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ABSTRACT

Solar retrofits are devices of structures designed to be attached to existing buildings to augment their existing heating sources with solar energy. An investigation of how solar retrofits should be designed to suit the climate and resources of Arkansas is the subject of this report. Following an introduction (section 1), section 2 focuses on solar greenhouses. Topics discussed include the nature of solar greenhouses, site requirements and costs, sun motion and orientation, greenhouse-house connection, glazing, heat storage, winter/summer temperature control, greenhouse gardening, and construction notes. Case studies are also provided. Section 3 focuses on the fundamentals of solar air heaters, including modular solar air heaters, performance, and design methods. Section 4, focusing on batch solar water heaters, includes an introduction, brief history, design, performance, and limitations. Appendices include a glossary, references for solar greenhouses, air heaters and water heaters, lists of solar periodicals and solar information sources, and solar radiation data (including maps for each month, evaluation of solar radiation maps, and such technical information as tilt factors for various regions of Arkansas). (Author/JN)

arkansas solar retrofit guide

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I. INTRODUCTION

The concept of using the sun to heat buildings is an ancient one. The emergence of "solar architecture" is not so much the birth of a new technology as a rebirth of age-old principles. As in the past, the reason for this re-emergence is the high cost of fuel.

The scarcity of trees, which were the primary source of heating fuel in ancient Greece, prompted that culture to utilize solar energy in dramatic ways. Entire cities were oriented to the south to take advantage of the low winter sun. Solar laws were enacted that prevented the construction of a building if it would shade adjacent buildings during the winter months. Similar laws are now being considered in America.

The Romans also had difficulty finding enough wood for heating fuel because they used most of their wood to build ships. Gradually, the high cost of importing wood from distant places prompted the Romans to find solar solutions to their heating needs. When the Romans began to use glass as a window material, solar architecture took a giant leap forward. Many public and private buildings had large south-facing windows to admit and trap solar energy, thus greatly reducing the need for conventional heating fuels. Overhangs above the windows shaded the structures from the high summer sun. Entryways were recessed to protect them from winter winds. The concept of designing buildings in response to natural climatic forces became commonplace.

Today, with our growing scarcity of fossil fuels, we find ourselves in a situation similar to earlier civilizations. About one-third of all energy consumed in the U.S. is used to heat and cool buildings. We have to import one-third of our petroleum, which everybody knows is getting more scarce and more expensive. We have designed nearly all of our buildings with the notion that our energy supply would be forever cheap and plentiful. Architects and planners were not concerned with the orientation of buildings to the sun or with insulation because the cost of heating and cooling was so low. The era of cheap energy is over, but we are stuck with all those inefficient buildings that require enormous amounts of mechanical power (i.e., fossil fuels) to be comfortable.

Energy conservation is an obvious way to reduce energy demand and is much easier and more economical than drilling for more oil or gas or mining more coal. However, after energy conservation measures have been taken, many buildings can be economically adapted to utilize solar energy for space heating or water heating purposes. **Solar retrofits** are devices or structures designed to be attached to existing buildings to augment their existing heating sources with solar energy. The investigation of how solar retrofits should be designed to suit the climate and resources of Arkansas is the subject of this report.

The solar retrofits examined during this project were **greenhouses, air heaters,** and **water heaters.** They all have several things in common other than being "added on" to a building:

1. Through the research and demonstration programs of the Arkansas Energy Office and several community organizations throughout the state, the solar retrofits have been tested and proven to be cost-effective in Arkansas.
2. All are built from locally available building materials and require only basic carpentry and/or plumbing skills to construct. This puts them within reach of many low and middle income people.
3. All of the retrofits qualify the owner for a 40% federal income tax credit and a 100% state income tax deduction.

The majority of solar retrofit demonstration projects in Arkansas have been funded through CETA training programs, the Ozarks Regional Commission, and the Renewable Energy Grant Programs of the Arkansas Energy Office and the U.S. Department of Energy. Agencies such as the Office of Human Concern of Rogers and Community Energy Futures of Little Rock have demonstrated in local workshops held around the state that individuals can easily learn to construct the devices. A variety of solar retrofits have also been developed by other organizations, including Crowley's Ridge Development Council, Crawford-Sebastion Community Development Council, and the Northwest Arkansas Economic Development District. What remains to be developed is a broad understanding of this simple technology among Arkansans.

Most people in Arkansas already feel that solar energy should play a strong roll in their energy future. This was indicated by the *Arkansas Energy/Environmental Survey 1980,* by Dr. John S. Miller, Jerry Donoho and Marvin Orndorff of the University of Arkansas at Little Rock, in which 401 families from throughout the state were interviewed. A convincing 85% of those surveyed favored more solar development, while only 28% favored additional nuclear power plants.

The Arkansas Solar Retrofit Guide was written to take the mystery out of solar energy for those who want to use it in their homes or businesses but do not know how. A composite of successful construction and operation methods is presented in a format to help individuals build solar retrofits for themselves. Also, it is hoped that local businesses will be encouraged to offer solar retrofits as an extension of their existing services. For instance, carpenters and contractors could offer solar greenhouses, plumbers could build solar water heaters, and heating contractors could build solar air heaters. These professions already have all the technical skills necessary to build solar retrofits; they only need to learn how easy and profitable the devices would be to build and install.

Two other publications that are companion texts to this report have been published by the Arkansas Energy Office. The first text, *Solar Greenhouses in Arkansas*, presents a general overview of solar greenhouse concepts. The second text, *Arkansas Climate Atlas*, illustrates in map form the weather statistics of Arkansas, including solar radiation data that is useful for designing any solar application. This solar radiation data, developed by Dr. Dan Turner and I.H. Battle of the University of Arkansas at Fayetteville, has been included in this report as Appendix G.

II. SOLAR GREENHOUSES

A. WHAT IS A SOLAR GREENHOUSE?

Like all greenhouses, a solar greenhouse is a sunny room well suited for growing plants. However, a conventional greenhouse with glass on all sides needs a heating source other than the sun to keep it warm during the winter. The solar greenhouse relies only on the sun to keep itself warm and actually produces excess heat that can be used to help warm a house or other building.

The solar greenhouses described in this report are called "attached" solar greenhouses because they are built onto an existing building. They differ from a conventional greenhouse in several other ways:

1. Most of the glass or other glazing is on the south side, where it collects more energy during the day than it loses at night.
2. A double layer of glazing is often used to reduce heat losses at night.
3. The north wall of the solar greenhouse is attached to the south wall of the house, allowing excess heat to flow from the greenhouse to the house.
4. Heat storage materials such as rocks, containers of water, or concrete blocks are included in the greenhouse to absorb heat from the sun during the day and slowly release it at night to keep the space warm.
5. The east and west walls, roof, and foundation are well insulated to further reduce heat losses.

By orienting the greenhouse to take advantage of natural climatic forces, it can be heated entirely by solar energy. Proper design of the thermal storage and ventilation will ensure adequate light and temperature levels for year-round plant growth.

In winter, the solar greenhouse traps as much solar energy as possible. Some of this heat is absorbed by the thermal storage and some is distributed by natural air convection or a fan through openings to the

