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ABSTRACT

Solar technology systems are being studied, managed, built and offered as an effective alternative energy option. This publication presents background material for the building and operation of better sunspaces and greenhouses. Recent developments in solar technology are explained and information on solar greenhouse and sunspace is provided (in question and answer format) in these categories: (1) design; (2) construction; (3) management, maintenance, and safety; (4) horticulture; (5) construction workshops; and (6) information sources. Guidance in the identification of common mistakes in design. construction, and operation that affect performance of these solar structures is given. Suggestions to help consumers apply and utilize information on solar technology systems effectively are also included. (ML)

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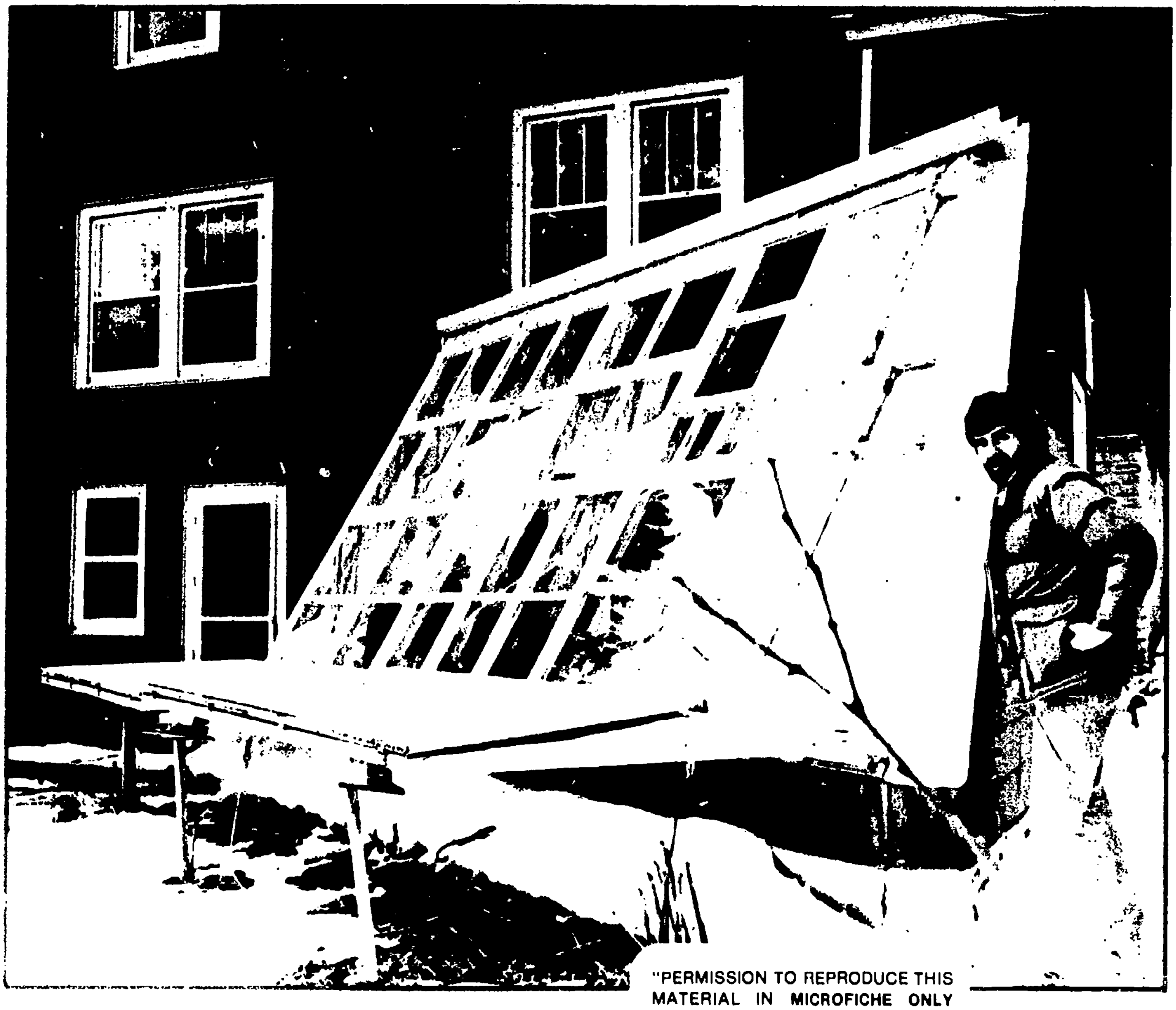

Prepared for
U.S. Department of Energy
Assistant Secretary, Conservation and
Renewable Energy
Small Scale Technology Branch
Appropriate Technology Program
Under Contract
No. DE-AC01-82CE15095

SOLAR GREENHOUSES AND SUNSPACES: LESSONS LEARNED

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PREFACE

From 1978 to 1981, the U.S. Department of Energy (DOE) awarded more than 2,000 small grants to individuals, organizations and small businesses across the nation to research and demonstrate appropriate technologies. Grants were given in the general areas of conservation, solar, biomass, wind, geothermal and hydro power. In 1982, the National Center for Appropriate Technology (NCAT) was placed under contract to review final reports from each DOE grantee to extract new ideas and other proven concepts that could be of value in applying appropriate technologies to energy problems. Each chapter of this publication has a list of selected projects reviewed in preparation of this document.

This booklet is one in a series of publications that focuses on appropriate technologies and their application in the home and the workplace. These publications combine a qualitative assessment of the DOE grant projects by NCAT with the results of current research.

Prepared By:

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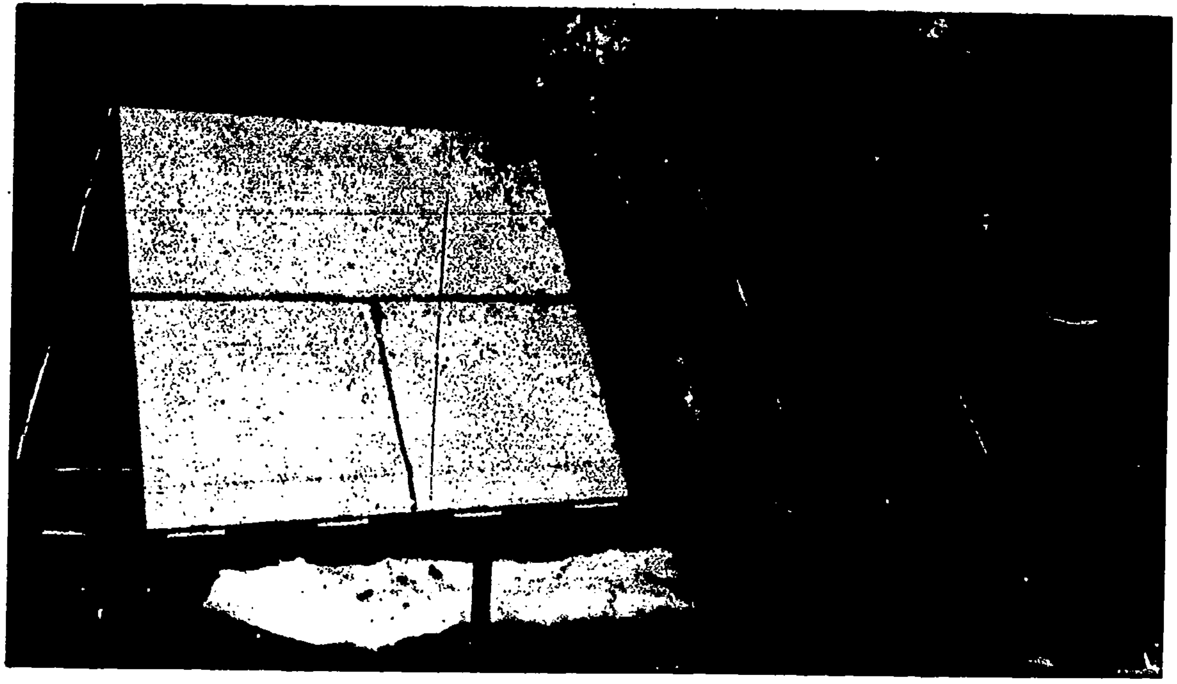
DOE/CE/15095-8
January 1984

CONTENTS



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INTRODUCTION

Solar greenhouses and sunspaces are popular. One measure of that popularity is the number of people who received grants from the U.S. Department of Energy's (DOE) Appropriate Technology Small Grants Program. Nearly 200 of the 2,200 total grantees studied, built, managed, and improved greenhouses or sunspaces.

There are several reasons for this interest. Sunspaces can provide heat and save energy, and they can provide pleasant living areas. Greenhouses can produce food by extending the growing season or making it possible to garden year round. Greenhouses and sunspaces also are a good way to demonstrate how solar energy can be harnessed effectively, and many alternative energy workshops and demonstrations use greenhouses as their focus.

It is also possible to build and use greenhouses and sunspaces without a great deal of sophisticated knowledge or skills, and they do not have to be expensive. Also, they are a relatively forgiving solar technology—they can work fairly well despite mistakes that might have been made during design or construction or that occur in operation.

However, despite these advantages, many greenhouses do not perform as well as they should. As more and more are built, used, and observed, more ways of improvement are developed.

SUNSPACE OR GREENHOUSE?

Terminology develops and changes just as technology does. Years ago, buildings used solariums, conservatories, hot houses, and sun porches for health purposes, to moderate temperatures, to let in light, and to grow plants. In the early Twentieth Century, some of these residential applications began to fade away, and this solar technology was used most often in commercial greenhouses used primarily to grow ornamental or exotic plants. As the interest in solar energy developed during the past two decades, the term "greenhouse" was applied to heat-gathering structures, living areas, and the traditional plant-growing greenhouse. Recent developments in architecture and building technology, with their increased attention to energy efficiency, have brought the term "sunspace" into prominence. In response to this changing terminology, and in the interests of accuracy, this publication uses the term sunspace for areas designed primarily for heating purposes and as living spaces, and the term greenhouse for solar structures designed primarily for plant growth.

The experiences of the DOE grantees provide valuable information for others to use in building and operating better sunspaces and greenhouses. Their experiences are the basis for *Solar Greenhouses and Sunspaces: Lessons Learned.*

This publication is divided into six major categories: design; construction tips; management, maintenance, and safety; horticulture; greenhouse construction workshops; and information sources.

Each chapter presents basic background material on the topic and relevant information from selected project reports. A question and answer format is used to present information on ways greenhouses and sunspaces can be improved.

Solar Greenhouses and Sunspaces: Lessons Learned has been developed as a supplement to the existing literature to help prospective sunspace/greenhouse owner/builders get started in the right direction. It is not a text book, and is not a substitute for any of the good "how-to" greenhouse books available. Its purpose is to identify common mistakes in design, construction and/or operation that affect performance, and provide useful advice to help consumers avoid these mistakes. In essence, *Solar Greenhouses and Sunspaces: Lessons Learned* is a book of experiences designed to help novices apply and utilize this technology in the most effective way.

CHAPTER ONE

DESIGN IT RIGHT

Greenhouses and sunspaces can produce heat, produce plants, or provide a pleasant living space. They can do any one of these things very well, but they rarely do all three well at the same time. For example, an efficient heat-gathering sunspace will wither most plants.

On the other hand, a greenhouse designed and operated to produce an abundant variety of food won't have much room to relax in and won't produce heat consistently enough to supplement a furnace. A sunspace designed as a living area will have moderate temperatures that are too low for supplemental space heating and likely will not have enough room for substantial food production.

Horticultural greenhouses require moderate temperatures and are not usually effective space heaters.

The first design step has to be to decide what the sunspace or greenhouse is being designed to do, taking into account what seems desirable and possible now, and what your needs will be one year (or 20 years) from now. Try to imagine all of the possible opportunities or problems. For example, a sunspace attached to a library in Mississippi was designed specifically with a vertical south wall to accommodate a door which would permit access to wheelchairs. In another example, a grantee in Montana considered adding a greenhouse to a senior citizens' center only to find that parking spaces and landscaping at the only possible greenhouse site were more valuable to the members than a greenhouse would be. In this case, the best design was to not build a greenhouse at all.

The sunspace or greenhouse builder should also consider his or her neighbors. Neighbors will likely frown on a badly built, ugly structure emerging next door, but they may easily accept one that obviously fits in the neighborhood. If the neighbors are upset, it may also lead to more formal problems like covenants and zoning and building codes specifically written to keep "those things" out. Some of these regulations are difficult enough to comply with now, so the builder should do everything she or he can to simplify, not complicate matters.

After the purpose is determined, other issues must be addressed. Different sunspaces and greenhouses demand different kinds of attention. For example, horticultural greenhouses for serious plant production require soil, water, and lots of tending. Consequently, an attached greenhouse would not be desirable for someone who travels frequently or who has white carpeting in the room adjacent to the greenhouse. To get the most out of a sunspace designed for heating, thermal shades may have to be pulled or other insulation may have to be put in place every night. Again, daily attention may not be possible, and the costs associated with a fairly sophisticated, automatic control system may be prohibitive.

Costs, in general, will also vary depending on the purpose of the sunspace or greenhouse. A living area sunspace will have to be secure, built to last, and attractive. One grantee in California found that a simple sunspace cost $500 rather than $300, because it was attached to an office that had to be locked and secured at night. Horticultural greenhouses don't necessarily have to look as good, and they can be constructed with some temporary shortcuts (flexible plastic glazing instead of glass or rigid plastic, for example). However, greenhouses may have extra costs for such things as movable insulation and plumbing.

One key point should be kept in mind when designing each type of sunspace or greenhouse. With horticultural greenhouses, plenty of light is essential. Heating sunspaces need to gather a lot of thermal energy. Living area sunspaces need to maintain moderate temperatures. There are a variety of ways that greenhouses and sunspaces can be designed to get the most light, heat, or liveability. These design features focus primarily on how the light is let in, how thermal storage is used, and how air movement is controlled.

Everything hinges on a well-thought-out master plan. Don't shortchange the design. Don't take anything for granted. It is cheaper to design and re-design on paper than it is to revise plans during construction, or to modify a sunspace or greenhouse after it is built and working poorly. Grantees at a community college in Virginia found that there was so much interest in their proposed greenhouse that the design was expanded and the south wall was reconfigured *before construction* to provide more room for biological study. But in Kentucky, the purpose of a grant project was to correct design and construction problems discovered after the greenhouse went into operation.

The design aspects of light, thermal storage, and ventilation are covered in more detail in the following questions and answers. Later chapters will look at how light, storage, and ventilation can be managed after the greenhouse or sunspace has been built.

Q. ***Do greenhouses and sun spaces have to face due south?***

A. Most do face south, but sometimes it can actually be better if they don't. There are any number of techniques and devices available to help the greenhouse designer be sure that a greenhouse or sunspace faces south, assuming that it will perform at its very best with this orientation. Actually a greenhouse or sunspace can be oriented within about 25° of due south and still collect 90 percent of the solar energy that it would if it faced precisely south. Beyond 25°, however, the percentage falls off rapidly and there are abundant examples of greenhouses and sunspaces that have performed poorly because they were sited improperly.

Orienting the greenhouse or sunspace so it does not face due south can be an effective way to control light and heat gain. A slight easterly orientation can help to gain heat in the morning and limit it in the afternoon. This orientation may be particularly advantageous where, in the spring and fall, some heating is needed in the morning but afternoons may be too hot.

Many prospective sites may have building or lot limitations that don't allow a greenhouse/sunspace to be built quite where it should be. In such cases, siting requires a little more imagination. For example, a grantee in New Mexico wanted a sunspace but had no southern exposure available to work with. He built a "sunspace" anyway, but on the north side of his home. This "sunspace" uses a panel of vertical glazing that extends above the roof line of the house and does face south (known to architects as clerestory windows) (Figure 1.1). The amount of light entering the "sunspace" is increased by a reflective panel that also serves as an insulator when it is closed against the glazing. This design works particularly well in the Southwest, because this "sunspace" is also cool in the summer. In the summer, the "sunspace" is used to increase ventilation by drawing warm air from the rest of the house and exhausting it through a vent at the top of the "sunspace."

The important thing to remember is that a sunspace or greenhouse must be located to do what it is intended to do and designed accordingly. In other words, it can be *designed* to accommodate an orientation that is not due south, but it just won't perform like it should if the orientation and the design are not coordinated properly. A sunspace that is intended to provide heat, but that cannot be located to face approximately south, will have to be designed to compensate for the fact that less light will be coming in, by increasing the glazing area, for example. In some cases, a different kind of sunspace may be the solution. One grantee in Delaware found that the orientation of the existing building would not permit a real, heat-producing attached sunspace, so the porch was converted to a living area sunspace instead.

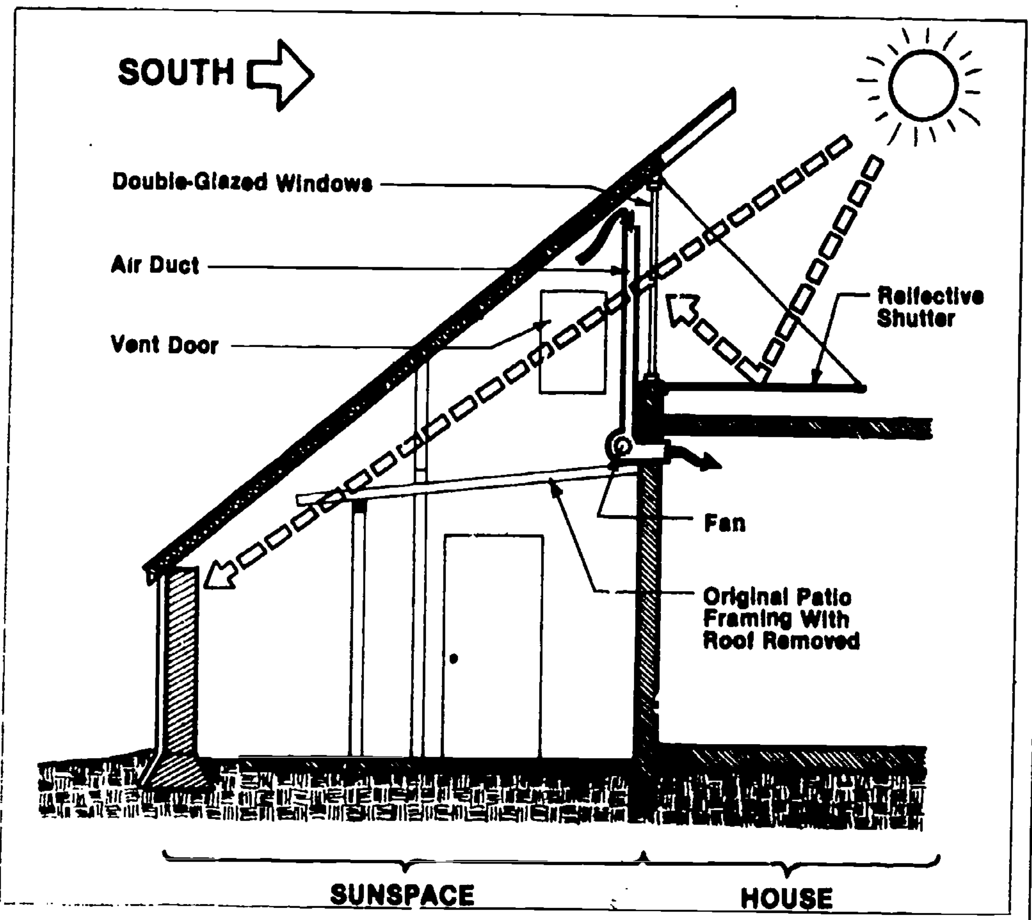


Figure 1.1 This innovative northside "sunspace" was designed and built by a grantee in New Mexico.

