80211 (303) 455-3309

"Solera" solar greenhouse kits include active and/or passive solar systems. These lean-to type kits include prefabricated roof and wall modules in 4 foot sections. Framing is redwood; glazing is Acrylite SDP. 3½" polystyrene foam insulation, and a solid core door are included in end walls. A one year materials and workmanship guarantee is provided.

Sturdi-Built Mfg. Company

11304 SW Boones Ferry Road
Portland, OR 97219 (503) 244-4100

Free greenhouse kit catalog. Redwood framed glass and fiberglass glazed greenhouses including units that are easily made "solar reliant." Sturdi-Built also is a dealer for Thermofor vent actuators.

Texas Greenhouse Company

2717 St. Louis Avenue
Fort Worth, TX 76110 (817) 926-5447

Redwood and galvanized steel glass greenhouse kits including several that look "solarizable." Texas Greenhouse also carries a complete line of greenhouse supplies and instruments. Both kit and supply catalogs are available free.

Turner Greenhouses

Hwy. 117 South
Goldsboro, NC 27530 (919) 734-8345

Greenhouse kit and growing supplies catalog—free. Rectangular, free-standing and lean-to type rust-proofed steel frame/fiberglass or polyethylene glazed greenhouses are featured in Turner's catalog. No emphasis is put on energy conservation but their units have that potential.

Vegetable Factory, Inc.

100 Court Street
Copiague, NY 11726 (800) 221-2550
(516) 842-9300
from NY State

Greenhouse kits catalog—one of the first national greenhouse kits manufacturers to promote energy-efficient greenhouses. Their "Solar Panel" greenhouse kits utilize two fiberglass reinforced acrylic glazing layers bonded to a rigid aluminum frame. Illustrations of their lean-to model attached to a mass wall are included in Vegetable Factory's free catalog.

Weather Energy Systems

P.O. Box 574
Falmouth, MA 02540 (617) 563-9337

Controllers designed for hybrid solar greenhouses that vary air flow to storage according to temperature. The W.E.S. "Plexus" controller increases blower speed in 16, 35 RPM increments starting at the adjustable low setting and reaching maximum (560 RPM) at 10°C above that setting.

VENT AND WINDOW TREATMENTS

Appropriate Technology Corporation

P.O. Box 975
Brattleboro, VT 05301 (802) 257-1773

"Window Quilt" insulating polyester window shade manufacturer. When closed, the shade reduces heat loss through a single glazed window to one-fifth the uninsulated value (R 4-5 years R 9). The foil-lined polyester quilt is air sealed by plastic tracks on the sides and by pressure against the window trim at top and bottom, when down. The shade material rolls up like a normal window shade, when not in use. $4.25/sq. ft. is the suggested retail price for Window Quilt — check with A.T. Corporation for the name of the nearest dealer.

Bramen Company, Inc.

P.O. Box 70
Salem, MA 01970 (617) 745-7765

"Thermofor" thermally-active vent operator importers and distributors. The units can be set to start vent operation at any temperature between 55° and 80°F and will open completely when temperature gains 20°F above the starting setting. Thermofor can lift a vent up to 30 pounds up to 12". Thermofor carries a 5-year warranty and costs $49.50.

Celanese Fibers Marketing Co.

1211 Avenue of the Americas
New York, NY 10036 (212) 764-8303

"Polar Guard" fiberfill insulation for use in insulating shades. Contact Celanese Fibers about a local source for Polar Guard.

Dalen Products, Inc.

201 Sherlake Drive
Knoxville, TN 37922 (615) 690-0050

"Solarvent" thermally actuated vent opener manufacturer. . . opens a nine pound vent 7½" (will lift up to a twenty pound vent with the counter balance spring accessory). Solarvent begins operation at 68°F and is fully extended at 75°F. Cost is $24.95 (postpaid) for the actuator and an additional $3.25 for counter-balance springs. You can order direct from Dalen. . .a six-month, moneyback guarantee is offered.