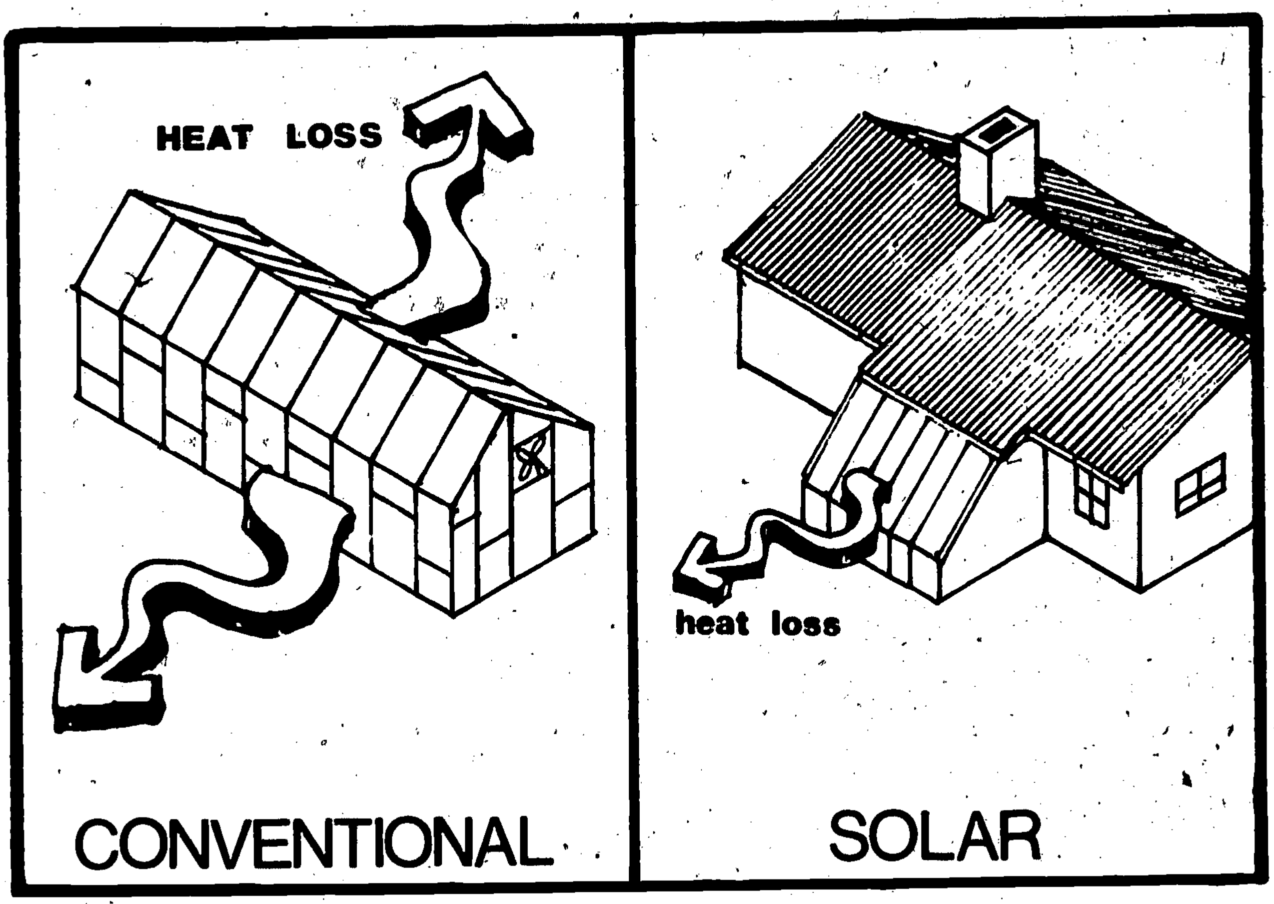


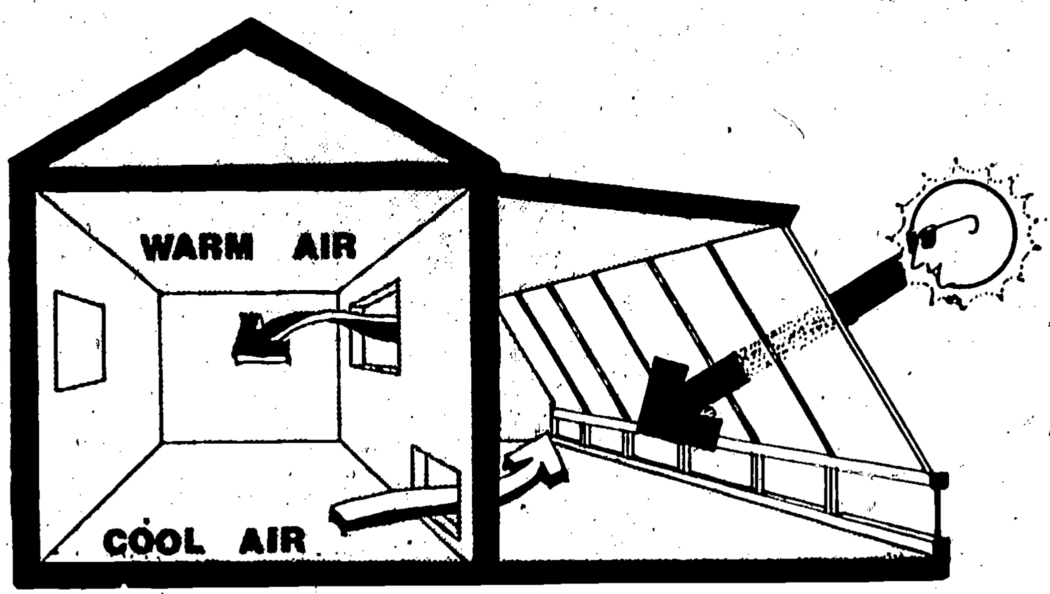
FIG. A-1

house during sunny winter days. The greenhouse also serves a valuable function as an insulator to reduce heat loss from the house to the outdoors at night.

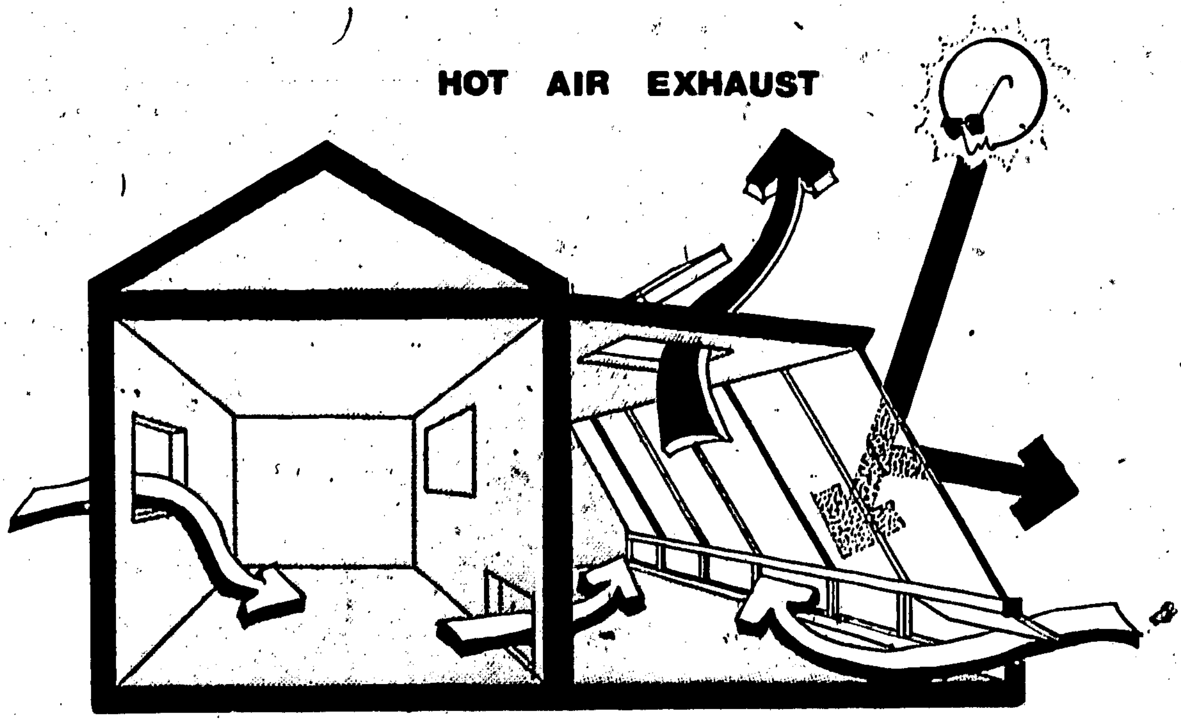
In summer, conventional greenhouses require huge fans to keep cool, whereas solar greenhouses utilize non-mechanical shading and ventilation techniques. Vents to the outside are opened and shading devices are used to keep the space cool. The thermal storage also helps to keep summer temperatures low by absorbing any excess heat within the space. In fact, a properly designed solar greenhouse will be able to produce cool weather crops such as lettuce and spinach during the summer as well as in winter.

This project concerns the appropriate design, construction, and operation of solar greenhouses for Arkansans who will use them for both food and heat. The designs will be somewhat different for people who want to use the room for heating purposes only and not for growing plants. This type of retrofit is called a "sunspace" or "sun room" which could be designed as an entryway, recreation room, garage, and so forth.