The books cited in Chapter Six provide instruction on siting greenhouses and sunspaces. The information they present can be used as a basis to modify designs as necessary for sunspaces or greenhouses that cannot or should not face directly south.

Q. ***Can a porch be converted into a sunspace?***

A. It was common for many larger, older homes to be built with sun porches, and there is no reason that an existing home cannot be improved with the addition of a sunspace today. In its simplest form, a porch can be enclosed with vertical glazing (plastic, salvaged storm windows, etc.) to serve as a sheltered entryway. This type of sun porch cuts the force of winter winds, keeps warm air from rushing out of the house, and provides a certain amount of solar heat gain. If a sun porch is constructed well enough, the solar heat it gains can be moved into the house through existing windows and doors. Porches can also provide the starting point for more extensive remodeling, limited only by the designer's imagination, physical limitations of the lot or house, and the money available.

To avoid problems and gain the most from the addition of a sun porch, keep two things in mind: structural soundness and ventilation. If a sun porch is to be used as a real heat-gathering sunspace or a plant-growing greenhouse, be sure the existing foundation and structure are sound. Thermal storage units or planting beds can add more weight than some old porches can bear. Examine the existing porch carefully and proceed accordingly, reinforcing the porch first, if that is what is required.

Like other types of sunspaces, a sun porch may overheat in warm weather. Some portions of the glazing should be removable or vents should be built in to let hot air out in the summer. The use of recycled storm windows or sliding glass doors can be convenient for this purpose if the sunspace is designed so that at least a couple of windows can be opened or removed to provide cross-ventilation in the summer. If some sort of shading and screens are provided as well, the porch can also be a more pleasant place to spend time in the summer.

Q. *Can a sunspace be added to a mobile home?*

A. Sunspace additions to mobile homes have proven to be an effective way to save energy. They too can be as simple as an enclosed entryway or as extensive as a full-length sunspace. The simple, entryway sunspaces can save energy by buffering the entrance from the weather. [illegible] sunspaces can provide a lot of heat, because the sunspace can have so much heat-gathering volume compared with the size of the mobile home.

As a grantee in Montana discovered, mobile homes have one distinctive feature that has to be kept in mind. The tops of entry doors are fairly high off the ground, and this requires a sunspace design that permits the door to swing freely out into the sunspace (Figure 1.2). A straight, lean-to design will not work.

Another grantee in California points out that a mobile home should be weatherized properly *before* adding a sunspace. Otherwise, the heat gained by the sunspace may just flow out through the mobile home without much benefit.

Many mobile home parks or local governments limit the kinds of structures that can be added to mobile homes. Be sure to check beforehand to see if there are any restrictions that might prohibit or limit the addition of a sunspace.

Q. *Why is it important to take long-term land use plans into account when developing a greenhouse or sunspace project?*

A. A project can end in disappointment if the greenhouse or sunspace is proposed for land that is not owned by the builders. The landowner and builder should develop a strong written agreement which spells out the responsibilities of both parties. If the land is owned by an institution, one staff person may grant permission to build a sunspace or greenhouse without knowing about long term plans for the land.

In Louisiana, a student club received a grant to build a greenhouse on the university farm. The farm is now being moved and the greenhouse will have to be torn down and rebuilt on a new farm site. A food co-op in Rhode Island received a grant to build a greenhouse as part of a community food center. Permission for construction was given by the local university. One week after the greenhouse was opened, the university sold the land and the greenhouse had to be dismantled.

Q. *Can a sunspace or greenhouse be designed for sloping terrain?*

A. It may not be as easy to build on a slope, but if the site has an adequate southern exposure, there can be benefits from designing a sunspace or greenhouse to take advantage of a slope. Most sunspaces and greenhouses perform better if they are insulated, and building into a slope can use the earth as insulation. Or, with a more sophisticated design, the earth can be used for thermal storage. Also, since warm air rises, building on a slope can aid in the natural convection of heat to adjacent higher parts of the house.

To avoid disaster, the greenhouse or sunspace must be built into a slope that is stable and drains away from the structure. A grantee in Guam designed a greenhouse intended to stand up under typhoon winds, and the greenhouse was built into a slope to help protect it. However, during construction, torrential rains saturated the slope and the resulting landslide caved in the end wall and filled in the excavation. Saturated or improperly drained slopes can be a problem anywhere, and a grantee in Maine suggests that any greenhouse built into a slope should have some form of built-in drainage. Good drainage helps to moderate the buildup of water in the slope and helps to move water away from the greenhouse or sunspace.

Too much earth on the ends limits the area that can be glazed. The opposite might be true in the south, however, where the cooling effect of the earth in the summer might be beneficial. The Maine grantee also noted that either the natural use of earth or earth berming on the end walls should be minimized in horticultural greenhouses, especially in northern locations where light is at a premium for plant growth; but heat losses at night through those glazed end walls will also have to be considered.

Q. *Can a sunspace or green house be designed to work with just solar energy?*

A. Many people hope that their sunspaces and greenhouses can be designed to require no energy in addition to that from the sun. In some parts of the country, there simply is not enough solar radiation for greenhouses and sunspaces to work entirely that way in the winter. In much of the country, totally passive sunspaces and greenhouses are *possible,* but they must be designed very thoughtfully and carefully. However, sunspace and greenhouse performance always depends on the weather, and the very best design may not overcome that occasional cold spell during a week of cloudy days. Air movement is critical for both sunspace and horticultural greenhouses. (Chapter Three presents an in-depth look at the importance of ventilation.) Virtually any house that relies on a sunspace as a heat source will benefit from the use of fans to move the air from the sunspace. Fairly simple systems that use small fans can be very effective and low-cost. A grantee in California found that a large patio door opening onto the sunspace was not enough to let heat move naturally into the house. The installation of a small fan did move the warm air inside and was much easier to control.

In Oklahoma, a grantee found that an electrically powered air delivery system (with heat storage) increased his electrical consumption slightly, but the sunspace gained and delivered heat so effectively that his natural gas consumption was reduced and his overall energy bill was lower.

The same is true for horticultural greenhouses that are counted on to produce food for income. The use of

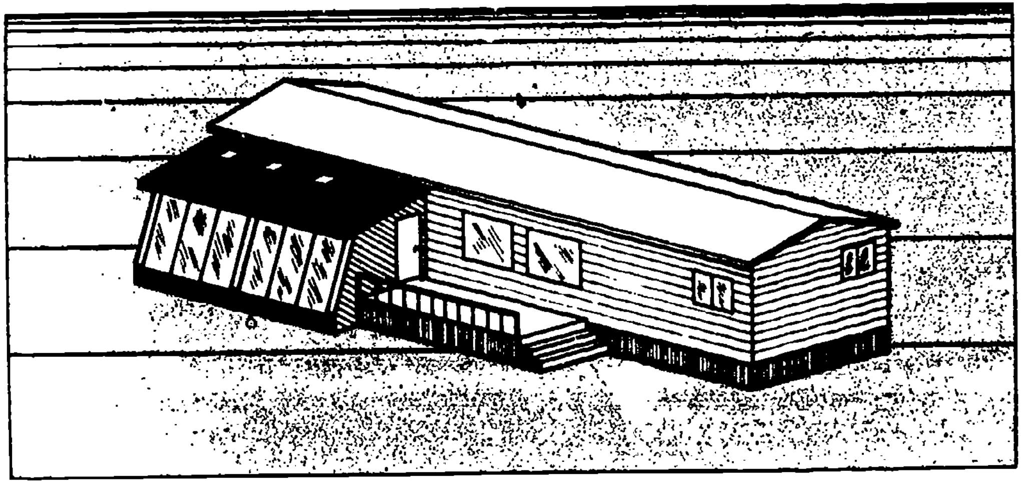


Figure 1.2 Sunspaces attached to mobile homes require special designs to accommodate mobile home entry doors which are fairly high off the ground.

supplemental heat sources (or supplemental light, in some cases) in greenhouses can provide more flexibility at the design stage. This flexibility is especially useful, because compromises between heat and light are often necessary. With supplemental heat available, more glazing can be added, whch could result in some heat loss, in order to provide more light for the plants.

Q. *What are the advantages and disadvantages of a two-story attached sunspace?*

A. The main advantage is the main disadvantage: a tall sunspace can gather a lot of heat. If the space next to the house is limited, a sunspace can go up instead of out, and when well-managed, this can be very effective for heat gathering. The sunspace can also be designed so that it serves dual functions with the bottom half used to grow plants and the top for heat.

Heat behaves the way it is supposed to in a tall sunspace; it goes up. Sometimes it is hard to keep the first floor warm while at the same time the second floor is overheating. A second floor deck built out into the sunspace is an attractive idea, but it may not be especially practical because of the overheating problem.

To get the most from this type of sunspace, keep these things in mind. A two-story greenhouse may not work well if it depends only on natural ventilation and circulation. Somehow, the hot air at the top of the sunspace has to be forced down. Several grantees reported that the best designs control air flow with fans that force the air down through ducts (plenums). Plenums work much better than just mounting fans on the ceiling.

Make sure too, that the house can be isolated from the sunspace. If an upstairs room is totally open to the sunspace, temperatures will be stifling during the summer and even on some bright, moderate temperature days in the winter. Windows or sliding glass doors can be used to provide the feeling of openness and to help control heat flow. Curtains behind the windows and doors can help block the sun and assure privacy.

It is also a good idea to design a two-story sunspace with zones in mind, as a Massachusetts grantee did. For example, if plants are grown on the bottom level, the sunspace can be designed to let light into that portion year round, but internal shading devices can be designed into the top half to keep the sun out and heat down during the warmer months.

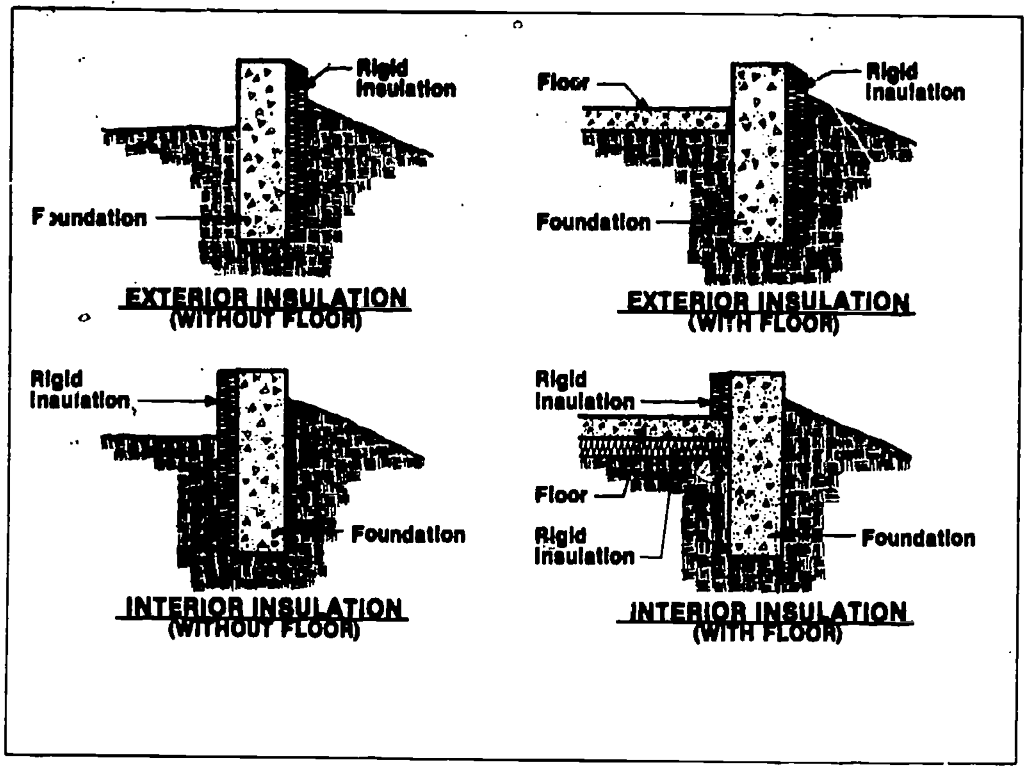


Figure 1.3* *The foundations of greenhouses and sunspaces in northern climates should be well insulated. This can allow the interior floor of the greenhouse to serve as thermal storage.

Q. *Should greenhouses and sun spaces be insulated?*

A. To get the most out of heat from the sun (or back-up heat if it is used), a greenhouse or sunspace should be insulated. The only exception to the insulation rule might be some commercial horticultural greenhouses, especially existing ones that are retrofitted for solar. As a grantee in Maine points out, the amount of glazing in a commercial greenhouse can be so massive that insulating the foundation, end walls, and kneewalls will conserve only a minimal amount of energy compared with the heat lost through the glazing. However, even large, commercial greenhouses can use a combination of insulating techniques (night curtains, dual glazing, etc.) that may be cost-effective in the long run. A Tennessee grantee converted an existing commercial greenhouse to solar and insulated all of the non-glazed area, which resulted in a 46 percent reduction in fuel oil consumption the first year. The point is that cost-benefit analyses for big commercial greenhouses have to be very comprehensive to determine the real value of increased insulation.

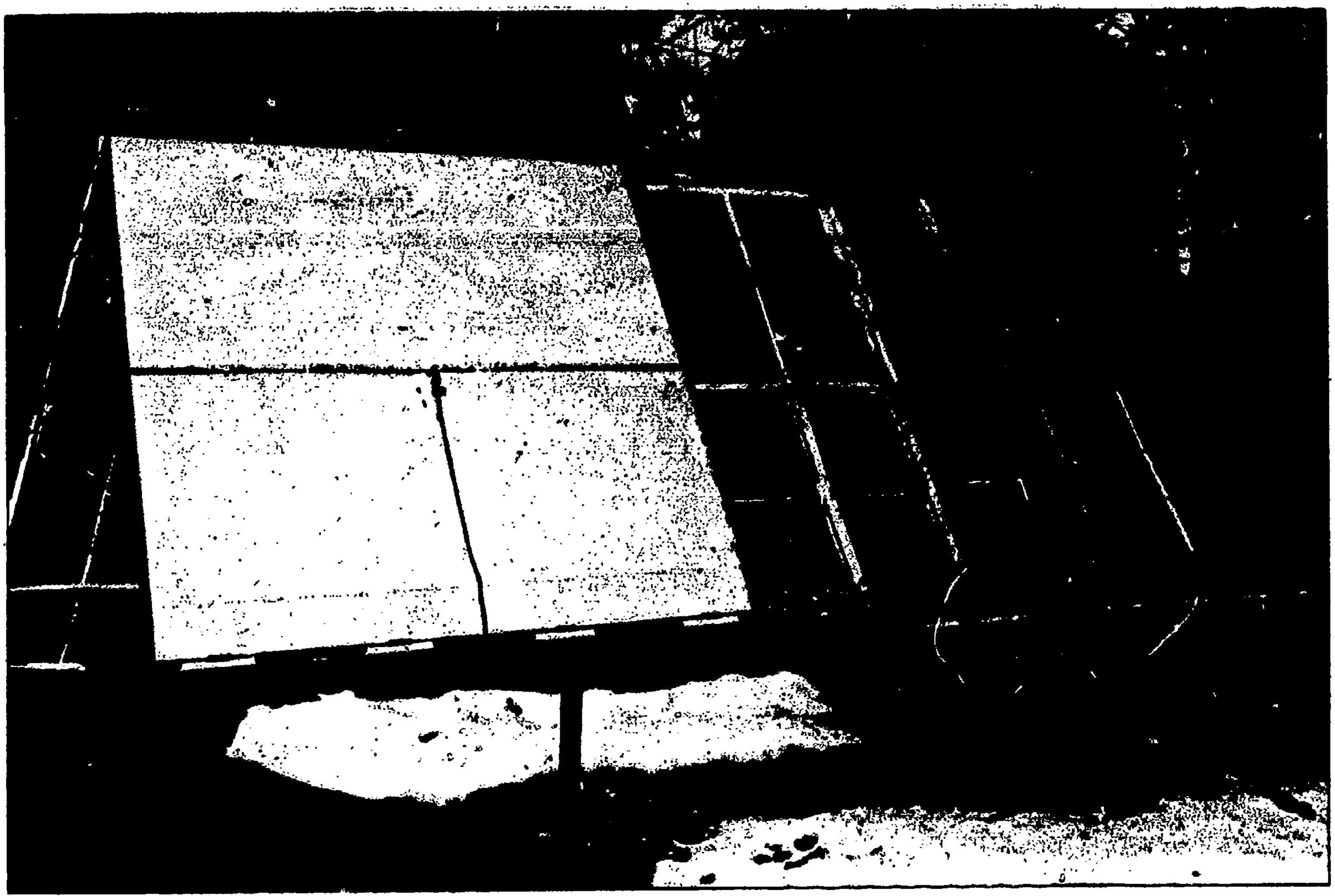
Two basic kinds of insulation are available, permanent and movable, and both have to be considered during design if they are to work well. Permanent insulation may be applied to kneewalls, end walls, north walls (attached or free-standing), foundations, floors, roofs, and doors. Walls and ceilings are commonly insulated with fiberglass batts while some kind of rigid insulation is typically used on the outside of foundations (Figure 1.3).

Another option is to insulate the glazed areas with dual-pane glass, layers of plastic glazings, or some combination of these. However, as one grantee in Maine found out, too many layers of plastic glazing (in his case, three layers) on a greenhouse can cut out a lot of sunlight. Remember too that different glazing materials filter out different kinds of solar radiation and will have different effects on plants or heat production.

Movable insulation can be very effective, but this is perhaps the area of design that is least developed. A grantee in Kansas hoped to develop an insulating shutter design of moderate cost, that was not too cumbersome, with a snug fit, that could also reflect light—to no avail. Movable insulation can consist of rigid panels or insulating curtains or shades. The main objection to almost any form of movable insulation is that it takes effort to use it. Rigid insulation can be put in place each night and taken down each day and stored, or it might be designed with hinges or slides so that it can be stored more-or-less in place. Curtain insulation can be installed to be drawn much like curtains in the house.

The important thing is to think about insulation during the design stage so that managing the insulation will be as convenient as possible once the greenhouse or sunspace is built. Insulation that is installed as an afterthought rarely seems to work very well.

The books referenced in Chapter Six provide additional information on insulation strategies and materials.



Movable insulation can be closed at night to reduce heat loss through the glazing.

Q. *What is the best angle for the glazed south wall?*

A. The rule of thumb is to add 10° or 15° to the site latitude to get the angle of the glazed wall suitable for maximum wintertime heat production. So if a sunspace or greenhouse is built at 45° north latitude, the south-facing glazing should be sloped at a 55° to 60° angle.

However, the final selection of the "best" slope for the glazing depends on the purpose of the greenhouse or sunspace and any site limitations. Heating sunspaces are normally designed with the slope that lets the sun's rays pass through it as close to perpendicular as possible during the middle of the winter. However, the use of the optimum winter slope may also lead to overheating in the summer, as several grantees found out.

The glazing details of horticultural greenhouses vary more, because light rather than heat gain is the primary concern, and there are several ways that light levels can be increased. For example, glazing can be added to the east, west, and even north sides. (Chapter Four presents other ways to increase light levels in horticultural greenhouses.)

One grantee in New Hampshire found that vertical glazing worked very well, because so much light was reflected from the snow during the winter. Vertical glazing can be useful in other cases, too. If space is limited, and as a consequence the angle of the glazing is limited, more sunlight can be let in by increasing the glazed area.

Vertical glazing is also easier to maintain, leaks a lot less, and may stand up better because snow and rain run off more easily. Vertical glazing is also easier to keep clean. Water leakage can be a problem when windows that open are installed on a slope, but these windows are generally weather tight when installed vertically. For these reasons, vertical glazing is a popular choice for sunspaces and greenhouses.