Duracote Corporation

350 N. Diamond Street
Ravenna, OH 44266 (216) 292-3486

"Foylon" greenhouse shading/insulating material from Duracote consists of a thin sheet of aluminum foil bonded to a variety of natural and synthetic fabric reinforcements. The rot, mildew, and flame-resistant material was shown to reduce annual fuel costs by 57% in tests done at Penn State. Available from Duracote in 200 yard × 54" wide rolls for $2.85 per yard (64¢ per sq. ft.) plus shipping for type 2437.

Heat Motors, Inc.

635 W. Grandview Avenue
Sierra Madre, CA 91024 (213) 355-6919

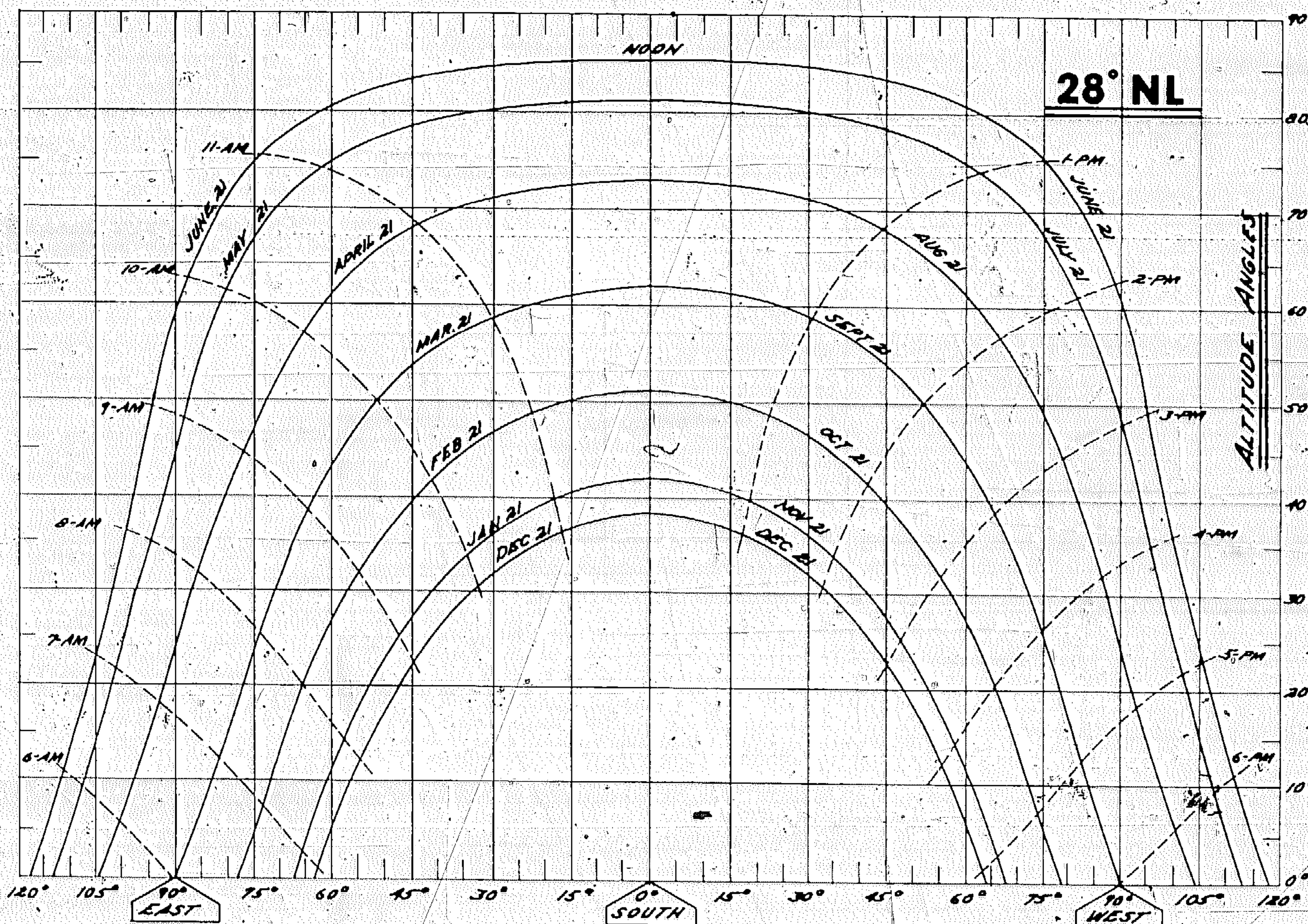
"Heat Motor" thermally actuated vent operator manufacturer—lifts a 50 pound vent 1" for each 10°F temperature rise with a Mark VI Heat Motor. Starting temperature can be set at any value between 50° and 90°F; total lift is 6". Cost is $66.10 plus shipping. If you're interested in lifting the entire roof for ventilation, a Mark I Heat Motor will lift 2,000 pounds one inch for each 10°F temperature rise! Cost is $2,000.00. Contact Heat Motors for a local dealer name.