Both sunspaces and solar greenhouses trap solar heat and distribute that heat through openings to the



WINTER — Air heated by the sun in the greenhouse flows into the house through upper openings; at the same time, cooler air is drawn from the house through lower openings. A fan may be used to increase the efficiency of the system.



SUMMER — Vents exhaust warm air from the greenhouse, and low-level windows admit cooling breezes.

FIG. A-2

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house, but a solar greenhouse requires more insulation and thermal storage to keep the plants warm at night. Also, specific lighting requirements for the plants and efficient arrangement of planting beds need to be considered in a solar greenhouse.

A solar greenhouse does more than collect solar energy to help heat the house; it also must be designed to meet the particular light and temperature requirement of plants. The most common error in solar greenhouse design is the lack of planning for how and where plants will be grown. Growing beds and shelves are often installed as an afterthought, resulting in a very inefficient use of the space. This can prove to be a costly mistake if you are planning to grow plants for food or for sale. Fig. A-3 illustrates common elements found in solar greenhouses.

FIG. A-3, Next Page

1. outer glazing, 2. inner glazing, 3. knee wall windows, 4. concrete foundation, 5. ground-level plant bed, 6. gravel floor, 7. masonry steps, 8. elevated plant bed, 9. house interior

B. SITE REQUIREMENTS AND COSTS

Before you begin to build a solar greenhouse, you should understand:

1. The solar greenhouse must face within 30 degrees of true south.

2. The site should be relatively free from shading by other buildings, other parts of the house, or evergreen trees. Trees that lose their leaves in the fall (deciduous) are ideal to have close to the greenhouse.

3. Openings such as doors or windows are needed on the south wall of the house where the greenhouse will be attached so that air can circulate to and from the house. If no openings exist, you will have to make openings into the wall for this purpose.

4. You do not need to be a professional carpenter, but you will need to work carefully to make simple measurements, hammer and saw straight, and caulk and paint neatly.

5. Greenhouses require consistent maintenance, including planting, watering and harvesting plants, opening and closing vents, and watching for pests.

6. The average cost of a typical 8 x 16 foot greenhouse as described in this report is $700 ($5.46 per square foot) if it is owner-built. If you hire a carpenter to build the greenhouse, expect to pay about twice that amount. This figure is based upon the assumption that all materials will be bought at 1981 retail prices. If you can use recycled materials or find a good bargain on glass at an auction or salvage yard, the cost could be much less.