Q. *Should glazing panels be curved or flat?*

A. Designers have been intrigued with both convex and concave curved glazing panels (Figure 1.4). The main advantage was thought to be that they would shed water and snow better than flat glazing. However, as several grantees discovered, the use of curved glazing creates more problems than it solves.

First of all, most flat glazings shed rain and snow as well as curved glazings do. Curved glazing requires a much more complex mounting design on the ends than flat glazing does. Curved glazing is difficult to install, because it has to be stressed, held at the proper curve, and then fastened down. This procedure is not simple, and many plastic glazing materials do not curve evenly. Because they are under stress, these panels are also harder to fasten down securely, and leaks can result.

The problem with leaks is compounded by the fact that curved glazing tends to move more than flat glazing does in response to temperature changes and wind. This movement works against the fasteners, which loosen up and allow the glazing to gap. In high winds, curved glazing may pop so that its curve is reversed. This kind of stress is likely to damage the glazing sooner or later.

Q. *How should greenhouses and sunspaces be designed for snowy areas?*

A. A snowfall on the greenhouse can be delightful, irritating, or catastrophic. In Massachusetts and Maine, grantees had problems with snow piling up and covering the glazing. And in Nebraska, a manufactured greenhouse collapsed under a load of snow.

Greenhouses and sunspaces should be designed to support the heaviest expected snow loads. One way to get enough support is with larger dimension lumber. However, bigger supports cast bigger shadows. Perhaps the easiest way to design a greenhouse or sunspace to minimize snow problems is to increase the slope of the glazed surface. The steeper the pitch (another case for vertical glazing), the quicker the snow will slide off, if it builds up at all.

There has been some speculation that snow will not slide off of multiple glazing as quickly as it will from single glazing, but experience indicates that there is little correlation. The theory was that the snow would melt faster on a single glazing, the water would act as a lubricant, and the snow would slide off. It appears, however, that gravity has more to do with it than melting, and when snow builds up to a certain level, its own weight will slide it off.

Using a higher kneewall has been suggested as a way to combat snow buildup (Figure 1.5). Kneewalls are a mixed blessing, however. They should be at least two-feet high to be effective, but if they are not glazed, they can cause shading and may trap cold air.

One other solution to the snow buildup problem that has proven effective is a snow shovel.

Q. *How can greenhouses and sunspaces be designed to minimize moisture problems?*

A. Moisture can create problems in greenhouses and sunspaces whether it is trapped inside or coming in from outside. Too much water from either source can lead to structural damage to the greenhouse or sunspace and sometimes to an adjoining house. Later chapters will deal with various management techniques that can be used to cope with moisture on the inside, but one design rule, especially for horticultural greenhouses, should be noted here: horizontal greenhouse structural pieces should not be flat. Any flat surface will gather a certain amount of water, and this can eventually cause wood to rot and metal to rust through. Make sure sill plates and other structural surfaces are bevelled (Figure 1.6).

Condensation on the inside is the most obvious and frequent concern, but water coming from outside can be just as troublesome. In many parts of the country with high rainfall levels and/or high ground water, drains should be installed to take water away from the greenhouse or sunspace. A grantee in Vermont discovered that water was standing in the greenhouse

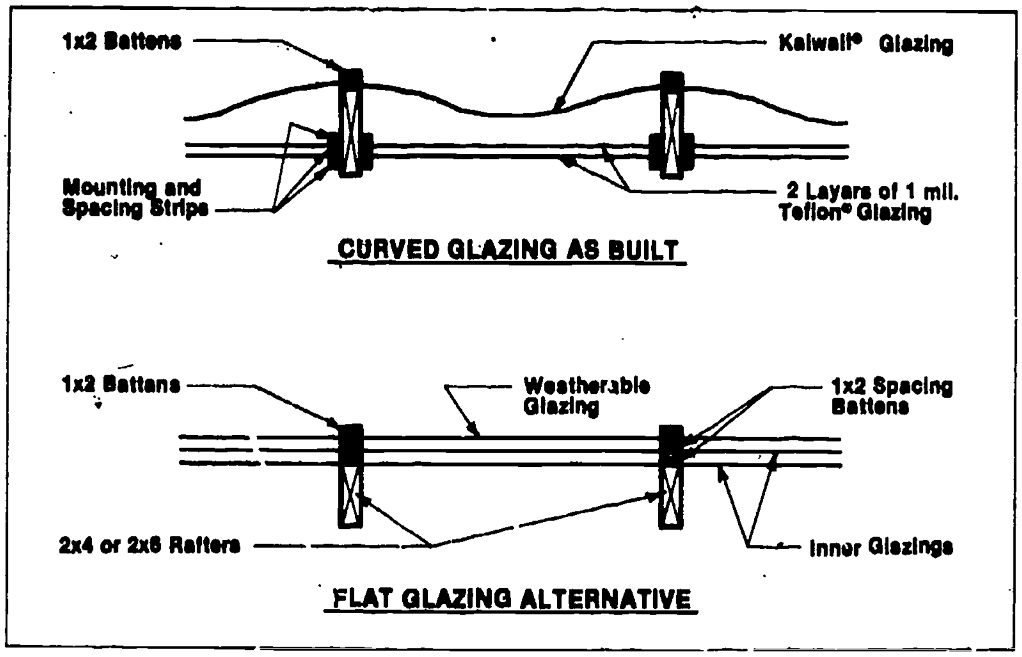


***Figure 1.4** Grantees discovered that curved glazing was difficult to work with and often not worth the trouble.*

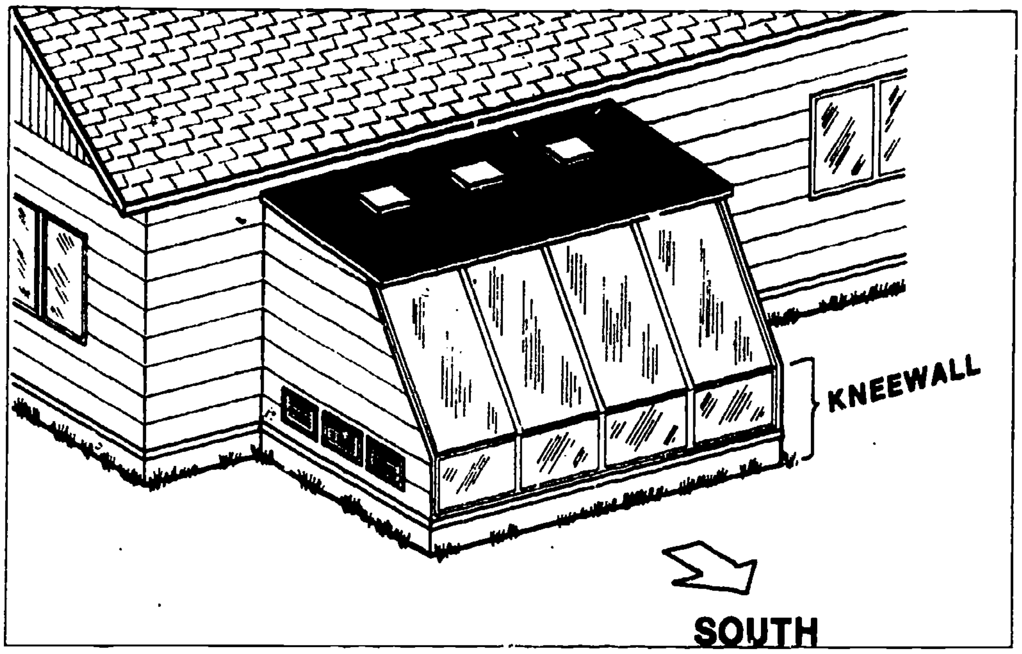


***Figure 1.5** Greenhouses and sunspaces can be designed with a kneewall to help reduce snow loading on the glazing.*

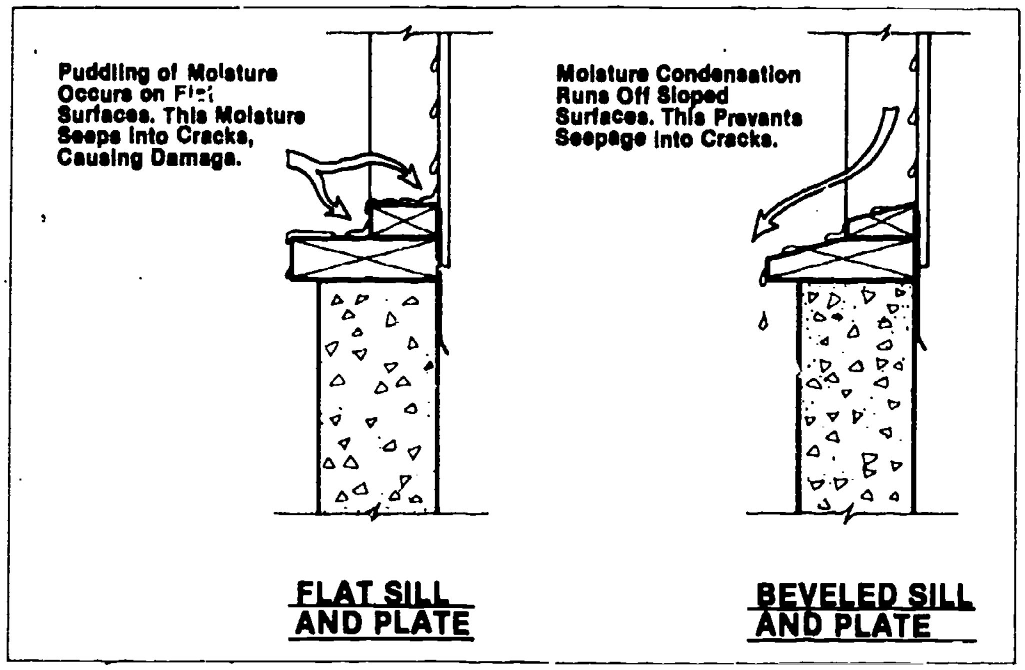


***Figure 1.6** Sill plates and other structural components should be bevelled to permit moisture to run off*

during construction. As a result, a trench was dug around the greenhouse and perforated drain pipe, bedded in pea gravel, was installed to provide drainage. As a North Carolina grantee pointed out, good drainage is especially important for greenhouses that are partially below grade, earth-bermed, or built into a hillside. Gutters also help to move water away from the greenhouse.

If greenhouses have concrete or other solid surface floors, plans must include a properly sloped built-in floor drain. Floor drains may also be a good idea in horticultural greenhouses that use a lot of water, even if the floor is made of gravel or some other porous material.

Q. *Do greenhouses and/or sun spaces qualify for the Federal solar energy tax credit?*

A. It depends. In order to qualify, a solar energy collection system must consist of the following components: a solar collection area (i.e., a large area of material transparent to solar radiation); an absorber (a surface exposed to solar radiation which absorbs the radiation and converts it to thermal energy); a storage mass; a heat distribution method; and heat regulation devices. A greenhouse or sunspace obviously contains most if not all of these components. But the Internal Revenue Service has also ruled that solar energy equipment which serves a dual purpose does not qualify for the tax credit. Thus, greenhouses and sunspaces are usually excluded. However, components (heat distribution, thermal storage, etc.) but not the greenhouse or sunspace itself might qualify. Some individuals who have designed their sunspace only as a heat producer and do not use the space for any other purpose have qualified for the full tax credit. Since each case is different and depends almost entirely on the design of the greenhouse/sunspace, you must contact the Internal Revenue Service for more information. But, it is probably wise not to plan on receiving the tax credit. Many states also have solar energy tax credits for which your greenhouse or sunspace may qualify.

A south-facing porch can often be converted into a sunspace.

GREENHOUSE AND SUNSPACE DESIGN

These summaries of selected greenhouse and sunspace projects from the DOE Appropriate Technology Small Grants Program include information from final reports that give some indication of the kinds of design applications and innovations that were developed. There may be a project in your area that you could see as you plan your greenhouse or sunspace.

Attached solar "sunspace" on north side of residence — DOE Region VI
Charles K. Witt — DOE Grant No. DE-FG46-80R612018
Las Cruces, NM — ATMIS ID: NM-80-001

A two-story solar "sunspace" was attached to the north side of a residence in Las Cruces, NM. One hundred fifty three square feet of vertical south-facing glazing accepts light from the sun and from a shutter/reflector panel. The greenhouse reduced home heating bills about 25% from November 80 to March 81. Limited performance data is presented in the report. Construction costs were reported at about $26/sq. ft. for this retrofit.

Liquid foam insulation for plastic greenhouses — DOE Region I
Otho S. Wells — DOE Grant No. DE-FG41-79R110038
Durham, NH — ATMIS ID: NH-79-003

A quonset-shaped, double-layer, polyethylene-glazed greenhouse was used to test the effectiveness of liquid foam insulation, which was injected between the two layers. Thermal conduction losses were reported to be reduced by an average of 30%.

Waste greenhouse heat to soil storage — DOE Region X
John Collette — DOE Grant No. DE-FG51-79R000063
Fairbanks, AK — ATMIS ID: AK-79-007

Excess heat in a greenhouse near Fairbanks, AK is used to heat the soil rather than being vented. Hot air in the greenhouse apex is blown through radiators giving up heat to an antifreeze solution, ethylene glycol. The solution is pumped through 3/4" plastic pipes at 4 levels in the soil (14, 18, 22 & 33"). Leaks in the piping system are a potential problem. The use of ethylene glycol (toxic) will immediately kill the plants near the leak—pinpointing the trouble spot for quick repair. Overall energy savings are estimated at 38%. Tomatoes matured 10-14 days earlier than ones in a control greenhouse. Total yield is reported to be 10-15% greater than the control.

Solar greenhouse and wood heated residence with subfloor—water/rock thermal storage — DOE Region II
David R. Mears — DOE Grant No. DE-FG42-79R205064
Belle Mead, NJ — ATMIS ID: NJ-79-009

The final report describes details of construction and monitored results of the performance of a water/rock thermal storage system. Storage is below the floor of the house and below the floor of an attached solar greenhouse. The water storage is coupled to a wood stove via piping under the house. Under the greenhouse the rock storage is coupled to an active solar collector system. Performance was reported to be good and no backup heat was required in this New Jersey house.

Demonstration for an advanced solar greenhouse with a water ceiling — DOE Region V
Environmental Research Institute of Michigan — DOE Grant No. DE-FG02-79R510122
Ann Arbor, MI — ATMIS ID: MI-79-006

A water ceiling was added to a pre-existing solar greenhouse with movable night time insulation/daytime reflector in Ann Arbor, MI. The water ceiling retards daytime overheating and provides additional thermal storage. The water ceiling caused no noticeable degradation in yield or maturation rate for non-flowering plants, but delayed maturation and slightly diminished yield for flowering plants was reported. Algae problems were reported and addressed.

Commercial greenhouse retrofit project — DOE Region IV
Nancy L. Whitehead — DOE Grant No. DE-FG44-80R410244
Strawberry Plains, TN — ATMIS ID: TN-80-012

A commercial quonset-type greenhouse was retrofitted with insulation and water storage in Strawberry Plains, TN. Two inches of beadboard insulation was added to the northern third of the greenhouse's arch. The doors, east and west walls, and the foundation perimeter were insulated. For heat storage, 120 55-gallon barrels of water were added under the planting beds and along the north wall. The retrofitted greenhouse reportedly used 45% less fuel oil.

CHAPTER TWO

BUILD IT RIGHT

CONSTRUCTION TIPS

Building a greenhouse or sunspace is a major project. Even the smallest, simplest greenhouse requires thoughtful planning and careful construction if it is to perform as it should. Others, such as a two-story sunspace addition to a new home or a school greenhouse that is a student laboratory, obviously must be built very well.

To be successful, the first step of construction happens during design. Good builders think about the sunspace or greenhouse construction process as they develop the plan, which includes both planning for the building materials, and the construction process itself: the necessary labor, tools, etc. Obviously, some things can't be controlled, like the weather, but the builder can plan to work in the summer rather than in the winter. It is precisely because some things cannot be anticipated or controlled that it is so necessary for the builder to control the things that he or she can.

Several building skills may be required to build a greenhouse or sunspace: excavation, concrete work, carpentry, glazing, electrical work, plumbing. Most of these skills are directly transferrable from general construction, but some, like glazing installation, may require some special techniques for sunspace or greenhouse applications. As several grantees found out, if you are not experienced, some tasks are not as simple as they appear to be. Sometimes it is much easier and ultimately less expensive to hire a qualified person to do some of the work.

Even though there are a variety of tasks involved in greenhouse or sunspace construction, one word applies to each of them: QUALITY. Greenhouses have failed spectacularly because they were built with poor materials or poor workmanship. The cheapest greenhouse demands a certain commitment of money and time. If you can't afford either of these, you probably cannot afford to build. A sunspace or greenhouse that is built properly two years from now will be much more productive and rewarding than one built poorly right away. And just think of the value that can come from an extra year of thought and planning.

Attention to detail is essential for quality construction. Some details are bigger than others, but every one is important. A grantee in Georgia built a wooden floor (thermal storage was not a priority in this case) for a sunspace addition. The floor joists were spaced unevenly, and consequently standard-sized insulation did not fit between the joists. As a result, the task of insulating under the floor was a time-consuming and frustrating process, a process which should have been fairly straightforward.

Joining wood components is a detail that is essential for building a good greenhouse or sunspace. One way to reduce the threat of moisture damage is to build good, tight joints in the framing. As a result, the whole structure is more solid and less prone to leaks, and helps to keep moisture out of the wood. Building good joints takes careful measurement and good saw work, relatively simple, but critical tasks.

The questions and answers that follow address some of the most common construction problems and ways the grantees learned to deal with them.

Q. *Why is it important to consult with code inspectors when building a greenhouse or sunspace?*

A. Building codes are drawn up to ensure that a structure won't collapse, or be a fire hazard, or create unhealthy living conditions. Such codes are meant to protect life, health, and safety, and not to prevent people from building. In many cases, the people who administer these codes can provide a great deal of good advice. The builder should keep these things in mind; it will make relations with regulators much more cordial and productive.

Several grantees experienced lengthy delays, because their greenhouses or sunspaces had to be redefined or redesigned to meet code requirements. There may also be additional costs associated with code-approved materials and construction details. It makes good sense to find out what these requirements are early in the planning process.

In Connecticut, a project did not meet the setback regulation (the distance a structure must be set back from the lot line), causing long delays in getting the site approved. A retrofit on a school in Connecticut experienced a 7-month delay as project organizers dealt with the special fire and building codes for schools. In Oklahoma, a rooftop greenhouse just didn't fit into any convenient code category. It was finally defined as a penthouse, and as such was issued a building permit. Another Connecticut grantee found (probably for the best) that his rooftop greenhouse could not be permitted, because the building was not strong enough to safely support the weight of a greenhouse.

In California, one grantee had to receive code variances from four separate local, county, and state agencies with jurisdiction over earthquake codes before a building permit was granted. Because the standards for the glazing material and attachment details were so strict, the grantee had to use professional labor for construction instead of volunteer workers.

Q. *Are there special things to keep in mind when attaching a sunspace or greenhouse to an existing building?*

A. Two things seem to be most important: keeping the sunspace/greenhouse square, and keeping moisture out of the existing structure.

It is rare to find an old building that is perfectly square, and some newer ones are not much better. The first step is to determine if there is anything about the existing building that will prohibit or seriously affect the sunspace or greenhouse addition. If some parts of the old structure are going to bear the weight of the greenhouse or sunspace, find out if they are sound enough to do the job and if they are in the right places. If these structural parts aren't quite right, determine what has to be done to make them right. All of this assessment takes careful measurement. Don't assume that things are as they appear to be. The top of one window may be an inch or two higher than the one 8 feet away, resulting in a greenhouse that is out of square if the windows are used as a level. Also, make sure that there aren't any hidden surprises, like a brick chimney in the wall where the sunspace or greenhouse was to be attached, or a shallow drain line where the foundation was supposed to be.