Insulated Shade Company

17 Water Street
Guilford, CT 06437

"High R" insulating shade manufacturer. The I.S. shade is composed of five layers of reflective plastic film that are held apart by plastic spacers when in the down position. The shade material (discounting air infiltration around its edges) gives and RIS when in the down position. PVC heads ($1.25/lin. ft.) can be bought for shade installation, or seal strips (50¢/lin. ft.) can be purchased for use with site-built wood jambs & heads. High-R shade material costs $2.75 per sq. ft. and shipping.

APPENDIX



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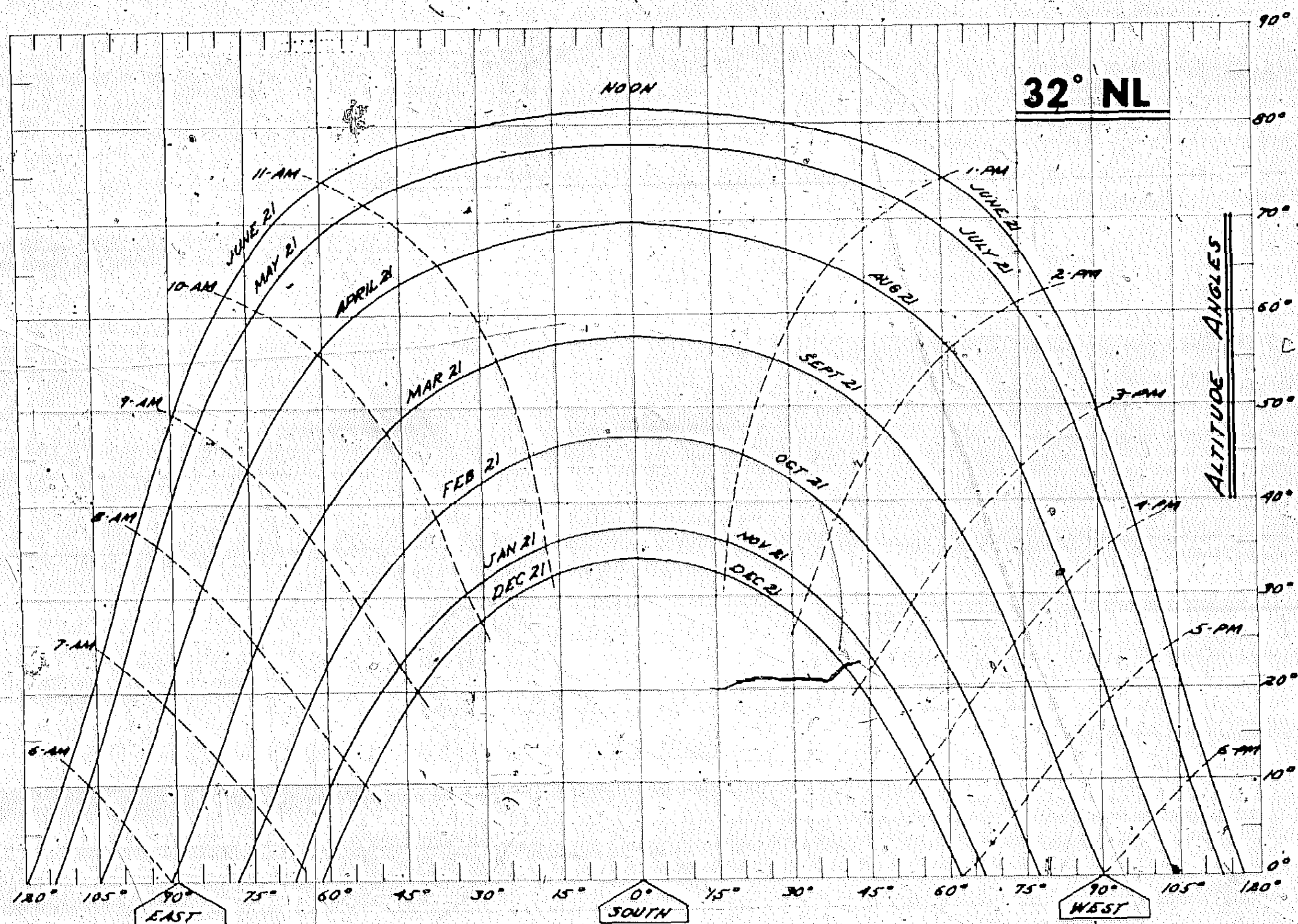
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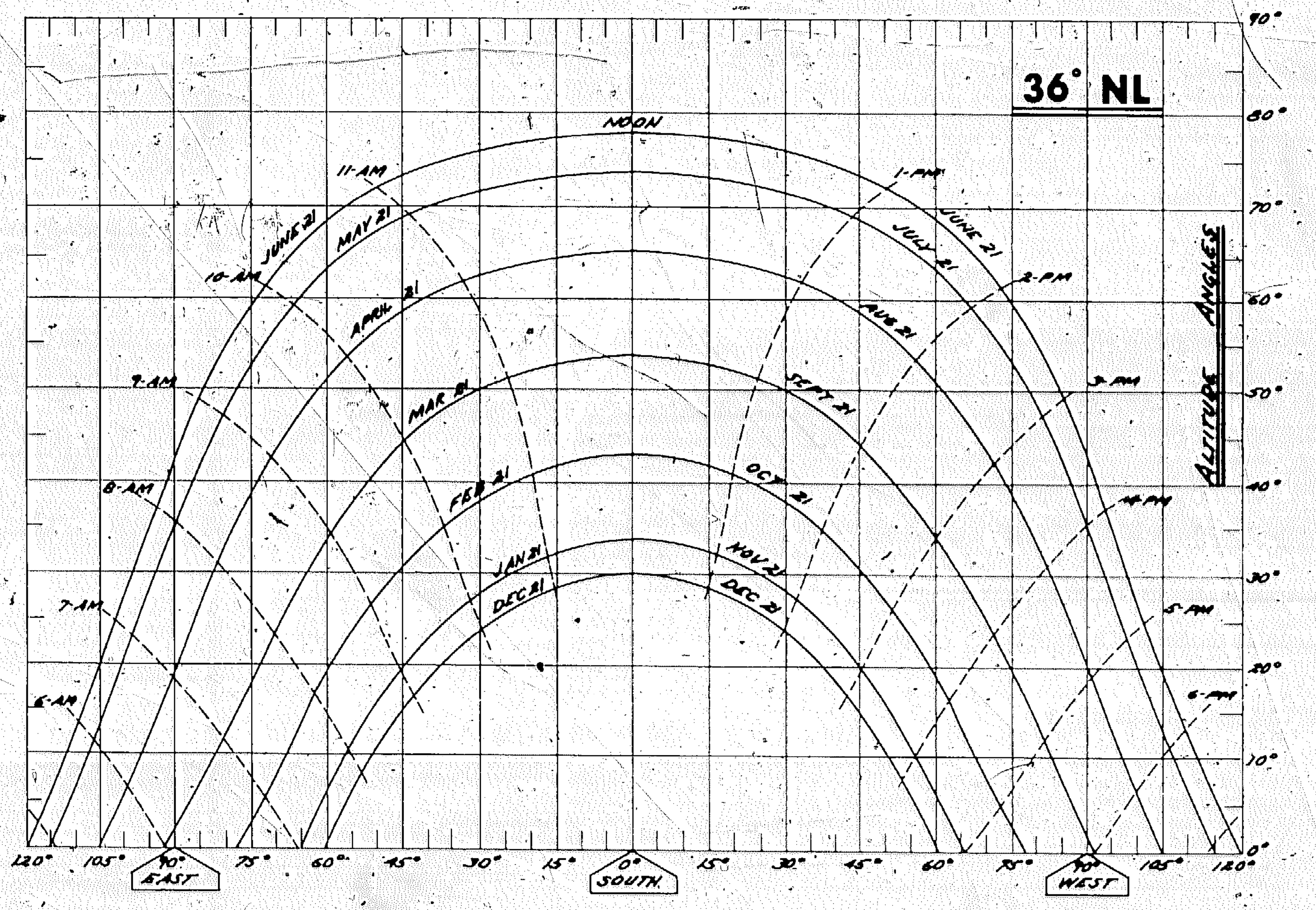