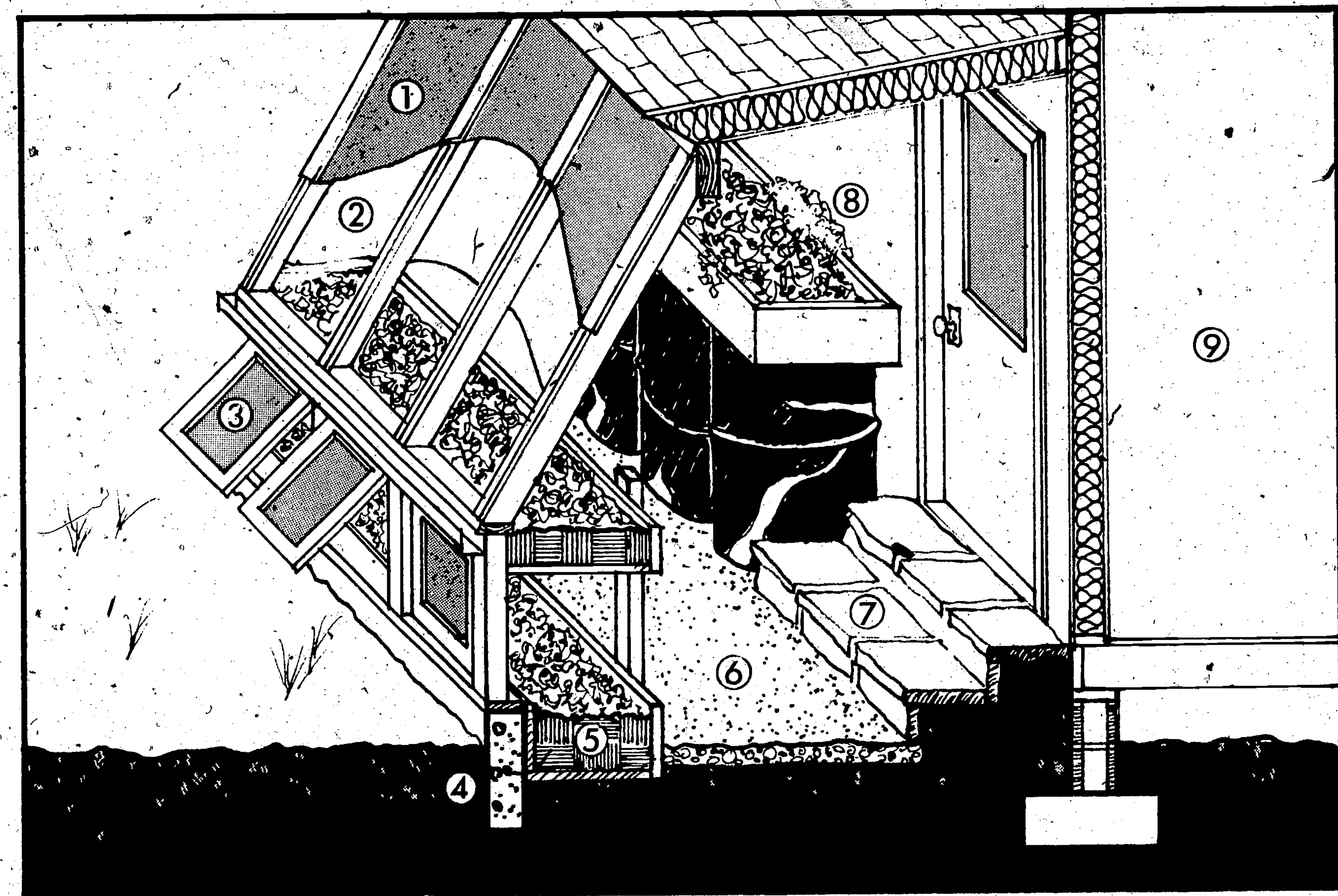

FIG. A-3

C. SUN MOTION AND ORIENTATION

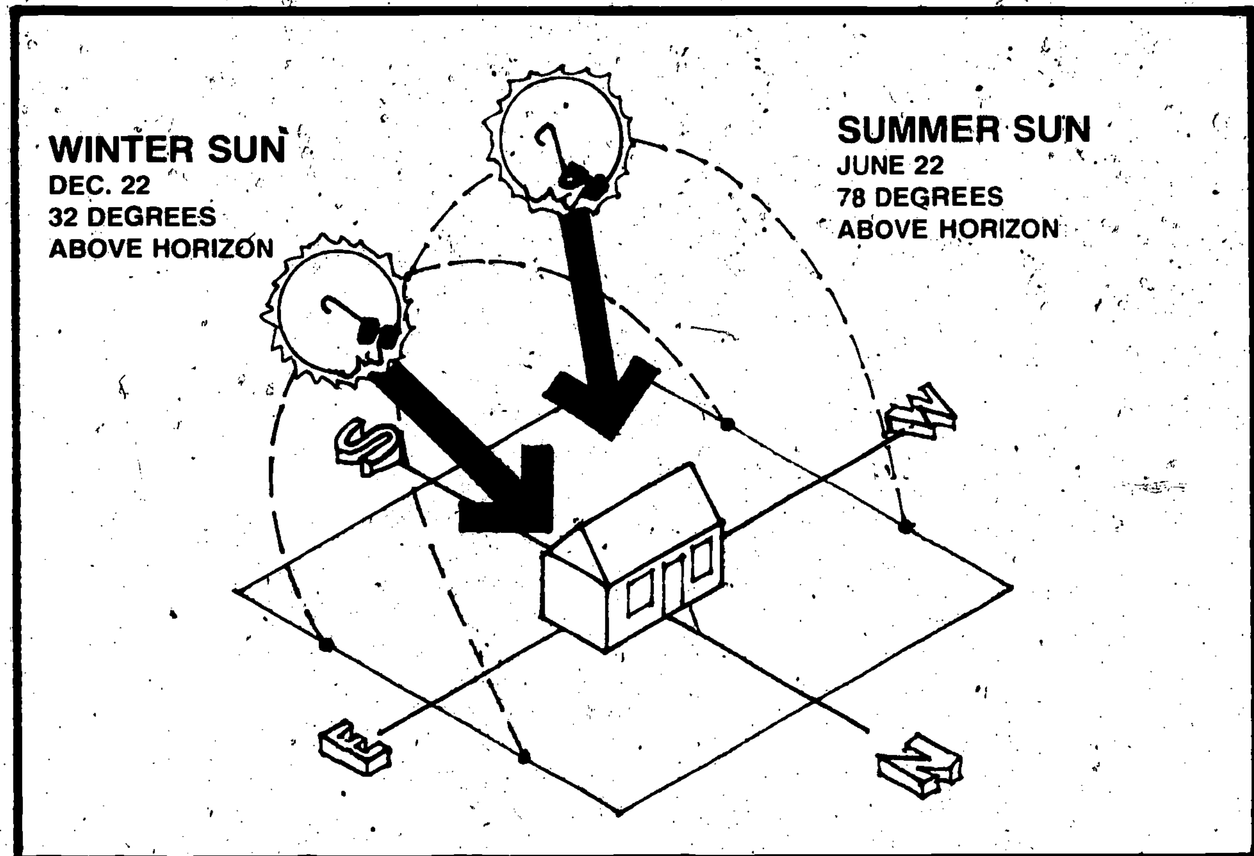

FIG. C-1

In order to design any solar device properly, it is necessary to understand how the sun moves across the sky. Everyone knows that the sun rises in the east, moves across the south sky, and sets in the west. However, the sun actually moves in a slightly different path every day. In winter, the sun rises slight south of due east, reaching the highest point only about 30 degrees above the south horizon at noon, and sets to the south of due west. A south-facing wall receives the most sunshine in winter, while east, west, and north walls all receive much less.

In summer, the sun rises to the north of due east, climbs to nearly straight overhead (78°) at noon, and sets to the north of due west. A vertical or tilted south wall receives very little direct sun on a summer day, while east and west walls and roofs receive several times as much sun.

In the spring and fall, the sun follows a path between the summer and winter paths. It rises due east, climbs to about 55° above the south horizon at noon, and sets due west. Walls facing south, east, and west and roofs all receive moderate amounts of sunshine.

In the temperate climate we experience in Arkansas, we need to both heat our houses in winter and cool them in summer. Orienting the solar greenhouse to the south makes it possible to take advantage of the sun's paths as the seasons change. The greenhouse receives the greatest amount of solar energy in winter, when heat is needed most, and it is easy to keep cool in summer with the aid of shading devices or nearby trees.

Even if the house does not have a side that faces due south, it may still be worthwhile to consider a solar greenhouse. The following table shows the reduction in the amount of winter sun available to walls which face slightly east or west of south.

Degrees East or West of South	% Loss of Available Sunshine
0 - 10°	0%
10 - 20°	5%
20 - 30°	10%
30 - 40°	20%
40 - 50°	25%

So even if the house is up to 45° off of due south, 75% of the sunshine and heating potential is still available. Actually, a slightly southeast orientation is preferred by many gardeners because the greenhouse will heat up faster in the morning, the plants will receive more of the favorable east light, and overheating from the late afternoon sun in spring and summer is less likely.

D. GREENHOUSE — HOUSE CONNECTION

More important than a true south direction is a **convenient access** to the greenhouse from the house. By building the greenhouse over existing windows or a door, venting the warm air to the house will be made simple. If no doors are present, it is usually not difficult to make a door out of an existing window opening.

By having a door between the house and greenhouse, you can avoid having to enter the greenhouse from the outside in winter, which causes a great deal of the heat to escape. Ideally, there should be two doors: one into the house for use in winter and one to the outside for ventilation and access in summer.

Air circulation to the house is vital in controlling the relative humidity as well as the temperature of the greenhouse. **Relative humidity** is defined as the actual amount of water in the air compared with the total possible amount of water the air can hold. Humidity is closely related to temperature: the colder the air, the less water it can contain. Since a high relative humidity (75% or higher) leads to pest and disease problems for plants, a solar greenhouse with its cool nighttime temperatures should be kept quite dry.

On winter days, the humidity in the greenhouse is kept down by the constant air exchange with the house. This distribution of humidified air is welcomed, since the air in most homes in winter is too dry because of furnaces, fireplaces, and other heating devices.

On winter nights, when there is no air exchange to the house, the humidity levels increase in the greenhouse, especially if there are many plants. This high humidity can cause

condensation, which is the result of warm humid air being cooled so the air can no longer hold the moisture. Since the glazing is the coldest surface in the greenhouse, water will condense there first. This water presents three problems; water droplets on the glazing reduce the amount of light that enters the greenhouse; water may drip onto plants, increasing pest and disease problems; and water may drip onto sills, promoting rot.

To avoid serious condensation problems, open the doors, windows, or vents to the house early in the morning to rapidly circulate the humidified air into the house. As the greenhouse air heats up, it will be able to absorb any condensed moisture from the previous evening.

The area of the open doors, windows, or vents to the house should be at least 20% of the common wall area so the air will circulate adequately and no fan will be needed. High vents and low vents of equal area will promote the ideal pattern of air circulation. As the solar heated air in the greenhouse is warmed, it rises into the house through the high vents. At the same time, cooler air from the house is drawn into the greenhouse through the lower vents. This natural **thermo-circulation** will perform continuously on any relatively sunny day.

Of course, most houses do not have ideally located high and low openings, and it would be impractical to build them. Strategically located doors and/or windows are usually a better solution than vents because they can provide access and a view into the greenhouse and also serve as vents when they are opened.

What type of connection you should make to the house often depends on what type of room will be adjacent to the greenhouse. For example, if the greenhouse is to adjoin a kitchen or living room, the connection would logically be a door and/or windows. However, the greenhouse may be connected to a bedroom or garage where heat is not needed during the day. In this case, a small thermostat-switched fan and insulated ducts can be installed in the attic to direct heated air to other rooms that are used in the daytime.

The R value (thermal resistance) of the common wall between the house and the greenhouse is an important factor in determining how warm the greenhouse will remain at night. The greenhouse acts as additional insulation and prevents infiltration through the wall to which it is attached, trapping heat that would otherwise escape to the outside. If the common wall is not insulated, or has a large glass area, there will be considerable heat flow from the house into the greenhouse on cold nights even with the doors and windows closed. However, this heat flow from the house is much less than would occur if there were no greenhouse. So the greenhouse serves an important function as a "thermal buffer zone" between the house and the outdoors by reducing heat loss from the house at night in addition to contributing a large amount of heat during the day.