A greenhouse or sunspace must be built on a sound foundation, and that is the place to start getting things square. Once there is a level foundation to work from, the greenhouse/sunspace will have to be adapted to the unique measurements of the existing building. Shims (pieces of wood or other materials used to build up or level surfaces) are an integral part of the process of matching the old building and the new structure. A grantee in Pennsylvania, whose rehabilitation of an old house included a new greenhouse, found that he was kept busy making and inserting shims to make the construction come out square. Just remember that shims are a finishing device, however, and not a substitute for load-bearing structural components.

Some moisture coming through vents, doors, and windows from an attached greenhouse into the living space is fine. But too much moisture from greenhouses can damage the structure it is attached to if it is allowed to saturate the wood, insulation, and sheet rock or plaster in the walls. If a greenhouse or sunspace addition involves a major renovation of the wall it is joined to, it is probably wise to take advantage of the opportunity to add some kind of plastic vapor retarder on the greenhouse/sunspace side of the wall during construction so that moisture will be kept from passing into the wall. If the wall is left intact, the greenhouse side should be caulked thoroughly and then sealed as tightly as possible with some kind of paint or other finish that stops moisture.

Q. *What are the best building materials to use?*

A. A durable greenhouse or sunspace must be built with good quality materials, which may require more money up front. But good materials will save money in the long run.

When selecting glazing materials, the primary criterion is how they transmit solar radiation. But don't forget the other considerations. Polyethylene glazings are temporary. They may work very well temporarily, but think about the labor and money required to replace them every year or so. There are some very good rigid plastic glazings, but generally they don't last forever either, and some of them tend to discolor. Cheap glass isn't necessarily a bargain either when you think about things like hail storms and vandalism. Tempered glass is best, and in some cases, safety glass may be necessary; but then cost is a factor.

There are several points to keep in mind when using tempered glass. Tempered glass comes in standard sizes. If irregular sizes are required, the glass will cost more, so design accordingly and plan to wait a little longer for specially ordered glass. The use of tempered glass may require even more care during design and construction, because tempered glass cannot be cut at the job site. Replacement glass for sliding patio doors is a good choice, because it is tempered, double-glazed, and comes in standard sizes. "Seconds" are sometimes available at discount prices.

Wood materials for framing can be preserved to last a long time, but some naturally last longer than others Redwood and cedar are common choices because they are attractive and durable. Untreated or lightly treated pine and fir can last as little as five years in a greenhouse, but cypress is known to have lasted for 150 years in wet environments. When using any wood in a greenhouse, it is wise to seal the cut ends. There are several primer/sealers good for this that dry quickly; boards can be cut, sealed and assembled without waiting.

Another common group of materials is known as fasteners: nails, screws, nuts and bolts. Only hot-dipped, galvanized nails hold up well enough for permanent greenhouse use, and screws, nuts and bolts should be made of brass, aluminum, or stainless steel, especially for use with redwood. Raw or poorly treated steel will deteriorate quickly in the acid present in redwood.

Q. *Can recycled materials be used in a greenhouse?*

A. Using recycled materials is as good an idea when building greenhouses and sunspaces as it is in general, as long as the materials are of adequate quality. Bricks, blocks, or stone make very nice floors, walkways, or planting bed supports (and add some thermal storage capacity), and, if they are even and sound, will work well for foundations and walls. Several grantees indicated that first-rate salvaged lumber is generally available. Reclaimed windows can be used, too, but remember that old glass is more brittle, and the quality varies. It may be best to use this glass on end walls rather than for the south glazing.

A grantee in Kentucky, who made extensive use of recycled materials, found that old materials are like old houses—they are not often true. Builders should be prepared to make changes and compromises during construction when using recycled supplies because the "fit" may not be exact.

Q. *Are foundations difficult to build?*

A. Many people who have never laid blocks or worked with concrete think anyone can do it. Grantees in both North Carolina and South Carolina report otherwise. Foundations are just that—the foundation for the whole sunspace or greenhouse. Consequently, they have to be done right, and it is not easy to build a strong, level foundation that has the critical job of supporting all that weight. A grantee in Delaware was able to do the masonry work, but it took much longer than anticipated to get it right.

Actually, foundation problems can start earlier with another seemingly simple task, site preparation and excavation. Several grantees found that it was possible to do their own excavation, but they were surprised at the time and labor it took to get the job done. Again, it may be smarter to leave excavation and masonry work to qualified contractors who can do a better job more quickly.

Q. *Is it hard to put up glazing?*

A. Yes. Grantees found that installing glazing that wouldn't leak was the most challenging construction task. Plastic glazings are somewhat easier than glass to work with, but they have their own problems.

Flexible plastic glazings can be torn or cut and it is not always easy to secure some types in place without tearing it in the process. It is very important that these glazings be sound when they are installed. Any tear or weakness is likely to spread, because the flexible plastic glazings move in the wind, when ventilator fans are working, or even when doors are opened or closed, all of which stress the material.

Most rigid plastic glazing is, in fact, not rigid, which becomes obvious when it is being installed and tends to sag between the rafters. To keep the glazing relatively even as it is being installed requires support and this task is not always simple. The slope of the south glazing also makes installation more awkward.

Structural support is also a problem when installing glass. The combination of the weight of glass and the angle of installation makes this work difficult. There is always a certain danger involved when working with glass, and the task requires enough people who are strong enough and handy enough to do the work safely.

Glass work is a task that may best be left to experienced glaziers. However, if glaziers do install the glass, make sure that everything is ready when they get there. Otherwise, you will end up paying them to watch while you work.

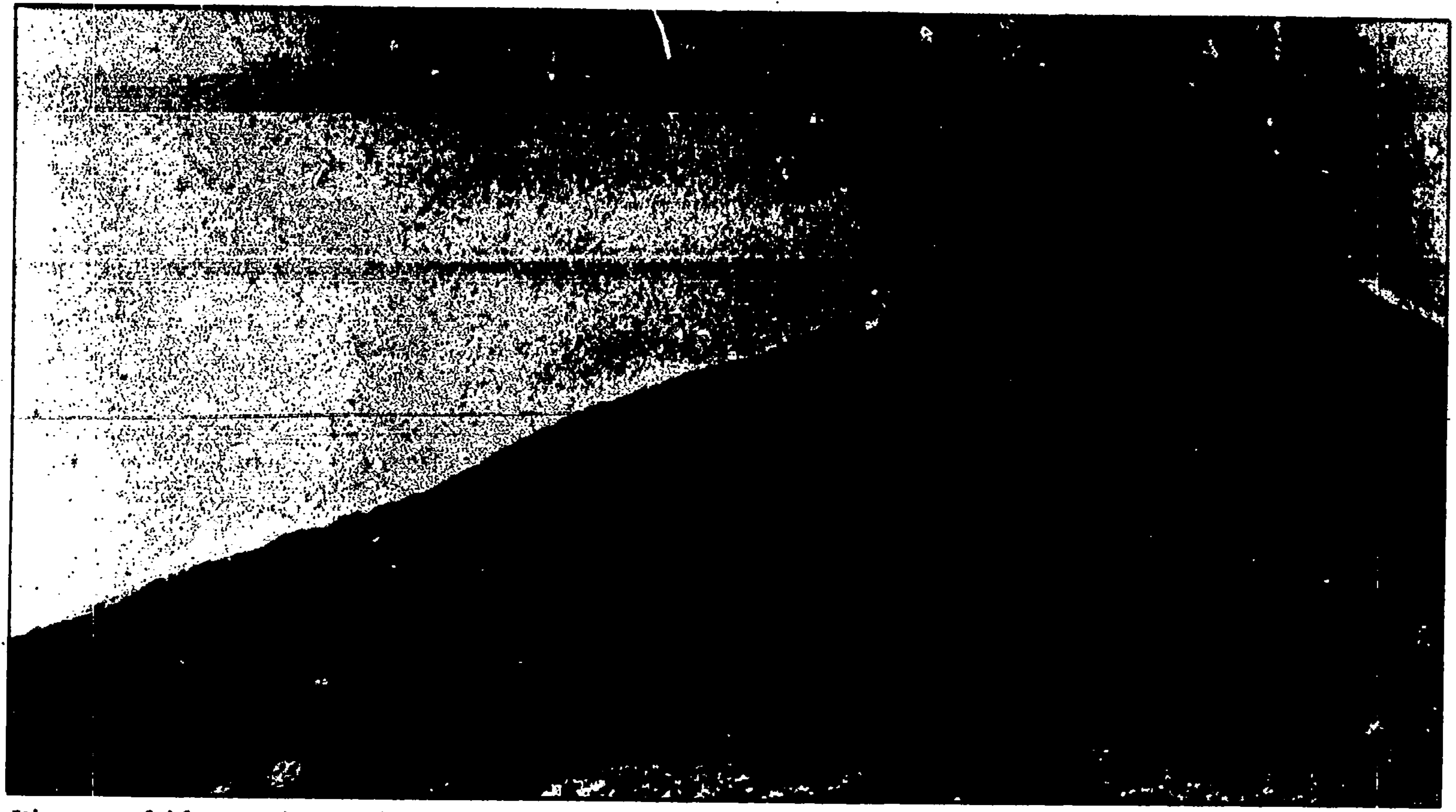
Q. *What should be caulked?*

A. Almost any crack. The glazing gets the most caulking, because it is the area that most often leaks. Glazing should be caulked wherever it is butted or overlapped. A grantee in Maine pointed out that the fasteners for the glazing should also be caulked. Silicone is usually the preferred caulking compound, because it adheres well, is strong, stays fairly flexible, is moisture-resistant, and lasts a relatively long time.

Caulking is done to keep moisture out and reduce infiltration, so any crack that can't be painted closed should probably be caulked. Caulking the cracks is especially important where the moisture from the greenhouse might get into an adjoining bulding, or where water from the outside leaking in might be a problem.

Laying a proper foundation is one of the most important aspects of construction. Many grantees found that it was more effective to hire a professional than to attempt it themselves.

Glazing is not a simple task. This greenhouse developed numerous leaks around the glazing and had to undergo costly repairs.



It's a good idea to thoroughly caulk your greenhouse or sunspace to help prevent air and water leaks.

Q. *How does the weather affect construction?*

A. Bad weather is a common cause of construction delays, and grantees from all over the country were set back by bad weather. About the only thing to do is to consider the possibility that the weather might not be good when it is supposed to be and develop an alternative schedule. Work should also be scheduled to avoid seasonal bad weather. A grantee in Vermont wasn't able to glaze the greenhouse in the fall, and the greenhouse frame stood half-finished through the winter.

Bad weather can be damaging as well as irritating. In Michigan, Kansas, and Utah, grantees had greenhouses virtually destroyed by bad weather while they were under construction. A greenhouse in California was damaged when rain bowed the rafters. To minimize weather damage, make sure the job site is as secure as possible any time work stops. It is a good idea to plan ahead for adequate work and storage space. Some work can be done inside if space is available, and materials should be stored inside when possible or protected from the elements if they have to be left out.

Another lesson that a California grantee learned was that work shouldn't be done in spite of the weather. It is only natural to want to get the job done, but in the California case, some of the caulking was done in the rain. As a result, the caulking did not adhere properly, and the whole caulking job had to be re-done.

Q. *How long does it take to build a sunspace or greenhouse?*

A. Longer than expected. Almost all of the grantees had to spend more time than anticipated to build their greenhouses or sunspaces, frequently leading to frustration and increased costs as well. Some grantees advised calculating the proposed labor requirements and then doubling it. Such estimates may be a little extreme, but the point is that the time requirements should be analyzed as carefully and accurately as possible. Then, a cushion of time, say 10 to 20 percent, should be added to the total time estimate for good measure.

The time it takes to build a greenhouse or sunspace varies depending on many factors: weather, skill of the builders, delivery of supplies, delays in contracted labor, etc. Some of the most ambitious projects were workshops. In some cases, with good organization, a simple design, and lots of workers, greenhouses were almost completed in two days. However, in many of these cases, it took weeks or months to get the greenhouses really finished. The labor for a greenhouse with 800 square feet of floor area in North Dakota was carefully recorded, and the work took a total of 900 person-hours. A greenhouse in North Carolina took one year to build, and others took even longer.

Q. *What problems can arise when using contractors on greenhouse or sunspace projects?*

A. During the construction season, contractors often have several projects underway at the same time. Any delays caused by project sponsors or resulting from problems getting materials, bad weather, or the contractor's other work will cause the construction schedule to change. These schedule changes can adversely affect any other contractors involved in the project.

In Rhode Island a grantee took more time to remove an enormous dead elm than originally had been anticipated. Consequently, the excavation contractor was not able to do his work when originally scheduled and had to reschedule it for a much later date. In Vermont, a glazing contractor had numerous other priority projects which caused extensive delays in the grantee's sunspace addition.

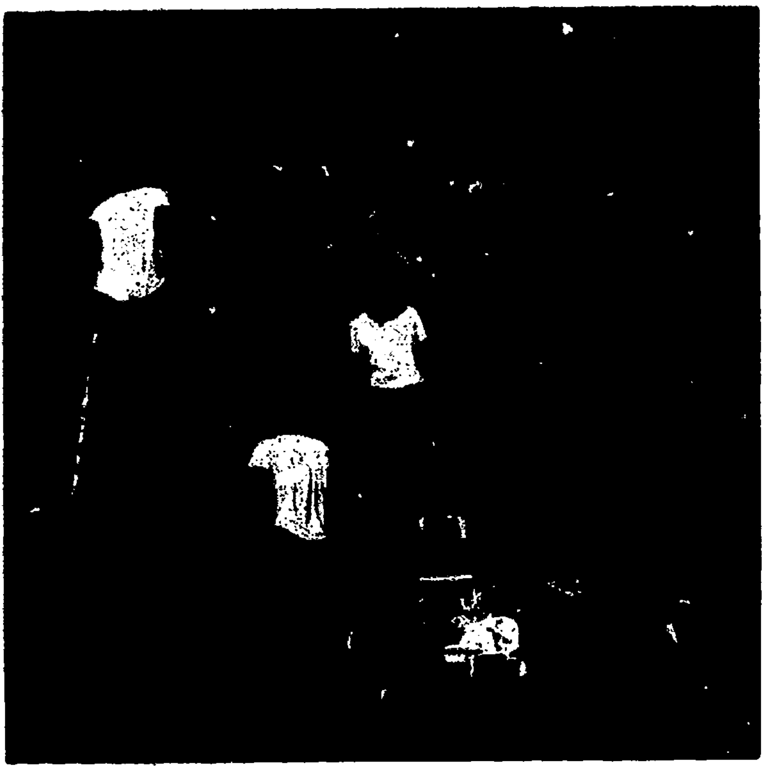
Underestimating the costs of contracted work when preparing a greenhouse or sunspace project is also a problem. Grantees in Connecticut planned to attach a greenhouse to a school. After the proposal was funded, the grantees discovered they could not find a contractor with solar greenhouse experience who could bid the job at the rate established in the grant. It is important to negotiate an estimated cost for the contracted service *before* acquiring the funding.

Always plan carefully when using contractors. Scheduling problems can cause long delays in project completion because contractors are usually very busy during the construction season.

Q. *How can the availability of materials affect the construction sequence?*

A. Greenhouses and sunspaces are becoming more common, but the special materials needed to build them are not always available in local stores, and materials sometimes must be ordered from suppliers outside the area. Two problems may result. First, several grantees reported delays in receiving materials. For example, a Maryland grantee waited over four months for fans and thermostats and a Massachusetts grantee reported that it took a long time to acquire the proper lumber needed to build the greenhouse. Second, some grantees received materials that were damaged, especially shipments of greenhouse kits.

It is important to determine what warranties and guarantees cover materials, before they are purchased. Nebraska grantees had trouble getting satisfaction when their manufactured greenhouse collapsed in a storm.



Special materials needed for sunspace or greenhouse construction are not always available in local stores. Order well in advance so that they are available when needed.

GREENHOUSE CONSTRUCTION

These summaries of greenhouse projects provide information on construction techniques and problems encountered.

Solar greenhouses for northern California
Lynn Nelson
Berkeley, CA
DOE Region IX
DOE Grant No. DE-F003 78SR01056
ATMIS ID: CA-78-051

Six solar greenhouses were retrofitted on residences using hands-on workshops. Four identical attached solar greenhouses [illegible] were constructed and instrumented in Pacheco, CA. [illegible] performance was [illegible] various [illegible] of operation of vents in the common wall, and single vs. double glazing.

South-facing porch conversion into a sunspace
[illegible]
Kansas City, KS
DOE Region VII
DOE Grant No. DE-FG47-80R701158
ATMIS ID: KS-80-017

[illegible] porch in Kansas City, KS were [illegible] 67 sq. ft. of the porch [illegible] as a vestibule. [illegible] of glazing are presented in this report. [illegible] and 13 percent in [illegible]

Solar greenhouse for small farm
[illegible]
[illegible]
DOE Region I
DOE Grant No. DE-FG41-79R110051
ATMIS ID: [illegible]

A 648-sq. ft. [illegible] solar greenhouse was designed and [illegible] for [illegible] commercial use. Design and construction [illegible] are presented. Limited thermal performance data is also included.

Cheap solar heated greenhouse
[illegible]
[illegible], MA
DOE Region I
DOE Grant No. DE-FG41-79R110054
ATMIS ID: MA-79-[illegible]

A [illegible] greenhouse was constructed in [illegible], MA [illegible] R-11 [illegible] and 27 [illegible]

Solar wall [illegible]
[illegible]
[illegible], PA
DOE [illegible]
DOE Grant No. [illegible]
ATMIS ID: [illegible]

[illegible] from 5.4 to 10.4 [illegible] degree day.

CHAPTER THREE

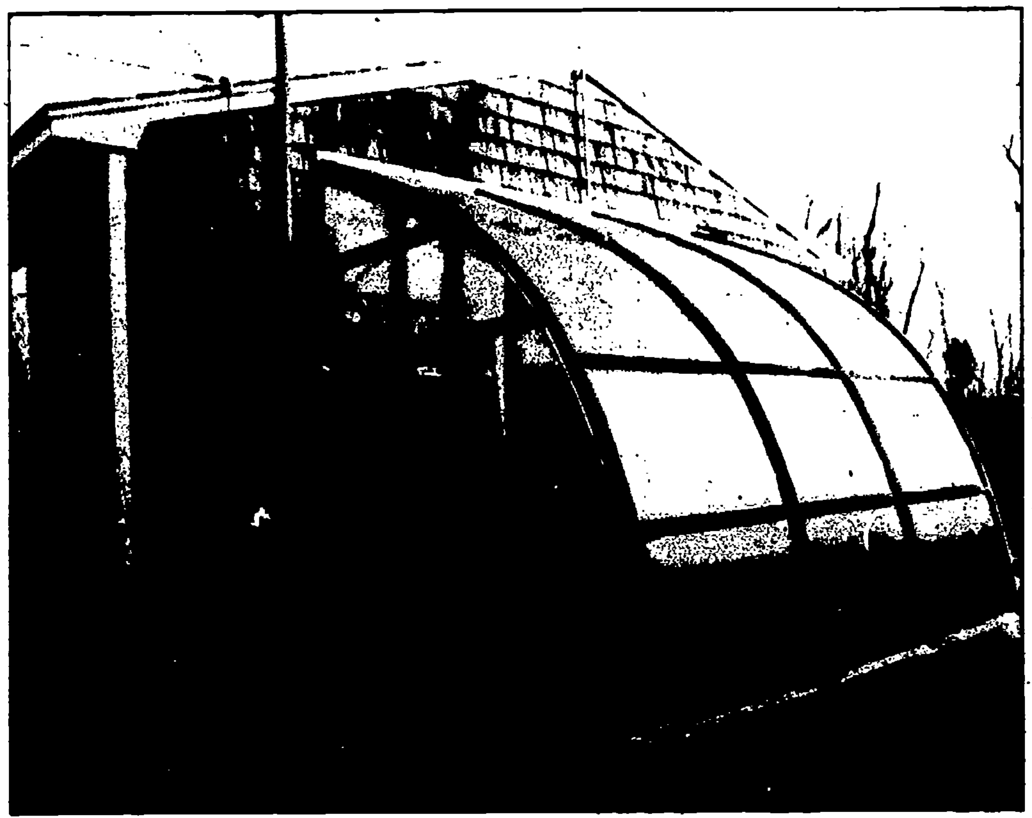
MANAGEMENT, MAINTENANCE, AND SAFETY

Just as it is important to know what a sunspace or greenhouse is expected to do before you design and build it, it is also important to realize that the purpose of a greenhouse or sunspace will dictate how it must be managed. A sunspace used primarily for space heat should maintain higher temperatures and lower humidity levels than a horticultural greenhouse because the major goal is to transfer as much heat as possible to the interior living space. For horticulture, more heat should be retained in the greenhouse to promote plant growth.