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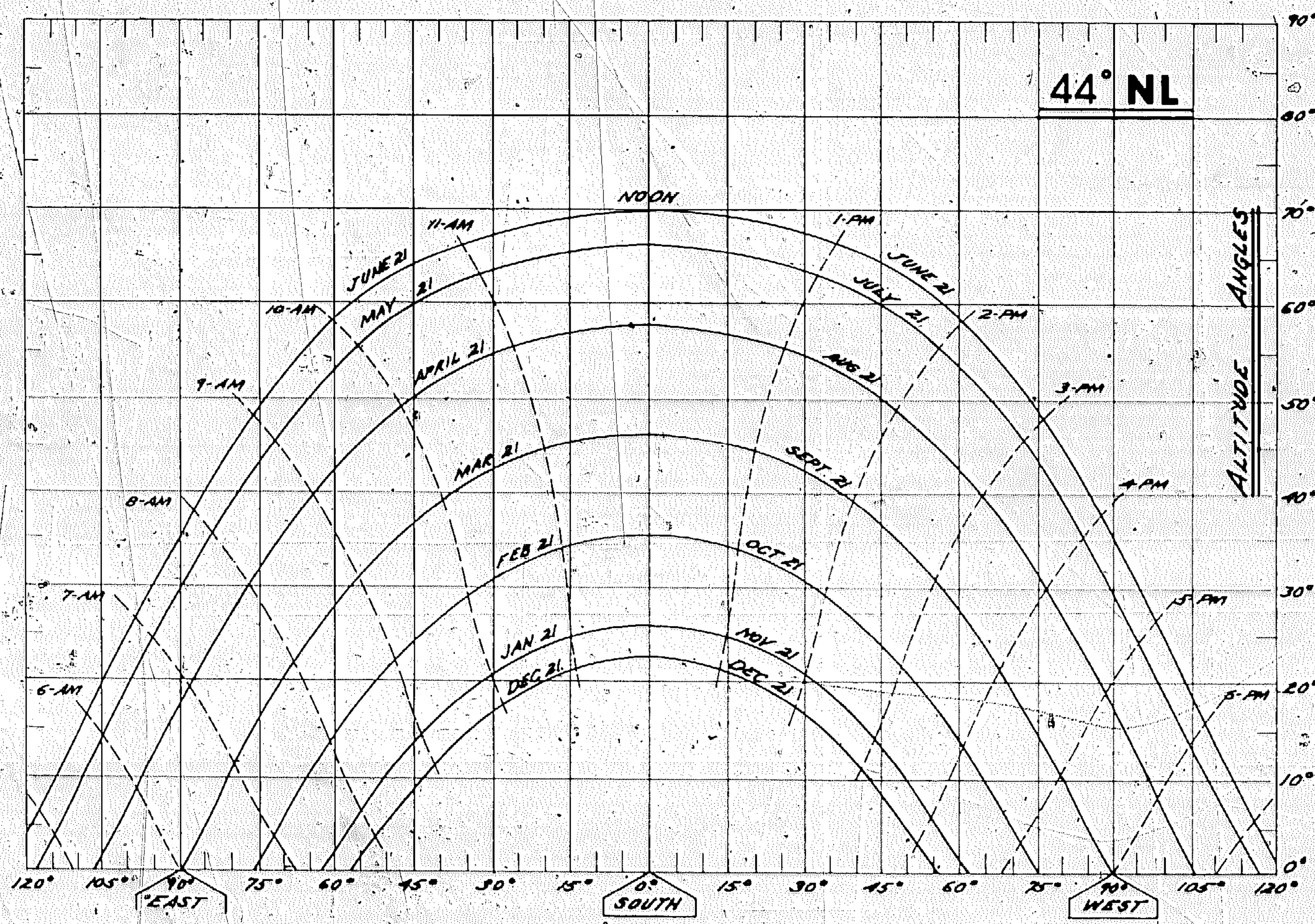
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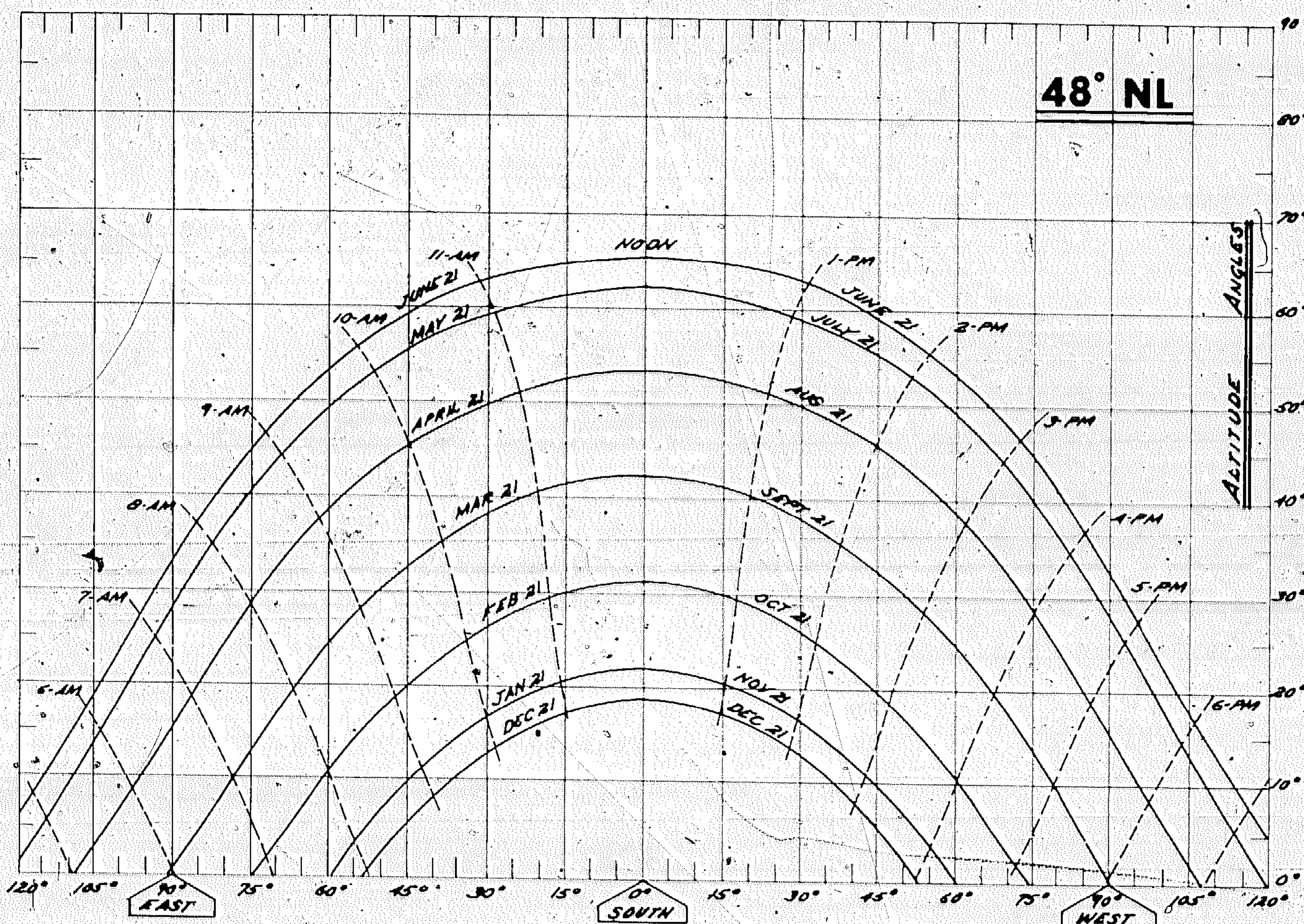
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