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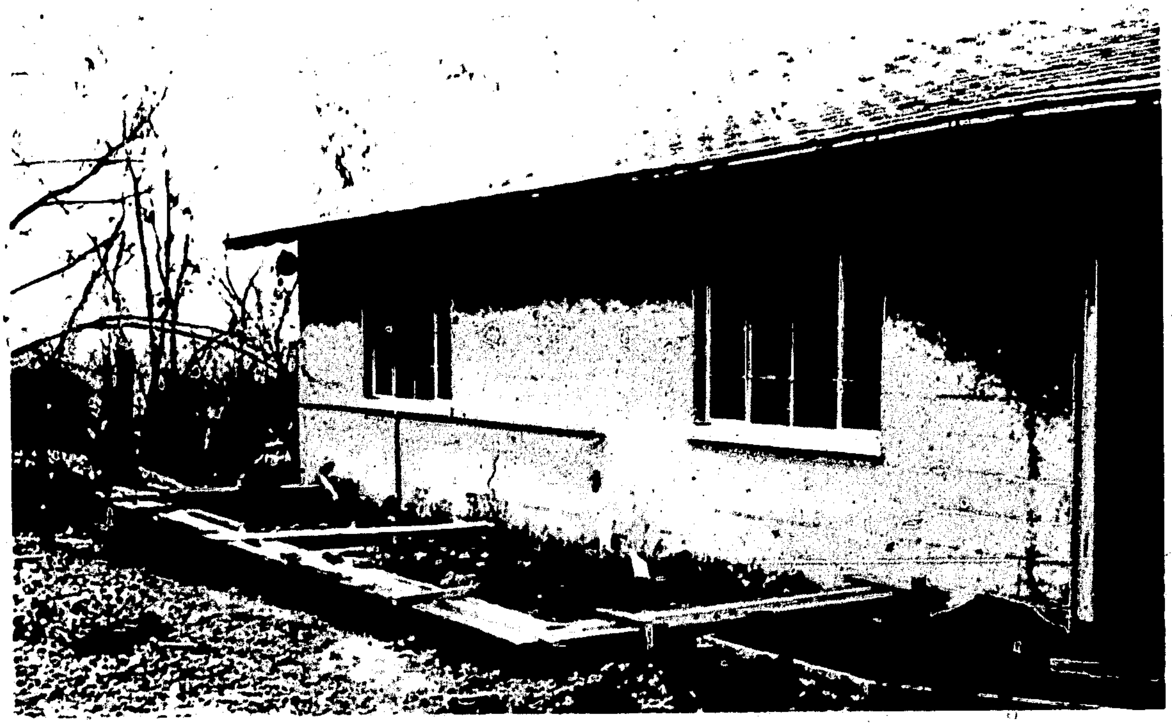
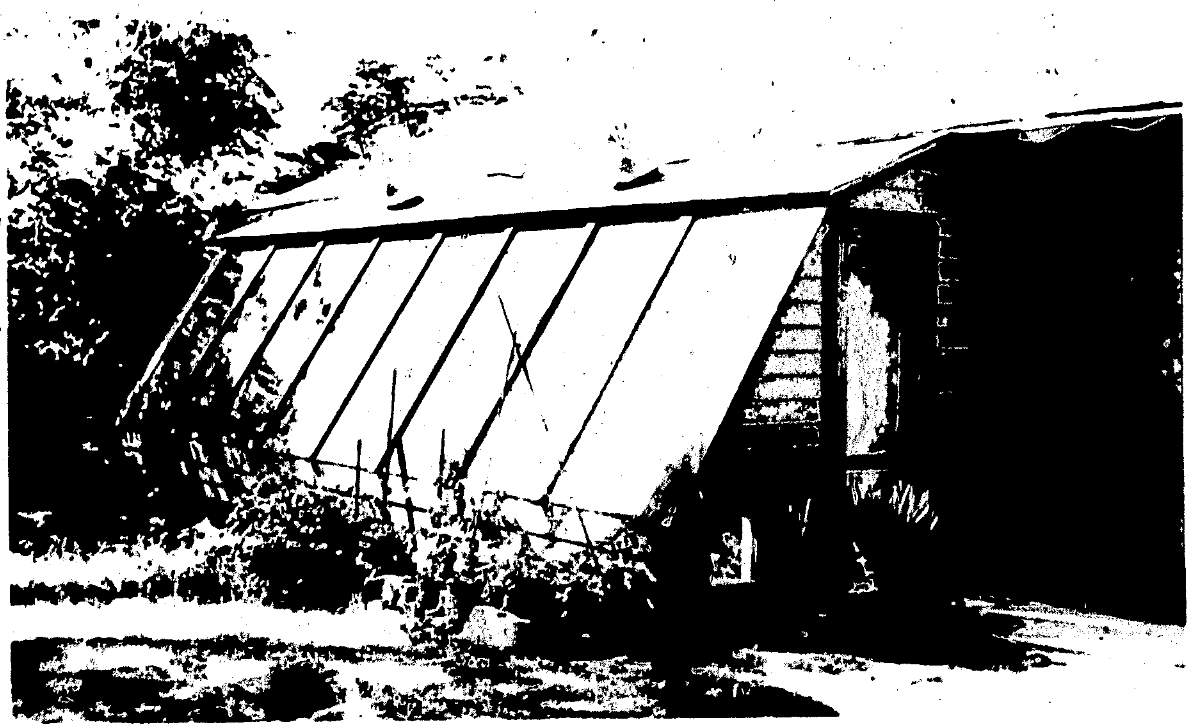


In this view of a solar greenhouse under construction, the forming for the concrete grade beam has just been completed and is ready for the pouring of the concrete. The two large windows will provide good heat transfer to and from the building, and the concrete block wall will help serve as heat storage. Note that the gas meter had to be relocated outside of the greenhouse.



The completed greenhouse shows how the rafters of the existing building have been extended to form the roof of the greenhouse. This arrangement eliminates the need for an interior beam or column. Although there are no vents in the knee wall, summer temperatures inside the greenhouse remain cool by using side wall vents (including a screen door), roof ventilators, and shade from nearby trees. (Village Preschool, Fayetteville).

E. GLAZING

Glazing is glass, fiberglass, plastic, or other material which allows light to pass through. A larger glazing area results in more energy collected and more heating of the greenhouse and adjoining house.

Our studies have found that, for best heating performance, the glazing should cover only the south face of the greenhouse and not the east or west walls, because much more heat will be lost through those walls than they will gain from solar radiation. The narrow configuration of the space and the reflective interior walls ensure that the plants will receive enough light to grow properly without east or west glazing.

In Arkansas, the glazing should be tilted to an angle of about 60° from the horizontal. This angle will maximize heat and light transmission in winter when the sun rises to its midday angle of about 30° above the south horizon. Thus, nearly all the available **direct radiation**, which is the form of solar radiation we receive on clear days, can pass straight through the glazing. Tilted glazing also collects a large amount of **diffuse radiation**, which is the solar energy available on cloudy days. Diffuse radiation represents about 25% of the average total solar heat received in winter in Arkansas.

Although vertical glazing is generally easy to construct and shade in the summer, it must be designed with caution in solar greenhouses. In some of the vertical-glazed greenhouses that were studied, the plants suffered from a problem called **phototropism**; that is, they tended to grow at an angle towards the incoming light instead of straight up.

The reason plants grow so well in conventional greenhouses is that light comes in from all directions, just as if the plants were outside. But in solar greenhouses, light enters mainly from the south. To prevent the plants from growing toward the south, the light must be reflected off the side walls and house wall to simulate outdoor light conditions as closely as possible. Such a balance of light is difficult to achieve with a vertical-glazed greenhouse unless the glazing is used in the roof or side walls as well as in the south wall. Such extensive use of glazing will cause the greenhouse to lose more heat at night and will require additional shading and ventilation in summer to prevent overheating.

Phototropism can be avoided in greenhouses with tilted glazings if care is taken to arrange the plants properly within the greenhouse. The light will always be stronger from the south, but a tilted glazing allows much light to also enter from above and penetrate all the way to the house wall, where it can be reflected back to the plants.

In Arkansas, solar greenhouses will perform much better if two layers of glazing are used (**double glazing**). This was demonstrated in an experiment performed at the Siloam Springs Child Development Center greenhouse. After several weeks of continuous monitoring of indoor and outdoor temperatures with double glazing, the inner layer of glazing was removed, and the monitoring continued with only a single layer of glazing.

A very consistent pattern emerged showing night time temperatures in the greenhouse to average 10° F warmer with double glazing than with single glazing. On very cold nights, when the outside temperature drops below 15° F, this difference could

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Note how the bottom edge of the tilted glazing hangs over the sill, allowing rainwater to drip directly into the gutter and eliminating the possibility of leakage. The knee wall windows open outward to provide ventilation in summer. (Pulaski County Council On Aging, Little Rock. Photo by Cathy Milmore) determine whether or not the plants will freeze. Although the extra layer of glazing will reduce solar gain by about 10%, it will reduce heat loss at night by nearly 50%.

Tempered glass panels are by far the most preferred type of glazing for solar greenhouses. Unlike fiberglass, they are locally available anywhere in Arkansas and will never deteriorate. Glass greenhouses afford a clear view to the outside, which is an important consideration that is often overlooked, and will add more value to the adjoining home or building than the cost of the greenhouse.

Most local glass companies stock "replacement panels," which are tempered glass sheets used to make sliding glass doors, usually 3/16" thick and in standard sizes of 28" x 76", 34" x 76" or 46" x 76", costing between $20 to $30 per panel. Their superior strength makes them ideal for tilted surfaces that must withstand severe thermal stresses, wind and snow loads, and impact from hail and other objects. Often, panels with slight imperfections (seconds) can be bought at a very low price from wholesale glass distributors and salvage stores.

Non-tempered **window glass** is also locally available in single or double strength. Window glass can be cut to custom sizes and has a very high solar transmittance of 0.91, but is easily broken and should be used only in low-stress applications such as vertical glazing.