The chief management concerns involve temperature, air flow, light, and humidity. Thermal storage is critical to minimize temperature fluctuations in horticultural greenhouses and passive solar sunspaces. Energy is stored in materials such as water, masonry, or rocks—materials capable of absorbing radiant solar energy and releasing thermal energy. At night and on cloudy days when direct solar energy is not available, heat stored in these materials is released in the greenhouse or sunspace.

In many greenhouses and sunspaces, overheating is a problem. Generally, overheating is caused by not enough thermal storage, by too much or improper glazing, or poor air movement. Even in mid-winter, improperly designed or managed greenhouses and sunspaces can be too hot on sunny days, and some cooling may be required on most days in the spring, summer and fall.

Humidity levels especially in horticultural greenhouses also may have to be regulated both during the summer and winter. Generally, the best levels of greenhouse relative humidity are about 55 to 75 percent. (Relative humidity is a measure of the amount of moisture in the air compared with the total amount the air can hold at any particular temperature.) At relative humidities above 75 percent, mold, disease, and pest problems increase. However, the desirable relative humidity for a greenhouse is significantly higher than that recommended for houses, so warm air ducted from an attached greenhouse into a home can cause moisture problems. Unexpected condensation inside the house could indicate that the air from an attached greenhouse is too humid.



Effective sunspaces and greenhouses are usually designed to do one thing well—in this case it's space heating.

The high moisture levels commonly found in horticultural greenhouses can also lead to both maintenance and safety problems. With high humidity levels and water everywhere electricity can be a special problem.

Safety and maintenance, in general, are critical considerations to the management and enjoyment of any greenhouse or sunspace. Yet, because greenhouses and sunspaces are a relatively new phenomenon, not enough thought has been given to safety and maintenance procedures.

Proper and safe management is not complex. But, from the experiences of grantees, it is clear that it's easy to make management mistakes that take all the fun out of owning and operating a greenhouse or sunspace.

A greenhouse or sunspace can be designed just right and constructed without a flaw. But, unless the technology is managed and used properly, performance can be disappointing. The answers that follow address several common questions relating to a variety of management concerns.

Q. ***What materials can be used to store thermal energy?***

A. Besides water and rock, soil and masonry are the most common thermal storage materials. Water can store the most energy per unit volume, nearly three times that of rock or masonry. The 55-gallon drum seems to be the universal water storage container. They are so popular that some dealers now charge as much as $20 for a used oil drum. Do not assume that 55-gallon drums can be had free for the asking.

Deep soil growing beds in greenhouses can also provide significant thermal storage. Even though most of the thermal storage takes place in the upper few inches of the bed, they can contribute as much as 20 percent of the total storage capacity of a greenhouse.

Rock and masonry thermal storage in greenhouses and sunspaces is often more difficult to work with. Rock bed storage usually requires duct work, fans or blowers and controls, and still, is often inefficient. As a result, rock bed storage can be expensive. Washed river rock or crushed gravel is commonly used on the floor of horticultural greenhouses, and it is highly recommended for drainage purposes. But don't count on gravel floors as a thermal storage medium. Since warm air rises, the rocks are usually in the coldest part of the greenhouse.

Masonry walls can store a significant amount of heat. To be most effective, they should be built of dense materials (not hollow concrete blocks), be in direct sunlight for at least one-half of the day, and be well-insulated from the outdoor environment. If reflected light is not specifically required for plant growth, masonry thermal storage walls and floors should be painted a dark color to absorb as much solar radiation as possible.

Various substances known as phase change materials which store thermal energy when they melt and release that energy when the material solidifies again are also coming into use in certain greenhouse or sunspace applications. The use of phase change materials was studied by some grantees, but their use is still not widespread. Generally, these materials can be expensive and are sometimes difficult to obtain.

Q. ***What precautions are needed when using 55-gallon drums for water storage?***

A. A 55-gallon drum filled with water weighs about 450 pounds A wall of nine 55-gallon drums weighs about two tons. Filled water barrels are permanent fixtures. Care must be taken when stacking drums, one on top of another, to make sure they are secure and well supported from below. Barrels must also be treated with a rust inhibitor (3 tablespoons tri-sodium phosphate per barrel), and a cup of motor oil (a good way to recycle used oil) should be floated on top of the water in the barrel to reduce evaporation. It is also a good idea to leave an inch or two of room at the top of the barrel to allow for expansion and contraction as water temperatures change. Also, leave the plugs (or bungs) out of the barrels for the same reason.

Q. ***What other containers can be used for water storage?***

A. Water can be stored in grease and chemical drums (make sure they're clean before use), 5-gallon oil or honey containers, and numerous plastic containers such as milk jugs and 2-liter soda pop containers. Most recycled plastic containers get brittle with age, particularly when exposed to direct sunlight, so be prepared to replace them every few years. Glass containers (gallon jugs, etc.) are also suitable if the greenhouse temperatures do not drop below freezing and they are properly stored to prevent breakage.

Fiberglass water storage containers, in many different shapes and sizes, are commercially available. These containers are generally sturdy and can be quite stylish, but they are expensive. Early versions of these containers were sometimes prone to leaks, but the containers on the market today appear to perform very well.

Q. ***How much thermal storage is needed?***

A. The amount of thermal storage required in a horticultural greenhouse depends to a large extent on whether the greenhouse will be used for year-round food production. It is possible to design and build a greenhouse that is almost 100 percent solar reliant even in severe northern climates. However, most greenhouses have just enough thermal storage to survive one or perhaps two cloudy winter days without back-up heat. The following chart (Figure 3.1) provides a useful rule of thumb for determining the volume of thermal storage required.

Q. ***What is the best back-up heating system?***

A. Electric space heaters are probably the most common source of back-up heat for solar greenhouses. They are inexpensive to purchase and convenient to operate. But, if they are used extensively they can be expensive, because electricity is the highest priced fuel in most places. When shopping for an electric space heater, be sure to buy one with a fan so that the heat can be moved throughout the greenhouse.

Several grantees used wood stoves for back-up heat. They can perform well in a greenhouse, but there are several points to consider. First, a good, energy-efficient wood stove is expensive. Cheaper, "sheet metal" stoves are not very durable, nor will

		For Season Extension		For Year-Round Growing	
		WATER gallons/ft² 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	2⅓	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

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Figure 3.1 Greenhouse thermal storage requirements.

they burn all night. The length of burn for a woodstove is critical because the coldest time of the day is usually just before dawn—a terrible time to get up and build or stoke a fire. Wood is also becoming more expensive, in some places, as expensive per British thermal unit as other conventional fuels.

Woodstoves are also more difficult to regulate than other heat sources. A wood stove can't be set to come on when the air temperature in the greenhouse drops to 40°F or so. Thus, wood stoves often provide either too much or not enough back-up heat. Finally, a woodstove and stove pipe should be kept at least 3 feet away from all plants. This distance can be reduced by one half if the stove and pipe are shielded from the plants with some sort of non-flammable material such as sheet metal, bricks, or aluminum foil.

Combustion-type space heaters that burn natural gas, propane, fuel oil, or kerosene are commonly used to heat commercial greenhouses. They are less common in solar greenhouses. These heaters are usually cheaper to operate than electric heaters and since they can be controlled with a thermostat, they are more convenient and easier to operate than wood. All fuel-burning heaters *must* be vented to the outdoors. Combustion pollutants can harm plants as well as people. Also, compliance with fire codes and safety precautions is critical when using combustion appliances in greenhouses.

Q. *How much back-up heat will a greenhouse need?*

A. It depends primarily on the local climate and the amount of thermal storage in the greenhouse. Climatic factors include both the severity and length of the winter, the degree of cloudiness, and the prevailing wind speed and direction. Of course, these factors vary with each site, but for sizing back-up heat, it is probably adequate to divide the United States into warm, temperate, and cold climate zones. Assuming the greenhouse has enough thermal storage, the following chart (Figure 3.2) indicates the amount of back-up heat required. The chart gives the minimum number of watts of electric heat needed per square foot of greenhouse glazing. (A note tells how to use this chart to determine the demand for other kinds of fuel.)

Q. *Can natural ventilation be used to control greenhouse temperatures?*

A. Inadequate ventilation is one of most common greenhouse problems. Greenhouses can be ventilated either mechanically or passively (naturally). The key is to ventilate enough.

Many greenhouse designers prefer natural ventilation, but, as many grantees discovered, sizing errors are much more common with this approach. As a rule of thumb, the total vent area for a natural ventilation system should be about 1/6 of the floor area with the upper vents 20 to 30 percent larger than the lower ones. Natural ventilation systems commonly use doors, operable windows, and vent openings. The rate of air flow through these openings varies, and the total vent area has to be large enough to move some air, even on hot, windless days. In naturally windy areas, vents installed on the windward and leeward sides of the greenhouse can provide natural cross ventilation.

If winds are variable and likely to be calm during many summer days, natural ventilation will have to be induced using the stack effect. The stack effect relies on the natural buoyancy of warm air. Vents are installed in the east and west ends of the greenhouse and also near the peak of the greenhouse roof (Figure 3.3). (If the greenhouse is more than twice as long as it is wide, some lower vents should also be installed along the south wall.) As the air inside the greenhouse is warmed, it rises and moves out the upper vents while outside air is drawn in the lower vents.

Automatic vent opening devices should be used in any natural ventilation system. They are in place and

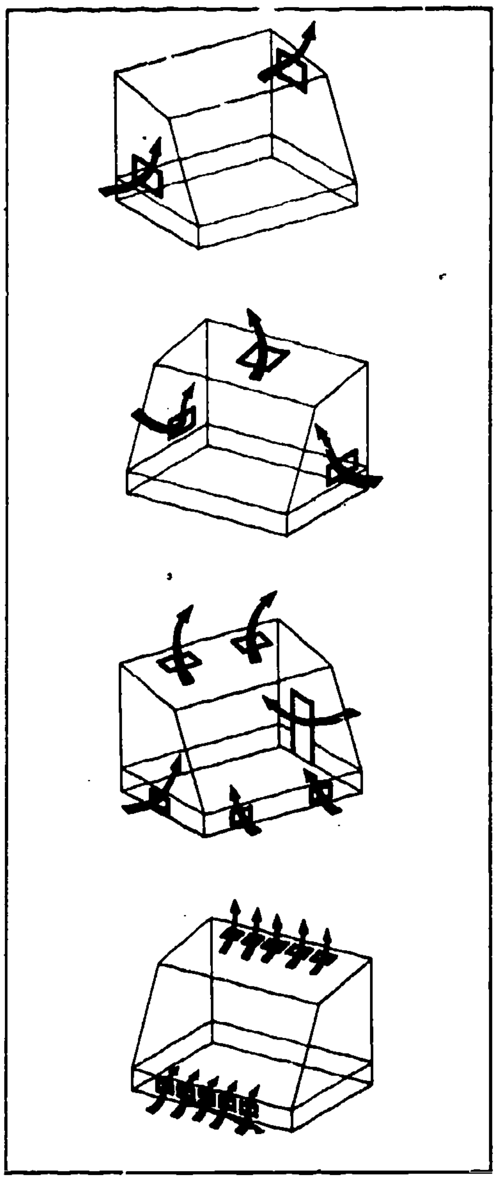

Figure 3.3 There are numerous greenhouse natural ventilation schemes.

		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

To use this chart to size fuel back-up heaters you need to convert watts into Btu's per hour (Btu/h). This is do [illegible] multiplying watts by 3.4. So, if an attached greenhouse required 2,000 watts of electric back-up capacity, you would need a combustion-type space heater sized to provide 6,800 Btu's per hour. This calculation also needs to be adjusted for the efficiency of the particular combustion device being used. To do this divide the number just obtained by the efficiency of the heating device. This can range from greater than .9 (90%) for some radiant kerosene heaters to less than .3 (30%) for some wood stoves. For example, if you are planning to use a propane heater with an efficiency of .7 (70%) for back-up heat and you require 2,000 watts of back-up capacity according to the chart, you would need a heater sized to provide 2,000 x 3.4 divided by .7 or 9,714 Btu's per hour.

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Figure 3.2 Greenhouse back-up heating requirements.

working every day; greenhouse operators are not. All vents should be designed so that they seal well to keep out unwanted air in the winter. Insulated covers for vents help reduce unwanted heat loss.

Several grantees used removable glazing to ventilate greenhouses in warm climates in the summer. The greenhouse is designed so that the glazing can be removed as summer approaches, and the greenhouse then operates as an outdoor garden. The glazing is reinstalled in the fall, and the greenhouse operates in its traditional fashion during the winter. For a system like this, be sure to use a lightweight, unbreakable glazing material and make sure the system seals well to prevent cold air and moisture leaks in the winter.

Q. *Is mechanical ventilation more effective than natural ventilation techniques?*

A. Mechanical or forced ventilation is often more consistent and reliable than passive methods, mechanical systems usually do not draw much current, and they can be fitted with thermostats to operate automatically. In Oregon, a grantee found that passive ventilation was not adequate for good plant growth, and a small fan was added.

A wall-mounted exhaust fan combined with a vent opening on the opposite side of the greenhouse is usually all that is required. Vent opening and exhaust fan covers can be insulated to minimize winter heat loss.

Ventilation rates of about 20 to 30 air changes per hour are often recommended for commercial greenhouses. For energy-conserving solar greenhouses, only one-fourth to one-half of this amount is usually necessary. One common rule of thumb is that for every 1,000 cubic feet of greenhouse volume, roughly 200 cubic feet per minute of fan capacity should be installed.

Q. *Can greenhouses be shaded to control temperatures?*

A. Yes, shading can be effective, and there are a number of shading options. One technique is to use deciduous trees for shade. When the leaves drop in the fall, most of the shading is removed and the sun shines into the greenhouse. However, before you rely on this approach, make sure that the leaves really drop in the fall. One grantee found that the leaves on his oak tree turned brown in the fall, but most of the leaves didn't drop until the spring. The greenhouse remained partially shaded all winter.

Ventilation fans can be fitted with insulated covers to reduce wintertime heat loss.

Climbing or fast-growing vegetation can also be used to shade the greenhouse. Climbing vines such as sweet peas can be trained to climb the south-facing glazing of the greenhouse. In warm and temperate climates, sunflowers grow fast enough and tall enough to provide significant summer shading for a greenhouse.

Another approach is to use roll down exterior shades made of slatted wood, bamboo, aluminum, or woven cloth which are installed near the top of the glazing. They are almost always manually controlled, so the greenhouse operator has to see that the shades are in the proper position. Shading cloths (a greenhouse specialty item) can be used for interior shading. These devices diffuse solar radiation, are relatively inexpensive, and can be left hanging all summer.

Shading paints are also available. They can be painted on the outside of the glazing in any thickness to provide the desired amount of shading. Rain gradually washes the paint off, so in most climates the glazing will be nearly clear again by fall. Residues on the glazing can be washed off with soap and water. Make sure that the shading paint is not toxic to plants which border the greenhouse. Also make sure that the paint is not harmful to the glazing material. For example, whitewash, a lime-based material, can degrade fiber-glass and plexiglass.

Q. *How can humidity be controlled in a horticultural greenhouse?*

A. Summer greenhouses are often too dry, particularly in the Great Plains, Rocky Mountains, and Southwest. In these areas, the increased ventilation necessary for cooling can also dry out the greenhouse. The traditional morning watering may have to be supplemented on some hot, dry days, and particular care must be taken to water regularly.

Conversely, in the wintertime, greenhouse relative humidity levels are typically too high. Condensing moisture, caused when warm humid air flows across a cooler surface such as glass, can drip unwanted moisture onto plants. Water drops on the glazing also reduce the amount of solar radiation that can enter a greenhouse. In addition, water dripping onto sills and other wooden greenhouse structural members can cause rotting.

There are a number of techniques available to reduce high greenhouse humidity levels. One is to limit watering. The more water that is available to evaporate, the higher the relative humidity will be. Here are several rules for watering developed by a grantee in Massachusetts:

- water as infrequently as soil and climatic conditions permit;
- reduce the quantity and frequency of watering in the winter;
- reduce or eliminate watering on dull or overcast days;
- water early in the day before the sun is high.

Ventilation also helps to reduce greenhouse humidity levels. Outside air almost always has less moisture than the air inside a greenhouse. Thus, wintertime ventilation may be required even when interior greenhouse temperatures are low. A fan can be controlled with a humidistat that turns the fan on when the humidity reaches a certain level. But take care, incoming cold air can stress or even freeze plants.

Q. *What can be done to prevent moisture from deteriorating the greenhouse?*

A. Whenever moisture contacts wood surfaces, the potential for degradation exists. Moisture damage is even more of a problem when rot-producing soil organisms are present. An unprotected piece of 2-inch lumber can totally rot away in five years or less.

Pressure-treated lumber, suitable for outdoor use, is a good choice as a structural building material if it will not come in direct contact with plants or soil. Many wood preservatives used in pressure treating are toxic. Copper naphthanate, which is not toxic to plants, does kill some beneficial soil bacteria when it is freshly applied. Urethane and oil-based paints that are free of asphalt, mercury, and lead are good coatings for wood in greenhouses.

The use of white paint inside the greenhouse has the additional benefit of increasing light levels, which can increase plant productivity. Blistered, cracked, or flaking paint should be touched up immediately to prevent much bigger painting and repair jobs later. Cracked, broken, or brittle caulk can be repaired at the same time. If a greenhouse was built with common construction nails (not galvanized), you should also check for any rusting or deterioration, and repair and replace nails as needed.

Planting beds can be preserved by lining the sides of the beds with polyethylene or some other inert plastic material to prevent moist soil from contacting the wooden beds. It's better to use wood scraps as battens when nailing down the plastic. *Do not* cover the bottom of the bed, because this will prevent proper drainage and could lead to root rot.

Q. *What special precautions are necessary when dealing with electricity in a greenhouse?*

A. Common sense is the best precaution. The first rule is to plan for the electrical system as you design the greenhouse. The electrical systems in too many greenhouses are afterthoughts. For example, electrical service has been added in many instances when mechanical ventilation had to be installed after the greenhouse was built.

The second rule is not to skimp on the electrical system. Make sure that the wiring and fixtures are of good quality and suitable for outdoor use. It is also a good idea to install ground fault interrupters. Shorts and electrical fires in solar greenhouses have occured and are dangerous.

Use your head. Don't water thermostats, fans, heaters, switches, junction boxes, or other parts of the electrical system. Also, greenhouse equipment such as exhaust fans and space heaters should be of good quality and properly grounded. Follow the manufacturers' recommendations for use of this equipment. Most manufacturers warn against use in or near water.