Sources of glass that are often overlooked are auctions, yard sales, landfills, and demolition projects. Scrounging for old windows and storm doors can save you hundreds of dollars and produce a unique and attractive greenhouse. Take the time to investigate these sources in your area before buying any new glazing. Remember, used glass works just as well as new glass; it just costs a lot less.

Fiberglass is a common name for fiberglass-reinforced polyester (FRP) glazing, which has been used for many years as a patio and carport covering. In recent years, several manufacturers have formulated the fiberglass with chemicals to resist yellowing and deterioration from the ultraviolet rays of the sun. However, even these treated glazings need to be recoated every few years with a special weathering agent to restore the original finish and resist decay.

Fiberglass is popular as a glazing for solar greenhouses and collectors because it is light-weight, impact-resistant, and easy to cut and install. Although it is cloudy enough to prevent a view to the outside, fiberglass will admit nearly as much solar radiation as glass. The cloudiness might be seen as an advantage in urban areas where privacy is a concern.

Fiberglass is usually available in 4-foot rolls or 26-inch wide corrugated panels in various lengths and thicknesses. The biggest complaint against the roll type is its appearance: it does not lie flat, resulting in a wavy pattern. Corrugated panels are much more rigid and give the feeling of a more permanent structure. Special redwood strips must be used along the supports of the panels for a tight seal to prevent air infiltration. Also, the enlarged surface area of the panels due to the corrugations will slightly increase the heat loss at night.

Many solar greenhouse designs of the late 1970's used fiberglass because its cost was so much less than glass. However, the cost of fiberglass has risen dramatically in the last three years, and its price now is very near that of glass. Since glass is available locally, affords a view to the outside, and is permanent, most solar greenhouses are now using glass rather than fiberglass.

Rigid plastic glazings are attractive, easy to handle and fabricate, and have high impact and fracture resistance. Most of the plastic products can be categorized as either **acrylics** or **polycarbonates.** Acrylics, such as Plexiglass, Lucite and Exolite, are known for their high solar transmittance and good resistance to ultraviolet light and weathering. Polycarbonates such as Lexan also have a very high impact strength but will yellow in sunlight sooner than acrylics.

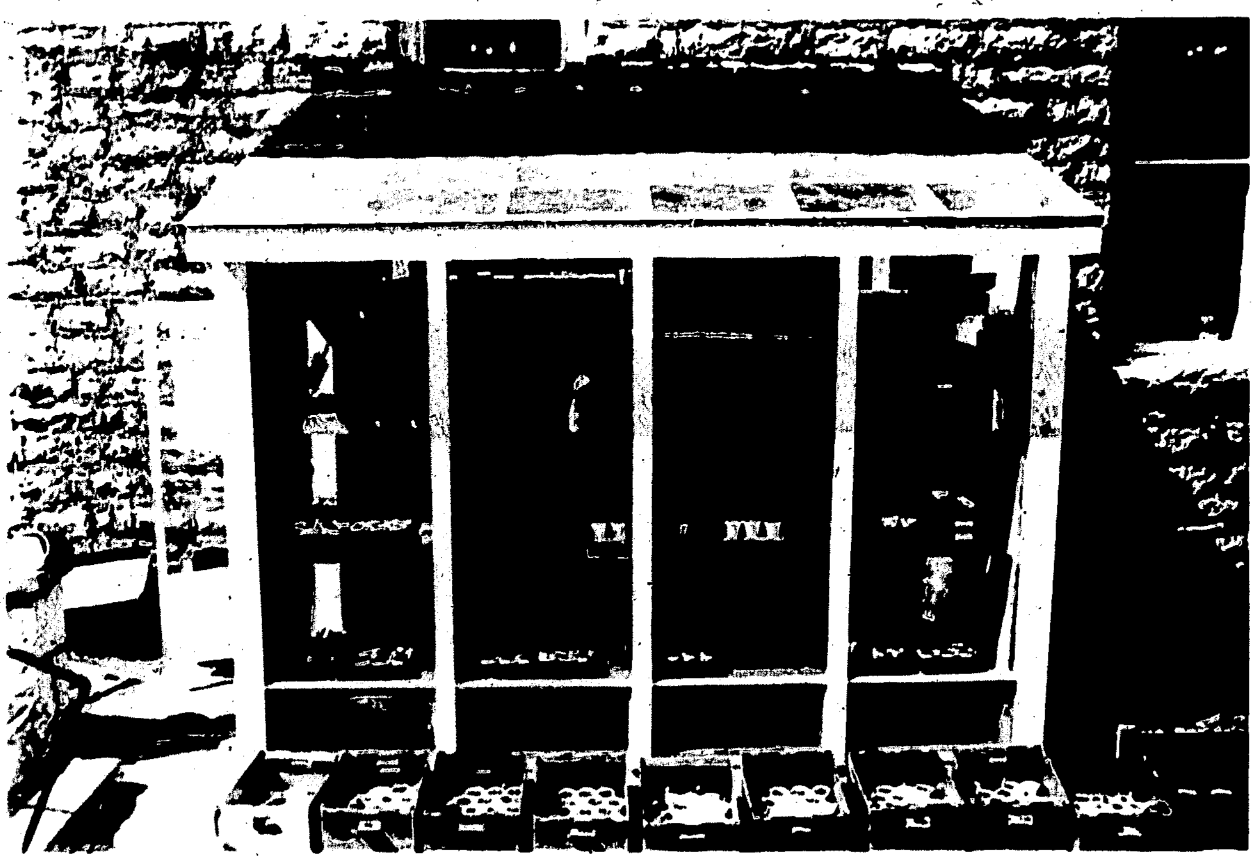
The major disadvantages of plastics as greenhouse glazines are their high cost and poor resistance to scratching. Like fiberglass products, plastics are petroleum-derived, so their cost will continue to rise with the cost of oil.

Doubled-glazed glass, fiberglass, or plastic panels that have been factory sealed to prevent condensation are usually too costly for most greenhouses. So double glazings are often assembled on the job, with an outer layer of glass or fiberglass to withstand the weather and an inner layer of polyethylene or vinyl film.

The lowest-cost inner glazing is polyethylene film. It is commonly used in the construction industry as a vapor barrier, so it is available at most building supply stores. Polyethylene comes in varying widths up to 12 feet and can be stapled to the bottom of glazing rafters in one continuous sheet. Useful life is limited to one or two years; however, considering the low cost of the material, replacing it every year is not a problem.

Some very successful greenhouse designs use polyethylene for both the inner and outer layers of glazing. In summer, the film is entirely removed to transform the space into outdoor garden or porch. In fall, new plastic is easily installed to create a solar room again.

Another type of inner glazing is clear, flexible plastic or vinyl film. These films are usually sold as storm window glazing and are easily cut to any size. When stretched over wood or aluminum or screen molding frames, they can be removed in summer and reused in winter for several years. By using the inner glazing just in winter, when it is needed, it will last much longer than when it is left on year-round. These films are more expensive than polyethelene but are also much stronger, so they can be handled from year to year without damage and, like glass, they offer a clear view to the outside.



Bill Brown of the Office of Human Concern designed this vertical glazed solar greenhouse for the senior center in Berryville. Half of the roof is glazed with fiberglass to permit light to enter from above and permit a light balance within the greenhouse. A row of vents along the bottom of the south glazing and side wall vents provide ventilation. There are four levels of plant shelves, each one supported by the vertical glazing columns. The senior center profitably sells plants and vegetables to residents of the community. (Photo by Bill Brown)

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F. HEAT STORAGE

Barrels filled with water support plant beds (under construction) and collect solar heat by day, then release the heat at night. Since no shade cloth is used, the fan is necessary to ventilate the greenhouse in summer. (Strandquist Greenhouse, Berryville)

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The sunlight that enters the solar greenhouse falls either on the plants, onto light-colored surfaces that reflect light back to the plants, or onto heat storage materials. These are heavy, dark-colored materials that have a high **thermal mass,** which means they act like heat "sponges" to absorb solar heat during the day and slowly release this heat to the air at night as the space cools down. The solar heat received by the greenhouse is therefore extended over a much longer time than when the sun is actually shining.