Q. *What precautions are necessary for greenhouse plumbing?*

A. Not providing plumbing is a serious mistake. Carrying irrigation water to a greenhouse is no fun at all. One common solution for attached greenhouses is to use an existing outdoor hose bib on the common wall or to install a new one connected to the household plumbing system.

Use good components in a greenhouse plumbing system and have an effective, accessible shut-off valve. Do not rely on a hose nozzle to shut off water. Most nozzles will eventually leak. In northern climates, be sure to provide freeze protection for the plumbing. Locate the plumbing in the warmest area of the greenhouse, and be sure to insulate pipes, particularly if they are run through any unheated spaces. Pay particular attention to the pipes if the house has just been weatherized. Plumbing in an unheated basement or crawlspace that has just been insulated from the rest of the house may freeze now, when it did not before. Again, in colder regions, be sure either to use freeze-resistant hydrants and drain pipes, or install heat tape in the winter. A hard freeze in a solar greenhouse, even one designed for only three-season use, is not a common problem, but it does happen and the results can be disastrous.

Q. *What makes greenhouse structures safe?*

A. Most greenhouse structural safety precautions have to be dealt with at the design stage. These structural safety features are generally specified by building codes. Local building code officials can help to interpret how the codes apply to specific greenhouse and sunspace applications.

There are a few precautions that merit special attention. The first is overhead glass. Use tempered glass in any overhead situation, or better yet substitute fiberglass-reinforced plastic or some other suitable plastic glazing material. Also, make sure the glazing is properly secured and supported. Many glazing materials (especially tempered or thermal pane glass) are very heavy and need to be properly supported.

You also need to make sure that your greenhouse or sunspace is designed to endure any local environmental conditions. Obviously, a greenhouse built in a rainy climate requires special measures to prevent structural damage from rotting. Less obvious, and more commonly overlooked, are the effects of wind and snow. At least two grantees had their greenhouses destroyed by high winds and others had problems with snow (Chapter One). In areas where either heavy snow loads or high winds can be expected, it is critical to make sure the greenhouse or sunspace is properly designed. It may help to have plans reviewed by a structural engineer.

GREENHOUSE MANAGEMENT, MAINTENANCE, AND SAFETY

These DOE projects provide information on greenhouse operation and management.

Kuskokwim solar greenhouse
Lowell Lambert
Aniak, AK

DOE Region X
DOE Grant No. DE-FG51-79R000061
ATMIS ID: AK-79-011

A 900-sq. ft. solar greenhouse was constructed in Aniak, AK. An internal reflector is raised at night to insulate the south glazing. Water storage is in forty 55-gallon drums on the north wall. A wood stove provides back-up heat for extended cloudy or cold periods. The greenhouse extends the local growing season from March through November. Little or no cost or performance data is given in a brief final report.

Solar greenhouse for Sunflower public library
Anice C. Powell
Indianola, MS

DOE Region IV
DOE Grant No. DE-FG44-81R410494
ATMIS ID: MS-81-009

A solar greenhouse (65 sq. ft.) was retrofitted on a small library in Sunflower, MS. The greenhouse functions as an airlock entryway and thermal storage is incorporated in the greenhouse to help supply space heat to the library in the winter. The east and west walls are removed in the summer for ventilation purposes. Limited or no performance data is presented.

Upgrading technical systems of the urban alternative homestead
M.J. Berry White
Louisville, KY

DOE Region IV
DOE Grant No. DE-FG44-80R410312
ATMIS ID: KY-80-011

The grantees implemented technical modifications discovered at the end of their 1979 funded project. Several aspects of the greenhouse and water/space heating systems needed upgrading because of poor design and construction using inadequately skilled labor. Specifically, a shade screen was installed outside the greenhouse for summer cooling and ductwork was installed to move excess heat from the greenhouse to the living space. This grant provided for remedying these technical shortcomings. Costs of materials are presented. No data on changes in performance is reported. Monitoring is planned.

Wintergreen cooperative solar greenhouse
Sheldon Klapper
Orange, MA

DOE Region I
DOE Grant No. DE-FG41-79R110042
ATMIS ID: MA-79-015

A 2800-sq. ft. passive solar community commercial greenhouse was constructed in Orange, MA using volunteer labor and workshops. The final report describes the greenhouse construction sequence and provides operation and management suggestions. About $1000 worth of vegetables and other plants were sold the first year. Thermal performance monitoring of the greenhouse was conducted and a biological pest control program was initiated.

CHAPTER FOUR

THE LIVING GREENHOUSE

A GUIDE TO GROWING PLANTS

Many solar greenhouses have been built primarily for horticultural purposes, particularly food production. But horticultural production, perhaps more than any other use, has been disappointing for owners and operators. The reasons for poor results vary, but a review of the grants indicates several common problems, including designs which don't take into account the biological and environmental needs of plants; a poor understanding of the basic principles of greenhouse horticulture by the grower/operator; and a lack of understanding of the additional time and resources required to operate the greenhouse.

Growing crops in a greenhouse can be challenging for even the most experienced gardener. Although the basic requirements of seeding, watering, cultivating, and harvesting are the same, the greenhouse environment is totally different from the garden. A greenhouse is enclosed and more controllable than a garden. It is also a much more intensive environment than the garden. Plants tend to grow more rapidly, but so do pests and diseases. The grower/operator must strive constantly to maintain control of this highly interrelated environment. In order to maximize production within a limited space, a greenhouse must provide the best possible conditions for plant growth. Thus, a basic understanding of the most critical biological processes and an awareness of the effects of changing environmental conditions on plant growth are essential.

For plants to grow, light, proper temperatures, water, carbon dioxide, and nutrients must be present at the right times and available in the correct amounts. If any one of these is absent or is in short supply, plant growth will be slowed or stop completely. The missing or lacking condition is commonly referred to as the "limiting factor." A review of the basic biological processes of plants will help to better understand how limiting factors affect plant growth.

The following questions and answers address how the greenhouse growing environment with its interrelated conditions can be managed to maintain and improve plant productivity.

Q. ***How can light levels in a solar greenhouse be increased?***

A. Much of the interior of the greenhouse may be shaded at certain times of day if east and west walls are not glazed. The length of the greenhouse determines how much shading will occur in the late afternoon and early mornings if the east and west walls are unglazed. Since many solar greenhouses have solid roofs, the interior may be shaded even more in the late spring, summer, and early fall when the sun is high in the sky. The steeper the glazing and deeper the greenhouse, the more potential for shading exists.

Because of shading problems, many grantees discovered that their solar greenhouses often had insufficient light levels for optimum growing conditions. Light is the source of energy in photosynthesis, and without light, growth stops (see Sidebar: The Basic Processes for Plant Life and Growth). For instance, in warmer months, plants toward the back of the greenhouse often are stressed due to poor light levels. They become ***phototropic*** as they lean toward the south glazing for light. This causes elongated, spindly, sometimes yellowish growth with decreased productivity. Squash plants have been known to break off at ground level due to the combination of heavy fruit and the stretching for light.

The best time to deal with light levels is during design and construction (Chapters One and Two). Be sure to calculate when and where shaded areas will occur within the greenhouse based on the depth, length, and orientation of the structure, the angle of the glazing, and the angle of the sun at different times of the year. (Books cited in Chapter Six provide information on how to do these calculations.) Pay particular attention to late spring, summer, and early fall conditions. If growing areas will be shaded at any time consider the following:

- Add glazing overhead. This is most helpful for summer conditions, especially in deeper greenhouses with steep glazing angles. Overhead glazing allows direct sunlight to penetrate farther into the interior. Insulating panels should be used to cover this glazing during late fall, winter, and early spring.

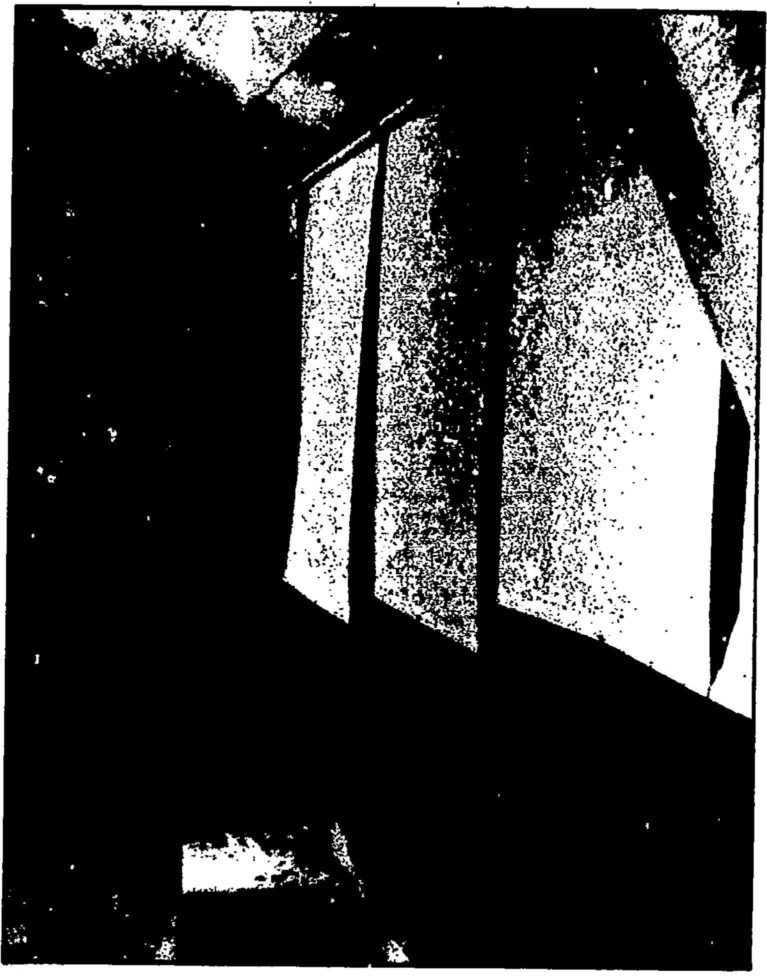
- Add glazing on the east and/or west walls. This will reduce early morning and late afternoon shadows. If only one end wall is glazed, it is generally better to glaze the east end which allows the greenhouse to warm up quickly in the mornings. The shorter the greenhouse is, the more the east and west walls will shade the interior. If a greenhouse is less than 12 feet long, both end walls probably should be glazed.

- The type of glazing material will affect the amount of light within the greenhouse. Some glazing materials such as fiber-reinforced plastics diffuse (scatter) the light better than other glazings. This helps to brighten otherwise shaded areas, and most plants do well in a strong diffuse light.

- To diffuse light even more, paint all interior walls white. (Be sure to use lead-free paint.) In the summer months, hanging a white curtain or other reflective material over the dark thermal mass in the greenhouse will also increase diffuse light levels.

- Plan your growing areas to minimize shading. Beds and benches should be placed where they will receive the most light. In a greenhouse with a kneewall, the beds or benches should be at least as high as the kneewall to prevent shading this prime growing area. As a grantee in Maine reports, place crops so that taller and vining plants are toward the back or east and west sides of the greenhouse so they won't shade other plants.

Overhead glazing lets in additional light when the sun is high in the sky in the summer.



A white curtain or blind installed in front of dark colored thermal mass can reflect light back on the growing beds.

THE BASIC PROCESSES FOR PLANT LIFE AND GROWTH

Sometimes described as the most important chemical reaction in the world, [illegible]. Simply put, photosynthesis is the combination of water and carbon dioxide in the presence of light to produce the carbohydrates necessary for plant growth. Water, carbon dioxide, and light must all be available in the proper proportions or the process of carbohydrate production slows or stops. Consequently, photosynthesis stops at night when there is no light.

During *respiration*, which occurs continually, the carbohydrates produced by photosynthesis combine with oxygen to produce new cells. Generally, higher temperatures increase the rate of respiration and lower temperatures slow it.

Transpiration is the loss of water through small openings, called *stomates*, in the surface of the leaf. Under normal conditions, stomates remain open in the presence of light and allow carbon dioxide to enter the leaf for photosynthesis. When certain environmental conditions exist, such as high temperatures, low humidity, or lack of water at the roots, the plant may lose too much water through transpiration. This results in wilting, a protective response which causes the stomates to close and photosynthesis to cease.

Q. *Is supplemental lighting effective?*

A. Yes. Many vegetables need a minimum of eight hours of daylight to grow and produce properly. In many northern climates this amount of sunlight is simply not available in the winter and supplemental lighting can be used to increase plant productivity. Lights can be used to start warm weather seedlings very early (January). According to a grantee in Massachusetts, fluorescent lamps—the standard white metal light fixtures with 48-inch "cool white" or "warm white" fluorescent tubes—can be used as grow lights. Both "cool" and "warm" fluorescent tubes are often used in the same fixture. These lights are typically 80-watt systems and cost between $20 and $60 per fixture. For growing seedlings, these lights should be installed within 3 to 5 inches of the tops of the seedlings. They need to be operated for only a few hours per day on overcast winter or early spring days. The result will be healthier, stockier plants.

Q. *How can the growing area of a greenhouse be used most effectively?*

A. One of the major goals of greenhouse designers and growers has been to get better use out of the space inside a greenhouse. Some experts suggest that about 70 percent of the floorspace of a greenhouse can be used as growing area. But the experience of grantees has shown that only 50 percent or less of the total floor area commonly is used for plant production. This is fine if the principal purpose of the greenhouse is for heat production, living space or recreation, but a much more effective use of space is required if the primary purpose is horticultural production.

There are a number of ways to use space more effectively. First, consider thermal storage containers. The common 55-gallon drum takes up a lot of space, but can be used to support growing containers or benches (Figure 4.1). Raised beds are another good way to use space effectively, because the area under the bed platforms can be used to store supplies or for thermal storage units. The walkways between the beds can also be narrower. Raised beds are also much easier and more convenient to work with than growing at ground level. Large pots, buckets and soil-filled drums can be tucked away in otherwise unused locations to provide additional growing space.

As a rule of thumb, the deeper the bed (up to about 2 feet), the better the plant growth. Raised beds, as with all growing containers, should also contain a few inches of sand and gravel in the bottom to aid in drainage. Drilling 3/4-inch holes in the bottom of the beds or building slotted bottoms are other common drainage techniques.

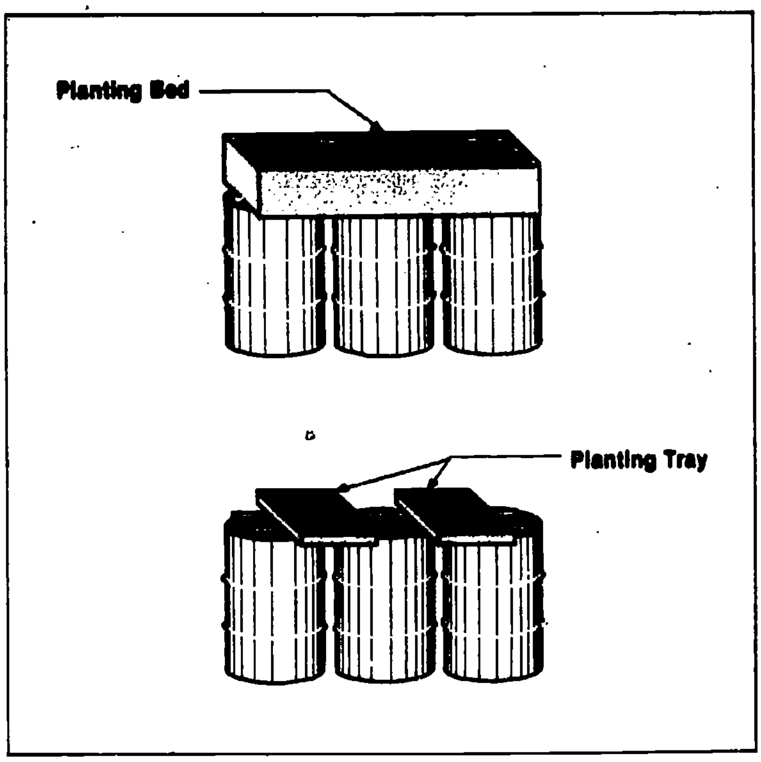


Figure 4.1 Fifty-five-gallon drums can be used to support planting beds and trays.

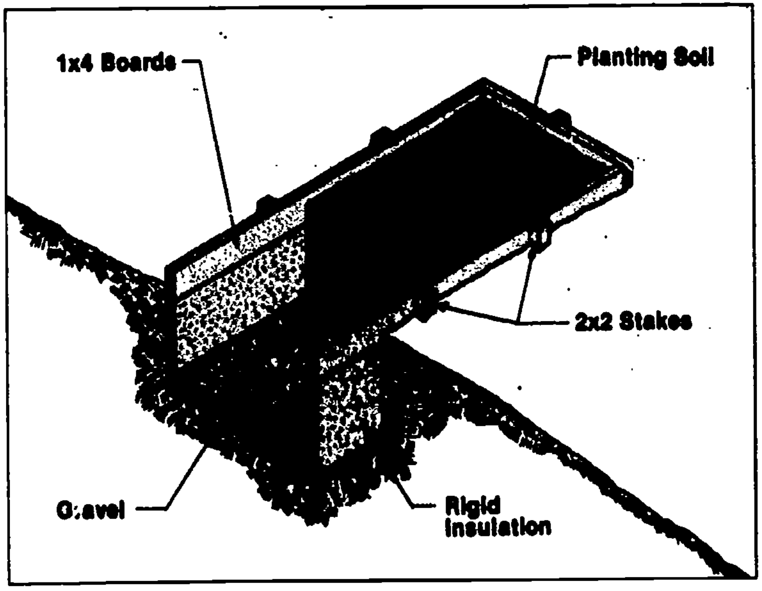


Figure 4.2 Trough growing beds are a good idea when planting at ground level.

Inadequate drainage leads to root rot and poor productivity. If a ground level growing bed is the only thing possible, you still need to provide adequate soil drainage. An insulated trough-type growing bed will function well in these circumstances (Figure 4.2). Also, with a ground level bed you should consider digging out the walkway or installing a kneeling platform to make access to the beds more comfortable.

Finally, greenhouses have quite a bit of vertical space, much of which often goes unused. Always remember potential shading effects, but be imaginative and let things hang or climb. Tomatoes and cucumbers in particular can be trained to climb to the ceiling rather than sprawl all over the growing bed and around other plants.

Think about ways to get tools up and out of the way. Many greenhouses have "air-lock entries" or vestibules incorporated in their designs to conserve energy. These are ideal areas to store tools and supplies. Keeping tools and supplies up and out of the way will reduce clutter and hazards. They are also great potting rooms during most of the year.

Q. *What are the seasonal differences in greenhouse growing practices?*

A. Summer in the greenhouse is characterized by long, hot days with lots of bright light (assuming the greenhouse is properly designed). In colder climates and higher elevations, the greenhouse can produce heat- and light-loving plants without damage from frost or hail. In warmer climates where outdoor gardens are in full swing, this may be the ideal time to clean and sterilize the greenhouse by allowing it to heat up to high temperatures while it is empty. A grantee in North Carolina successfully used this process, sealing the greenhouse for 4 to 7 days in the peak of the summer. Temperatures rose to between 120°F and 140°F and killed most disease-causing spores and insects.

Fall is a transition season. Summer crops can still produce well late into the fall. Several crops do well in the fall greenhouse and can be used as filler crops if transplants are ready to go in when summer crops such as tomatoes and cucumbers are pulled out. These fall vegetables include broccoli, cauliflower, chinese greens, lettuces, and chard. Spinach, beets and radishes are also suitable and should be seeded directly.

Late fall is the time to establish winter crops if the greenhouse will be used year round. The timing depends on the particular climate and greenhouse and is best determined by experience. Grantees in Maine and Michigan discovered that getting winter vegetables close to maturity before the coldest weather sets in is the key to winter greenhouse production.

Plant growth is often very slow in the winter due to the low temperatures and low light levels. Freezing temperatures inside northern greenhouses are not uncommon if back-up heat is not used. Without supplemental light and heat, the choice of crops is usually reduced to the most hardy vegetables: the leafy greens such as chard, kale, parsley, chinese greens, leaf lettuce, endive, mustard greens, and beet greens. Green onions, brussel sprouts, collards, and chicory are also suitable winter crops. Occasionally, crops such as carrots and peas are seeded in the fall and held over for spring production.

The spring greenhouse season is characterized by increasing light levels. Early spring can still be cold, but more light means increased production. As temperatures begin to warm up, vegetables such as squash, carrots, peas, and beans can be started. Seedlings for the outdoor garden and the summer greenhouse are usually given a high priority in the spring greenhouse.

Q. *What plant varieties are best in greenhouses?*

A. Because of light limitations and widely fluctuating temperatures, not all plants do well in the solar greenhouse. In addition, of the crops that do tolerate these conditions, some varieties produce better than others in different areas. Figure 4.3 shows the recommendations of a grantee in Massachusetts. (For NCAT's greenhouse growing experience in Butte, Montana, see *Thermal Performance. . .* cited in Chapter Six.)

Q. *Does greenhouse growing require any special soil mixture?*

A. Generally, yes. While the subject of greenhouse soil mixtures is very complex and different crops may require different soil compositions, one very important characteristic stands out. Greenhouse soils should be light and well aerated. One popular soil mix that drains well yet retains adequate moisture is two parts of good garden soil (black dirt), one part sand or perlite, and one part organic matter such as peat moss, compost, or well-rotted manure.

Earthworms also help aerate the soil. They multiply rapidly and will greatly improve the quality of greenhouse soil. Try bringing in earthworms from outdoors or buy your own crop in bulk from a fishing bait dealer.

Lettuce		
Type	**Variety**	**Characteristics**
Leaf	Salad Bowl	*Heat and cold tolerant, doesn't become bitter*
Leaf	Grand Rapids Forcing	*Excellent for winter and early spring*
Leaf	Grand Rapids	*Tip Burn Tolerant, very heat tolerant*
Leaf	Waldman's Dark Green	*Larger leaves, darker green*
Butterhead	Reine-des-Glaces	*Very slow to bolt, good heat tolerance*
Butterhead	Ostinata	*European greenhouse variety, heat tolerant*
Butterhead	Capitan	*European greenhouse variety, year round*
Romaine	Winter Density	*Suited to fall/winter conditions*
Romaine	Blonde Maraichere	*European variety, delicate taste*

Tomatoes	
Variety	**Characteristics**
Floramerica	*Self-topping (determinate), very disease resistant, excellent yield*
Gurney Girl	*Medium-large fruit, good resistance, very good taste*
Jumbo	*Medium-large, disease tolerant, some green shoulder*
Michigan-Ohio	*Medium fruit, resistant to Fusarium wilt, needs high light*
Moira	*Determinate, medium small, no green shoulder*
Tropic	*Large red fruit, resistant to Verticillium and Fusarium wilt*
Vendor	*Medium-large, very good disease resistance, good in low light*

Figure 4.3 Recommended greenhouse vegetable varieties for Massachusetts. Source: Klein, Miriam and Ron Alward, **Community Greenhouse Workbook,** ***Module III, Commonwealth of Massachusetts, Executive Office of Communities and Development.***

Q. *Is fertilization important for greenhouse growing?*

A. A well-regulated fertilization program is critical because greenhouse plant production is both continuous and intense. There are two basic ways to supply nutrients to plants in the greenhouse. The first method is to use commercially available inorganic chemical fertilizers. Inorganic fertilizers are available in precisely calculated strengths and are labeled according to their nitrogen (N), phosphorus(P), and potassium (K) contents. For example, a 10-10-10 fertilizer is 10 percent nitrogen, 10 percent phosphorus, and 10 percent potassium. These fertilizers are easy to use and are readily available at hardware stores, garden shops, nurseries, and greenhouse supply companies. Instructions for use are usually included on the fertilizer container.

The other approach is to maintain soil fertility with organic amendments. The key to this approach is maintenance. Many novice greenhouse organic gardeners tend to overlook the need to constantly test and amend their soils. Soil should be tested for the major nutrients (nitrogen, phosphorus, and potassium) and pH (the measure of the soil acidity) at least every six months and replenished as needed. Nitrogen, phosphorus, and potassium are the nutrients that are consumed in the largest quantities by plants and therefore are quickly depleted during intensive production. Maintaining proper pH levels (most vegetables prefer a range of 5.5 to 7.0) is also important because extreme acidity or alkalinity will affect the availability of nutrients to the plants.

The best (and cheapest) organic amendment is thoroughly decomposed compost. Well-rotted manures are also good. But as a grantee in Michigan noted, make sure the manure really is well rotted. Fresh manure will heat up in the soil as it decomposes and actually deplete the soil of nitrogen. Two to three inches of both compost and well-rotted manure can be added to the soil beds between plantings. Other forms of organic soil amendments include blood meal, bone meal, rock phosphate, fish emulsion, liquid seaweed, and wood ash. As noted on the package, each of these has particular strengths as far as N,P, and K are concerned. These organic amendments are often available where inorganic fertilizers are sold.

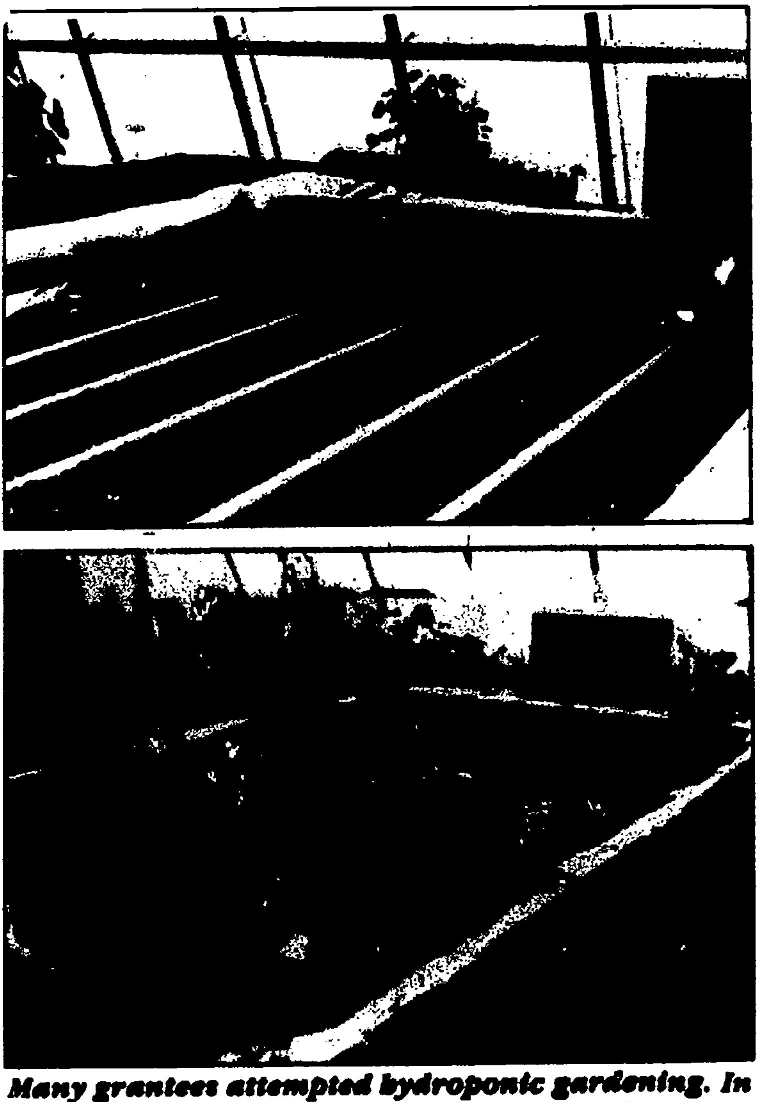
Q. ***Are hydroponics a good choice for the beginning greenhouse gardener?***

A. Probably not, because there is a certain "art" to hydroponic gardening. Hydroponics is the technique of growing plants in a soilless medium such as sand, gravel, or perlite. These inorganic substances act only as root supports for the plants. Nutrients, either organic or commercially prepared inorganic mixtures, are supplied to the plants by a system of irrigation usually run by pumps with timing devices. Most grantees who experimented with hydroponics were unsuccessful. However, hydroponic production can be fun if you like to play with gadgetry or enjoy a more high-tech approach to food production.

Successful hydroponic food production does have several advantages over soil culture.

- With a sterile growing medium there will be no problems with soil-borne diseases and no soil to amend.
- No weeding, watering, or cultivation is necessary.
- The use of commercially prepared fertilizer mixes ensures that nutrient requirements are met as long as directions are followed carefully.
- Automation saves time and labor once the system is set up.

However, there are additional costs of pumps, timers, piping, and tubing, and mixing containers, as well as the costs of maintaining the equipment that also have to be considered before you decide to install a hydroponic gardening system. Grantees found that hydroponic systems can be expensive.



Many grantees attempted hydroponic gardening. In this experimental system nutrients are circulated through perforated tubes located 8 inches below the surface of the gravel bed.

Q. ***How can greenhouse pests and diseases be prevented?***

A. They can't. Sooner or later pests and/or diseases will appear, even in the best managed greenhouse. The combination of three conditions leads to problems: the presence of a pest or pathogen, the proper environment, and a susceptible plant. Prevention of these conditions is always the best way to avoid problems, but it is not always easy to achieve.

The best way to deal with pest and disease problems is to be prepared with information and control techniques. Spend some time before problems arise learning about the most prevalent greenhouse diseases and how to recognize the most common greenhouse pests. Then find out what kinds of control techniques are available. Most importantly, spend time observing—really looking—at what is happening in the greenhouse. Don't disregard anything or assume that you know what is going on. Look at every brown spot, every wilted leaf and blemish. Look in all the corners, nooks, and crannies of the greenhouse for possible pest populations. When you suspect a problem, try to identify it. Seek help from books, experienced growers, or your local extension agent or agriculture school experts. Then determine what control technique(s) can be used.

The most common greenhouse pests are aphids, whiteflies, spider mites, mealybugs, scale, caterpillar-type worms, snails, and slugs. Controls for these invaders can vary from the most direct physical methods (handpicking and smashing), to spraying with chemicals or using biological control techniques. Biological controls include the use of insect predators and parasites as well as bacterial and fungous agents.

To use biological control techniques effectively, it is important to understand the environmental conditions necessary to establish and maintain a population of beneficial insects. Generally, high temperatures (over 90°) are detrimental to most insects, and all beneficial insects need a pesticide-free environment. Most insectories which supply beneficial insects will send along information about their handling, the conditions they need to thrive, and how to introduce them into the environment. (Be sure to request this information if it is not made available to you.) Ladybugs, for example, should be released in a greenhouse in the evenings or on cloudy days to allow them some time to get settled in their new home. If they are released on bright days, ladybugs will fly to the glazing and usually die as a result; this happened to a grantee in Michigan.

GREENHOUSE HORTICULTURE

Here are [illegible] examples of DOE Appropriate Technology projects which paid particular attention to greenhouse horticulture.

Community greenhouse handbook
Theodore [illegible] Live
Boston, MA
DOE Region I
DOE Grant No. DE-FG41-80R110420
ATMIS ID: MA-80-015

A detailed community solar greenhouse manual was prepared under this grant. The horticultural information is useful to all greenhouse operators, large or small. The manual addresses such topics as organization, management, finances, and crops. The information provided is comprehensive and highly useful. This three-volume series should be carefully reviewed by anyone considering establishing a community solar greenhouse.

Monitoring and evaluation of a passive solar greenhouse/aquaculture system
Bill Head
Eugene, OR
DOE Region X
DOE Grant No. DE-FG51-79R000065
ATMIS ID: OR-79-006

A greenhouse with aquaculture tanks in Eugene, OR was monitored for air, water, and soil temperature regimes. Locally produced [illegible], duckweed, earthworms, leaves, and comfrey were evaluated and utilized in fish production studies with African perch, channel catfish, and carp. Plant production and succession studies were conducted in the solar greenhouse, three coldframes, and a PVC-covered cloche. A very detailed report was prepared with performance data, drawings, and much more. The horticultural research indicates that year-round vegetable production in coldframes is possible in the Pacific Northwest.

Four Leaf Farm solar greenhouse
Timothy McAllen
Durham, NC
DOE Region IV
DOE Grant No. DE-FG44-80R410140
ATMIS ID: NC-79-009

A low-cost commercial solar greenhouse was constructed near Durham, NC. The 800-sq. ft. greenhouse is used to grow bedding plants and vegetable starts in the spring, tomatoes and cucumbers in the fall, and forced bulbs in the winter without the use of supplemental heat. The glazed area is 500 sq. ft. of 6-mil greenhouse polyethylene plastic. Two layers of glazing are separated by air blown from a 1/125 hp fan. Limited horticultural management information is provided in the final report.

Vermont News Guide solar greenhouse project
Glen W. [illegible]
Pawlet, VT
DOE Region I
DOE Grant No. DE-FG41-R110009
ATMIS ID: VT-79-[illegible]

A demonstration solar greenhouse in Pawlet, VT was monitored and used to generate interest in solar energy. Fifty weekly newspaper columns were written covering: 1) year-round greenhouse use and winter production; 2) practical solar space heating; 3) solar greenhouse products, sources, and techniques; 4) energy conservation. A solar slide show was given to about 1,000 people.

Urban Options cooperative solar greenhouse demonstration
East Lansing, MI
DOE Region V
DOE Grant No. DE-FG02-79R510128
ATMIS ID: MI-79-[illegible]

A [illegible] greenhouse was [illegible] to the Energy Demonstration [illegible] in East Lansing, MI. The greenhouse was [illegible]. Various vegetables were [illegible] used for [illegible] of the greenhouse. A [illegible] system was also installed. [illegible] payback is estimated at 3-5 years [illegible].

CHAPTER FIVE

SPREADING THE WORD

GREENHOUSE AND SUNSPACE CONSTRUCTION WORKSHOPS

Solar greenhouses and sunspaces, perhaps more than any other type of appropriate technology, have been widely disseminated through community workshop education. Some examples would be a group of local citizens gathering for a weekend, "barn-raising" of a greenhouse on the side of the town hall; food co-op members adding some growing space to a community store; or a group of city workers installing a sunspace on an elderly couple's home.

Construction workshops sponsored by DOE grantees have produced more than 100 greenhouses and sunspaces attached to a variety of buildings under various conditions: homes, community energy centers, public schools, university experimental farm units, environmental education centers, correction facilities, and several other local and state government buildings. These, and thousands more, have been built with an emphasis on community education and they demonstrate that solar greenhouse/sunspace technology can be effectively transferred through workshops. However, this transfer process does not always occur smoothly.

Collectively, the grantees learned a great deal about educating adults in hands-on, community construction workshops. The goal is to teach workshop participants enough about design, materials selection, and construction techniques so they can build their own greenhouses and then teach others their new skills. This strategy employs what is known as the multiplier effect, and it is intended to promote the construction of other greenhouses as a result of the community workshop. For example, one California project resulted in an average of twelve greenhouses being built for each of six workshops held.

Grantees from Vermont, Arkansas, Kansas, Washington, and California documented (based on limited monitoring periods) that from two to six additional greenhouses were constructed in the community for each greenhouse built in a workshop. A grantee from Connecticut reported that the publicity surrounding the success of his greenhouse project led to the funding of several additional greenhouses in the area.

Not all workshops have been unqualified successes, and some have failed. Many of the problems that have been mentioned previously in this publication, have affected greenhouses and sunspaces built under community or workshop conditions. In addition, certain problems associated with doing anything with groups of people have affected project successes.

The information that follows addresses several of the more important considerations when planning and conducting solar greenhouse/sunspace construction workshops. The lessons learned can be instrumental in future successes.

The effectiveness of workshops is multiplied when participants return home to build their own greenhouses or sunspaces.

Q. *How should community greenhouse/sunspace workshops be publicized?*

A. The greater the turnout for a community workshop the greater the likelihood that active participants will go on to build a large number of greenhouses or sunspaces. Publicity can be critical. Sponsors can use formal media such as television, radio, and newspapers, or informal media such as flyers, posters, newsletters, and word of mouth. The appropriate balance of publicity methods will differ from place to place based on the purpose and audience of the workshop and the characteristics of the community. It is always helpful to study the publicity efforts for other similar events in the local community.

A California grantee analyzed the effectiveness of his publicity efforts. He asked participants where they found out about the workshops, and the results are interesting: 47 percent read about them in the newspaper, 23 percent heard about them from friends, 13 percent from the flyer/poster, 6 percent from television, and 10 percent from other sources. The point is to use a variety of publicity means.

Also, timing is important in all publicity efforts. The day after a television story about the California project, over 50 people attended one of the workshops. However, attendance was down the next week, and stayed down until local newspapers began printing stories about the project. The grantee also collaborated with the producer of a community-owned television station to develop a videotape show about the project, which could be used to publicize subsequent workshops.

Both formal and informal media are excellent ways to publicize a workshop, and it always helps to know somebody. Another grantee in California reported that personal contact with a media representative well in advance of construction workshops proved invaluable. The media representative became familiar with the project and supported it with his coverage.

Q. *What are the most important considerations when designing community education programs?*

A. People may know how much time and effort it takes to prepare successful educational activities for children. These same people often don't realize that planning effective community education programs for adults often requires even more effort. Adults tend to have clearer expectations than children, and it is vital that the workshops be carefully designed and implemented with the specific audience in mind.

In Georgia, a grantee who developed a community education program for low-income adults found that understanding the education and achievement levels of the audience was essential when selecting or developing suitable educational materials to be used in the workshop. The grantee found that most of the available materials were written for literate, well-educated readers, and were hard to adapt for individuals with limited education. Like the Georgia workshop participants, those who could benefit most from the use of solar greenhouses and sunspaces are those without the reading skills to understand most of the materials presently available.

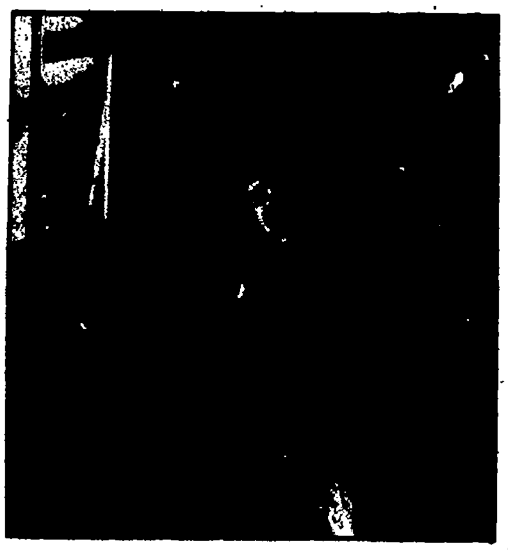
Another important element in designing a community workshop is evaluation. The California grantee who studied publicity efforts also used extensive evaluation after the workshop to find out how much the participants had learned and what recommendations they had for improving the program. Because of the evaluation response, subsequent workshops were modified and improved.

Several other grantees recommended that a brief evening program should precede the hands-on construction workshops. At the evening sessions, participants learned about solar theory and design, and materials. While these important topics were touched on during construction, grantees felt that the evening sessions provided a needed opportunity to ask questions and really learn the necessary background information. The evening session also left more time to concentrate on construction skills during the hands-on workshop session.