Without heat storage materials, the air temperature inside the greenhouse would get very hot on sunny days (over 140° F) and cool off rapidly at night. These extremes in temperature from day to night are undesirable and uncomfortable for both people and plants. Temperatures above 100° F can severely limit the growth of plants and kill many of them. Massive heat storage materials tend to stabilize the temperature, improving the comfort of the greenhouse for people and promoting productive plant growth.

A good way to understand the nature of heat storage materials is to think of being in a cave, where the temperature never changes regardless of whether it is summer or winter. The temperature doesn't fluctuate because the earth, with its enormous heat storage capacity, can absorb a large amount of heat in summer and gradually lose heat in winter without affecting the air temperature in the cave. To a lesser degree, the heat storage materials in the greenhouse act the same way: slowly absorbing and releasing energy to maintain even air temperatures without any mechanical controls.

Various kinds of heat storage materials have been used successfully in solar greenhouses, including barrels or other containers full of water, rocks, bricks, concrete blocks, and earth. Heat absorption needs to occur in direct sunlight to be effective, so the heat storage materials should be located where they will not be shaded by the plants.

The amount of heat storage needed to keep greenhouse temperatures stable will depend on how closely the greenhouse and adjoining house interact and share heat. If several large vents, windows, or a fan connect the greenhouse and house, the house will immediately receive the excess solar heat and prevent the greenhouse from overheating. If the openings are few or small between the house and the greenhouse, more heat storage may be needed.

The recommended minimum amounts of **thermal storage** are:

For every square foot of glazing:

4 gallons of enclosed water or
1 cubic foot of gravel or earth or
.75 cubic foot of rocks, bricks, or blocks

When you are thinking about how and where the heat storage will be placed in the greenhouse, you must also consider the arrangement of the planting beds. The planting beds and the heat storage will be competing for light, so the design of both elements needs to be integrated for efficient use of the space. A combination of water containers and masonry and earth planting beds are often the most practical solution. If the house wall is brick or exposed concrete block, it can serve a large portion of the heat storage requirements.

Dark-painted 55-gallon barrels of water are the most common form of thermal storage because they are inexpensive, locally available, and easily arranged to form supports for planting beds. Flat black is the most efficient color to absorb solar energy, but a dark blue, green, or red will do nearly as well. In a typical 8′ x 16′ greenhouse, 7 to 12 barrels should be used, with as many placed in direct

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sunlight as possible. They must be well supported and level, especially if they support planting beds or will be stacked one on top of the other. If the barrels are stacked, separate the upper barrels from the lower barrels with 2 x 4's or other boards so they will have continuous support. Also, it is a good idea to place a 1" or 2" layer of bead board between the barrels and the floor so the water will lose its heat to the air rather than to the floor.

Other containers that can be used are recycled glass or plastic jugs in which water has been dyed black. They must be placed on racks to prevent them from breaking under their own weight.

Rectangular-shaped, 5-gallon honey cans or gasoline cans are ideal for use as thermal storage because they can be compactly stacked against one another, with all sides touching. This arrangement saves space, eliminates the need for racks, and will absorb and transfer solar heat better than barrels.

Soil is also an excellent storage medium. Most people use it without realizing that it is acting as thermal storage. Wet soil in particular has the capacity to hold a lot of heat and to release it very slowly.

If dark-colored rocks, bricks, or concrete blocks are used for thermal storage, they should be incorporated as edges for the planting beds, flooring, or wall veneer. In this way, they will serve both as heat storage and as structural elements in the greenhouse.

G. WINTERTIME TEMPERATURE CONTROL

Solar greenhouses built in Arkansas to the specifications in this report will grow cool-tolerant food plants during winter without **auxiliary heating**. For plants requiring warmer minimum temperatures, such as tomatoes or fruits, you may have to slightly **open the door or windows** into the greenhouse on very cold (0° - 10° F) winter nights to allow more heat to flow from the house into the greenhouse.

There are two alternatives to this auxiliary heating method. One is to place a wood, gas, or electric heating device in the greenhouse. If you have to be gone for a few days, an electrical heating device on a thermostat would be the most efficient because it would only come on if and when the greenhouse temperature dropped to the required minimum.

The other alternative is to use **movable insulation** over the glazing at night to maintain warmer nighttime temperatures and increase the heating fuel savings of the home. Glazing is the largest heat loss problem of any greenhouse. Even well-sealed double glazing will lose heat at night about 12 times faster than an insulated wall. Movable insulation completely covers the glazing at night and is removed during the day to permit solar heat gain.

Covering large glazing areas with movable insulation presents several design problems. A successful system must:

1. Be easy to operate.
2. Not interfere with the plants.
3. Be conveniently retracted or stored during the day.
4. Have a tight fit when the insulation is covering the glazing at night.

Types of movable insulation include **rigid panels, folding shutters,** and **thermal curtains.** These are normally used on the inside of the glazing, although some greenhouses use exterior shutters. Exterior shutters are usually insulated panels that are hinged to the greenhouse along the bottom of the glazing. They are folded down during the day to reflect additional solar energy into the greenhouse and are closed by hand or by a wench and pulley system to serve as insulation at night.

The simplest and most practical movable insulation is **rigid styrene,** also called bead board. Normally purchased as 4′ x 8′ sheets that are 1″ or 2″ thick, bead board is a very lightweight material that can be easily cut with a utility knife to fit between the glazing rafters for a tight seal. A simple wooden latch can be used to lock the panels in place against the glazing. A convenient daytime storage area for the panels should be planned somewhere in the greenhouse so they will not shade the plants or thermal storage.

Thermal curtains can be made with a sewing machine by quilting a 1″ layer of polyester insulation and a polyethylene vapor barrier between two layers of fabric. Curtains should cover the entire glazing in one piece, thus eliminating the heat loss that occurs at the seams of rigid panels. The curtain is usually drawn to the top of the glazing by a cord and pulley hardware system like a Roman shade. There should be space allotted above the glazing so that the thermal curtain will not block the light when it is rolled up.

It should be remembered that, with the exception of the bead board panels, movable insulation systems will add considerably to the cost, complexity, and maintenance of the greenhouse. They are worthwhile only if warm (50° to 60° F) nighttime temperatures are desired.

Of all the methods to control wintertime temperatures at night, the most preferred is to simply leave the door or windows open, allowing heat from the house to keep the greenhouse warm. This method will never have to be used if you are growing only cool-tolerant plants and have adequate amounts of thermal storage and insulation. Even if you grow plants that require higher minimum temperatures, you will probably have to leave the door or windows open only a few nights a year, when the outside nighttime temperature drops below 10° F. The amount of heat the house gives the greenhouse on these few nights is far less than the total heat the greenhouse supplies to the house throughout the winter.

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H. SUMMERTIME TEMPERATURE CONTROL

There are two main factors that determine solar greenhouse temperatures in summer: **shading** and **ventilation.** A combination of the two is usually necessary to prevent overheating during the warm, humid summers of Arkansas.

The sun is at its highest position in the sky during summer, striking the glazing at a steep angle and causing much of the light to be reflected off the glazing. However, since the outside temperature is warm, it doesn't take much solar radiation to raise the greenhouse temperature. The best shading method is to have **deciduous trees** (those that lose their leaves in fall) close to the greenhouse. They will block most of the solar energy in summer, yet will allow the sunlight to reach the greenhouse in winter. If such trees do not already exist within 10′ to 15′ of the site, consider planting two or three fast-growing, early-blooming trees. Your local Soil Conservation office can help you make the right choice for your area.

Alternatives to shade trees are a **shading lattice** or a **shade cloth** attached to the outside of the glazing. A shading lattice is a lightweight wire or wooden mesh, built in sections, that is removed at the end of summer. Care must be taken not to totally block all the sunlight, or the plants may not grow well. The lattice can also be used as a support for vines or other plants to further shade the glazing.