Q. *How long does it take to complete a greenhouse or sunspace in a community workshop?*

A. A primary goal of most community workshops is to teach skills through hands-on experience. That goal is not exactly consistent with an efficient construction job. It is a common myth that a greenhouse can be built in one weekend by a group of largely non-skilled people. No matter how many skilled people participate or how well the event is organized, greenhouses simply cannot be completely built in a weekend.

The most successful projects constructed simple structures that required minimal construction skills. Other grantees built more substantial structures that required more time and sophisticated skills. But in both cases, construction took considerably longer than anticipated.



It is vital that workshops be carefully designed and implemented with the specific audience in mind.

Generally, grantees reported that greenhouses were approximately 60 to 90 percent complete at the end of a two-day workshop. A sophisticated greenhouse design was built in Michigan that took 1,000 hours to complete, and the workshop coordinator now stresses the need to plan for additional labor, perhaps by extending the workshop beyond a single weekend.

It is important to understand both how much time will be required during the workshops and how much time will be required to finish the greenhouse after the workshop is over. Grantees in California and Connecticut left final construction details to the homeowners, and found that this approach was usually unsuccessful because the homeowners had other time commitments and lacked adequate skills. In fact, in California, delays in finishing construction left a greenhouse vulnerable to bad weather, and extensive work was required to repair the damage.

Q. *How should cost estimates for greenhouse materials be figured?*

A. A large number of grantees reported cost overruns. Projects in Rhode Island and Maine found construction costs to be $1,000 higher than original estimates, while another grantee in Maine calculated that costs were 12 percent over original projections. Such overruns occur for two primary reasons. First, many workshop sponsors simply cannot estimate costs as well as solar contractors or other builders. Community groups often underestimate the amount of materials needed to complete a project or forget to incorporate additional costs that frequently arise with retrofit projects.

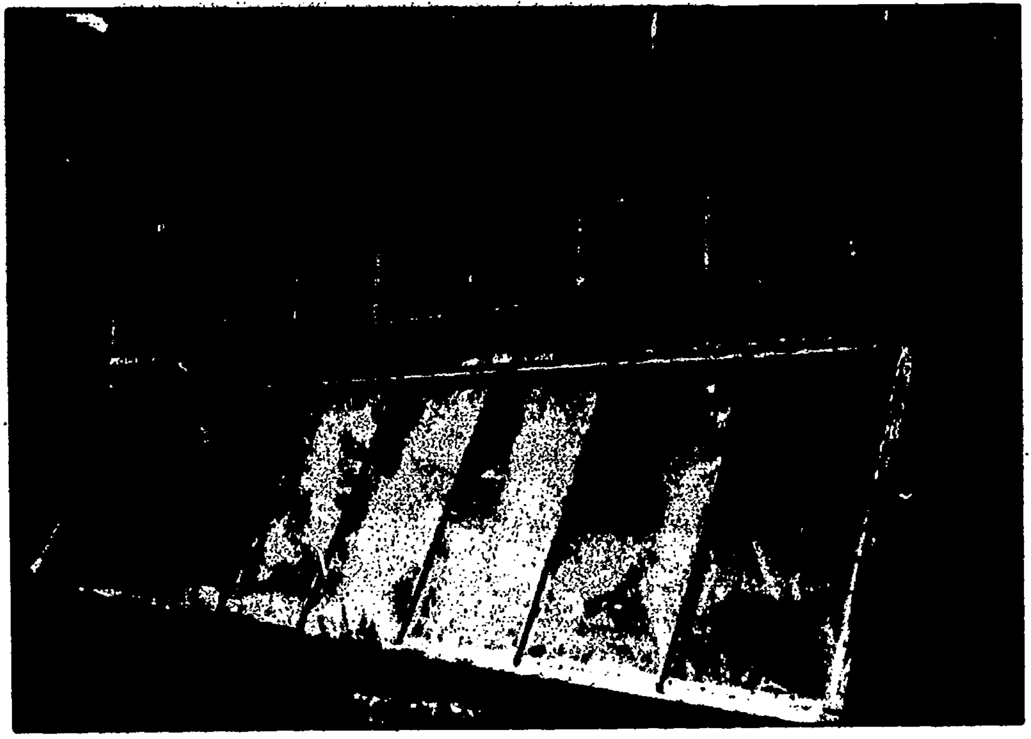
Second, cost estimates are made when funding is applied for or when the greenhouse is first designed, without considering cost increases due to inflation. By the time they were ready to build their greenhouses, grantees in Massachusetts, Kansas, Alabama, West Virginia, and Kentucky found that their original cost projections were too low. An individual can wait until he or she can afford the necessary materials. In a workshop setting, however, scheduling conflicts may make waiting difficult or impossible, leading to cost overruns.

Q. *What problems can occur if more than one funding source is used for a greenhouse/sunspace project?*

A. Many groups need funds from two or more sources to conduct their workshops. Funds for labor might be supplied by one source, materials funds by another. Coordinating a project that relies on multiple funding sources can be difficult. Funding delays at critical times can cripple a project. Several grantees now know that careful planning and effective communications with funding sources are mandatory. It is sometimes impossible for the project organizer to anticipate problems that arise, because the operations of the funding agencies are beyond his or her control. Nonetheless, coordinators must be aware of pitfalls. One Georgia grantee recommends applying only for grants that will cover both materials and labor.

Funding sources usually require detailed accounting and progress reports, and occasionally, for technical projects, systematic monitoring documentation. These requirements can cause problems, as a New Hampshire grantee found out; his proposed project was cut back as a consequence. Again, community organizations often do not have the experience to comply with the expectations of the funding source, and do not realize there are problems until it is too late. Grants documentation requirements can be even more of a problem when the organization is acting on behalf of local families who have even less experience. The community organizations must become familiar with all documentation requirements associated with a grant, and make these requirements clear to all participants as an integral part of the project management process.

Q. *Who should lead greenhouse/sunspace construction activities?*



It is a common myth that a greenhouse can be built in a one-weekend workshop by largely non-skilled people.

A. Solar greenhouses or sunspaces must be carefully constructed. Therefore, the workshop leader must know traditional building construction practices, and be experienced with some of the unique aspects of greenhouse/sunspace construction. A leader who is unfamiliar with carpentry, glazing, and electricity can hamper the construction process and disillusion the volunteers who come to contribute their time and learn new skills. Project organizers must be enthusiastic about their work, but enthusiasm alone is not enough.

Grantees in Massachusetts found that effective construction supervision is critical to the successful completion of the sunspace or greenhouse. Equally important is the fact that the leader must also be a good teacher and have the experience and patience needed to allow people to learn by doing things themselves.

Q. *What problems arise when volunteers are used to build a greenhouse or sunspace?*

A. Workshop volunteers are not just a source of free labor. They expect to work in exchange for new knowledge and skills. By learning these skills, volunteers become more self-reliant, better able to build their own sunspaces or greenhouses, and better able to assist others.

Project organizers must have realistic expectations of volunteers. Skill levels vary considerably among volunteers, and so does interest. In Michigan, 1,600 hours of volunteer work were needed to complete a small greenhouse retrofit of approximately 200 square feet. The volunteers were enthusiastic but often lacked even the most basic carpentry skills. In another project, a Massachusetts grantee found that the construction design was too sophisticated for the average volunteer, and staff members had to complete the greenhouse when volunteer interest waned. Grantees in Louisiana and Missouri also mentioned that the numbers of volunteers dropped off when construction took too long to complete.

In California, a grantee teaching a solar course at a community college discovered that his students could not receive credit for participating in construction workshops, because the construction site was in the jurisdiction of another college. Only the most interested students chose to continue with the project, which drastically reduced the anticipated construction labor pool and lengthened the schedule. This same grantee discovered that students were less likely to do some tasks (hand-digging trenches) than others (attaching the glazing). He eventually had to hire a contractor to complete the trenching.

Several grantees who relied on volunteer labor indicated that, at times, too many volunteers turned out when there were too few tasks while other grantees indicated they had too few volunteers when many hands were needed. These problems have to be addressed with careful management and planning so the right number of workers is available at various stages in the construction process. Such planning is essential if volunteers are to learn the basic skills for greenhouse construction without becoming frustrated or confused.

CONSTRUCTION WORKSHOPS

The following are typical community-based DOE Appropriate Technology projects. They provide information in a broad range of administrative areas.

Solar greenhouse for food and education
Philomena McCarthy
Tacoma, WA

DOE Region X
DOE Grant No. DE-FG51-81R001248
ATMIS ID: WA-81-014

The Sisters of Dominic in Tacoma, WA, received a grant to 1) rehabilitate their traditional greenhouse into a solar-reliant greenhouse, 2) to build two lean-to greenhouses on low-income homes, and 3) to provide educational programs to local residents. The construction of the greenhouses was hampered by few workers and heavy rains. The final report describes some of the difficulties involved in constructing a greenhouse using volunteer labor.

A passive solar retrofit and community
education package for a multi-use
commercial building
John Robinson
Oklahoma City, OK

DOE Region VI
33 OE Grant No. DE-FG46-80R612038
TMIS ID: OK-80-010

A sunspace was constructed on the roof of a multi-use commercial building in Oklahoma City, OK. The sunspace reduces heat loss through the roof during the heating season and reduces heat gain during the cooling season. A thermosiphon domestic hot water heating system was also installed. Solar workshops were given on greenhouses, domestic hot water systems, passive heating and cooling systems, and weatherization.

Kneecap food co-operative solar
greenhouse/garden project
Henry Gould
Providence, RI

DOE Region I
DOE Grant No. DE-FG-79R110019
ATMIS ID: RI-79-007

A solar greenhouse to be used primarily for food production was constructed by volunteers in a community workshop setting. The greenhouse had to be dismantled, however, because the local university sold the land on which the greenhouse was situated. Co-op members plan to use the materials to construct coldframes at a future date.

Solar greenhouse demonstration project
Larry Schaefer
New Haven, CT

DOE Region I
DOE Grant No. DE-FG41-80R110369
ATMIS ID: CT-80-008

A 16 ft. × 28 ft. greenhouse was retrofitted onto a local school. Tours and workshops for a variety of audiences were held (i.e., teachers, commercial greenhouse growers, and the general public). A horticultural vocational program for handicapped children operated in the greenhouse.

Do-it-yourself solar workshop
Dorsey H. Walker
Section, AL

DOE Region IV
DOE Grant No. DE-FG44-80R410226
ATMIS ID: AL-80-005

This project provided do-it-yourself solar appliance construction workshops for the residents of Jackson and DeKalb County, AL. Cooperating agencies included local high schools, the electric utility, low-income organizations, and local churches. Low-interest construction loans were also made available to workshop participants. This project is a successful model of community-based solar greenhouse construction. The techniques demonstrated should be useful in other locations in the United States.

CHAPTER SIX

WHAT OTHER SOURCES OF INFORMATION ARE AVAILABLE?

There are several publications, which are cited later in this chapter, that provide good information on many of the topics presented in this publication. These books, papers, and articles are a good place to start looking for answers to many of the questions that might come up as you design, build, or operate your sunspace or greenhouse.

State energy offices may be able to help with more specific questions. Most of these offices have knowledgeable people who can provide advice directly or provide references to other good sources. In some areas, garden clubs, energy conservation groups, food co-ops, or other community organizations may be helpful. A "fellowship" of greenhouse owners was organized by a grantee in Alabama to share their experiences and information.

In some cases, it may pay to consult a professional. A grantee in New York, who was primarily interested in researching and developing the design for an aquacultural and horticultural greenhouse, found that the construction details took up too much time. She suggested that a professional could have taken care of these details, and she could have concentrated on the broader design questions.

Professional help must be selected carefully. Several grantees had their projects complicated by poor service from contracted help. Remember that not all builders or even architects are familiar with solar greenhouse/sunspace design. Even though greenhouses and sunspaces are simple structures in some respects, they must be thoroughly understood before a good design can be developed. There are people who specialize in solar design who have the knowledge and experience to provide good service. However, don't assume that all "solar" architects or builders automatically provide quality work. Grantees in Maine had to fire their solar consultant halfway through the project. As with the selection of any professional, consider several contractors if possible, ask for references, and visit other greenhouses or sunspaces that they have produced.

If you feel your construction skills are weak, consider taking courses (usually available at night) at a local vocational-technical school before you try to build a greenhouse or sunspace. Courses in carpentry, plumbing, and wiring, designed with the novice adult in mind, are usually available. Your local vocational-technical school can also recommend supplemental reading materials.

There are no books written specifically about greenhouse safety and maintenance. However, most problems can be addressed through proper planning and common sense. Local building code and inspection departments will review plans to make sure designs are safe and meet local specifications. Information on greenhouse safety and maintenance can also probably be obtained from your state energy office, the Agricultural Extension Service, or your county agent.

Help in dealing with horticultural problems can come from many places. Books and other publications, available from many sources, including public libraries, are good sources of information. Greenhouse supply companies and garden shops often have knowledgeable individuals who could answer your questions. Local commercial greenhouse growers and nursery operators are often willing to share their knowledge. And your local cooperative extension agent is paid to aid the public with questions and problems in all areas of agriculture. Many state agriculture schools have horticulture departments which can provide a wealth of information.

Sunspaces and greenhouses must be carefully constructed.

Acquiring your own library of books and other materials is handy for quick reference when problems or questions arise. Here are some items that are particularly useful:

Four books provide good, general background information on solar greenhouses and sunspaces:

Yanda, Bill and Rick Fisher, *The Food and Heat Producing Solar Greenhouse,* John Muir Publications, Inc., Santa Fe, NM, 1980, available in many bookstores.

Greenhouse Gardening, A Sunset Book. Lane Publishing Co., Menlo Park, CA, 1976, available in many bookstores.

James C. McCullagh, ed. *The Solar Greenhouse Book,* Rodale Press, Inc., Emmaus, PA, 1978, available in many bookstores.

Alward, Ron and Andy Shapiro, *Low-Cost Passive Solar Greenhouses: A Design and Construction Guide,* The National Center for Appropriate Technology, Butte, MT, 1980. 173 pp. $7.00. Available from NCAT, P.O. Box 3838, Butte, MT 59702. Also available in many bookstores, published by Charles Scribners and Sons, New York.

Useful information on greenhouse operation and mangement can be found in the following books:

Wolfe, Delores, *Growing Food in Solar Greenhouses,* Dolphin Books, Doubleday & Company, Inc., Garden City, NY, 1981, 192 pp. $10.95. Available in many bookstores.

The introduction to this book describes the greenhouse growing environment and provides management information.

Bartholomew, Mel, *Square Foot Gardening,* Rodale Press, Emmaus, PA, 1981, 345 pp. $9.95. Available in many bookstores. This useful book was written for outdoor gardening but many of the intensive gardening management techniques can also be used in greenhouses.

Klein, Miriam and Ron Alward, *Community Greenhouse Workbook: Where do we go from here?* produced by Commonwealth of Massachusetts, Executive Office of Communities and Development. Available from: The Executive Office of Communities and Development, Attention: Ted Live, 100 Cambridge Street, Room 1103, Boston, MA 02220.

Module II of this three module series produced by a DOE Appropriate Technology grantee focuses on greenhouse design considerations. It also includes a wealth of information on how to manage a greenhouse once it is designed.

Clegg, Peter and Derry Watkins, *The Complete Greenhouse Book,* Garden Way Publishing Co., Charlotte, VT, 1978. 280 pp. $8.95. Available in many bookstores. Interspersed throughout this book is useful information on the management of solar greenhouses. The interior greenhouse environment is carefully described and techniques for managing that environment are provided.

For more information on greenhouse horticulture:

Smith, Shane, *The Bountiful Solar Greenhouse,* John Muir Publications, Inc., Santa Fe, NM, 1982. This is probably the best overall book on solar greenhouse horticulture currently available. It provides both the novice and more experienced greenhouse grower with a wealth of useful information from the author's own experience. It contains a good discussion of individual crops which includes vegetables, fruits, flowers, and herbs.

Mastalerz, John, *The Greenhouse Environment: The Effect of Environmental Factors on Flower Crops,* John Wiley and Sons, Inc., New York, NY, 1977. Although the focus of this book is on flower crops, the general theme of the effects of environmental factors in the greenhouse makes this an extremely valuable reference. This is a text book, so the approach is technical but readable.

Brady, Nyle C., *The Nature and Property of Soils,* MacMillan Publishing Co., New York, NY, 1974. This textbook is a definitive, technical source of information on soils. Anyone seriously interested in learning more about soils should read it.

Brooklyn Botanical Gardens, *Handbook on Biological Control of Plant Pests,* Brooklyn, NY, 1979. This small, nicely done publication with good photographs is a compendium of various articles on biological controls. It is an excellent introduction to the subject.

Yepson, Roger B., ed., *Organic Plant Protection,* Rodale Press, Inc., Emmaus, PA, 1976. Despite the focus on gardening outdoors, this book will provide the greenhouse grower with much useful information for plant protection using non-toxic, environmentally sensitive methods.

Beckford, Elwood and Stuart Dunn, *Lighting for Plant Growth,* The Kent State University Press, Kent, OH, 1972. This is a very technical book which includes excellent discussions of the physiological responses of plants to light such as phototropism and the role of light in photosynthesis. A good portion of the book deals with artificial lighting. The book is valuable to anyone interested in supplemental lighting techniques.

Douglas, James, *Beginner's Guide to Hydroponics,* Drake Publishers, Inc., New York, NY, 1973. This book provides a brief overview of hydroponic growing techniques using chemical fertilizer solutions and includes discussions of appropriate flower and vegetable crops.

Moody, Robert J., John R. McBride, and MacDonald Homer, *Thermal Performance and Horticultural Production of an Attached Solar Greenhouse In a Severe Northern Climate,* National Center for Appropriate Technology, Butte, MT, 1982, in *Proceedings of the Energy '82 Conference,* Regina, Saskatchewan, Canada. This technical paper presents NCAT's experience in operating a small attached solar greenhouse. Information is included on the performance of various varieties in the greenhouse.

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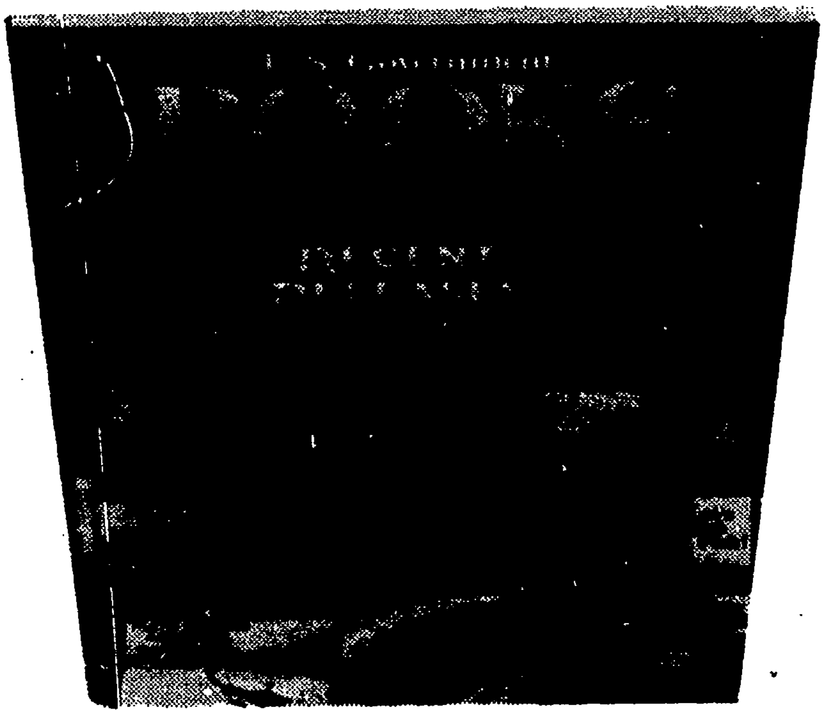

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