A **shade cloth** is a popular shading device used in conventional greenhouses. Made of an inexpensive but highly durable plastic called polypropylene, shade cloths are an excellent

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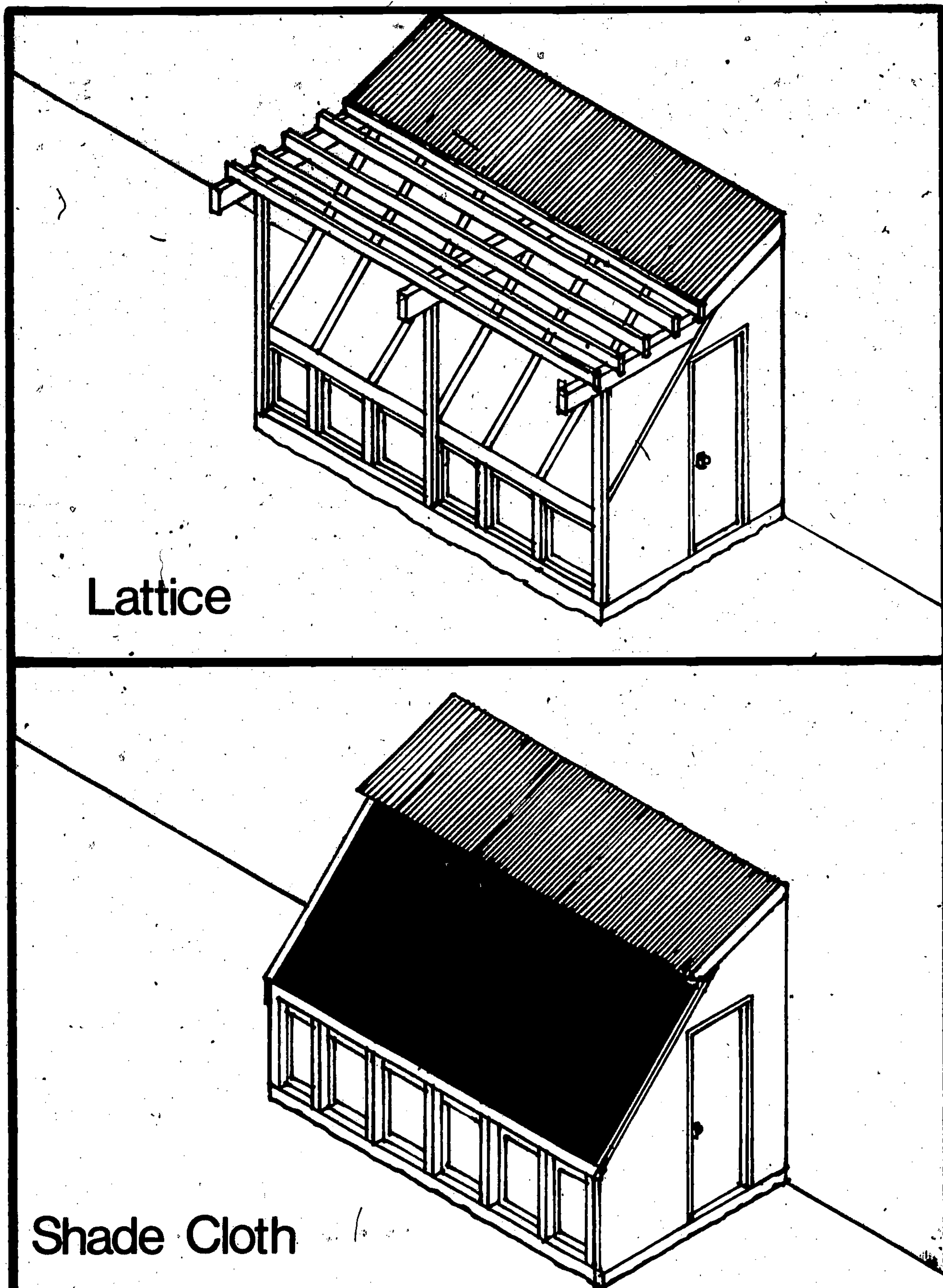

FIG. H-1

A screen door serves as a vent as well as a door in summer. Screens over all the vents are necessary to keep out insects. Note the two small lower vents on each side of the screen door. (Village Preschool, Fayetteville)

solution to shading problems. Shade cloths are custom ordered with grommets sewn into the edges to fit your greenhouse. The grommet holes are stretched over small hooks attached to the greenhouse for a neat appearance and easy removal in the fall.

In May of 1981, shade cloths rated at 50% shading capability were attached to three different Arkansas solar greenhouses being monitored for temperature control. The shade cloths were installed onto the greenhouses in the afternoon on clear days so that the immediate effect on greenhouse temperature could be observed. With the outside temperatures averaging 85° F, the inside temperatures dropped an average of 20° F within 30 minutes after the shade cloth was installed. The owners of the greenhouses have reported no adverse effects on the plants as a result of the shading.

Figure H-1 shows a comparison between shading methods. Whatever technique is used, be sure to place the shading device on the outside of the glazing. An interior shading device will block the sunlight only after it has passed through the glazing, causing heat to build up between the device and the glazing, thus reducing the effectiveness of the device in controlling greenhouse temperatures.

In addition to shading the glazing, **ventilation** of the greenhouse is vital for reducing temperature and humidity and increasing the level of carbon dioxide, which the plants need to ensure healthy growth. Since most of the wind in summer in Arkansas comes from the south, it is a good idea to build a continuous row of openable windows into the south knee wall of the greenhouse. Additional vents high on the east and west walls or roof are also needed to promote a thorough air exhaust. Doors or windows that can be screened and opened can save as vents. **The total vent area should be 1/5 to 1/3 of the floor area, depending on the shading available, to avoid using any mechanical ventilation.**

Roof vents have been more difficult to build because they have to be completely water tight when closed. On the other hand, the roof is the best place to put exhaust vents for good air circulation. A newly developed roof vent that has been proven to be effective in Arkansas and is relatively easy to build is the **thermal chimney.**

Thermal chimneys can be made from common attic ventilators (wind turbines) which can be purchased at most building supply stores. Sections of galvanized metal duct pipe are painted a dark color and connected to the base of the ventilator to extend its length as much as possible. When the sun strikes the chimney, the air inside warms and rises upward, pulling air from the greenhouse and creating a draft. The longer the chimney, the hotter the air will get and the more air will be drawn through the greenhouse. If the wind is blowing, there will also be a draft created by the whirling turbine on top of the chimney. Performance of the chimney can be drastically improved by wrapping it with a layer of flexible fiberglass glazing so the air inside will get much hotter. The chimney is easily sealed during winter from inside the greenhouse by an insulated shutter.

If for some reason you cannot include enough vents or shading for the greenhouse, a fan may be necessary. The proper fan size will depend on how much shading and ventilation exists but a rule of thumb is a CFM (cubic feet per minute) rating equal to at least two times the floor area. So a greenhouse with a floor area of 150 square feet would need a 300 CFM fan.

A propeller-type window fan should be placed in a screened opening high on the west wall. This arrangement will pull cooler air from the east side to the hotter west side. A thermostat on the fan is recommended to reduce power consumption and guarantee that the greenhouse will not overheat if you are gone for a few days.

In winter, the fan can be rearranged to blow solar heated air through a window into the house if necessary. Be sure to seal all the summertime vent openings air-tight in winter.

Thermal chimneys, shown on the left, are passive, self-regulating ventilation devices that can help keep the greenhouse cool during summer. The chimneys are painted dark green or black to increase the air temperature within the shafts and thus increase the air movement through the greenhouse. (O.H.C. Child Development Center, Siloam Springs)

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I. GREENHOUSE GARDENING

The skills of horticulture cannot be fully conveyed in this or any other single publication. Learning to grow plants can be a lifetime's work of study, experimentation, and application. If you already have some gardening experience, growing plants in the greenhouse will be easy once you learn the light and temperature variations during different times of the year. If you have no gardening experience, it is not difficult to acquire gardening skills by learning from those who have gardens. Whether or not you have a knowledge of horticulture, it is advisable to read books on the particular growing techniques used in solar greenhouses. (See Appendix B.)

To get the most economic and nutritional benefits from a solar greenhouse, **food plants** that have a high nutritional content in a small growing area should be grown. Of course, starting seedlings for transplanting to the garden or growing house plants for sale are also excellent uses of the solar greenhouse.

In general, leafy salad-type crops, such as lettuce, spinach, kale, chard, endive, chinese cabbage, celtuce, kohlrabi, and collards, do best in solar greenhouses. Tomatoes, cucumbers, peas (edible pod types), onions, leeks, chives, and cauliflower can be grown if attention is paid to the required growing conditions of the varieties selected. There are several characteristics of the crops to consider for a solar greenhouse: light

Photo by Mary Jo Rose

requirements, cold tolerance, size, daylight period required to flower and set fruit, time required from planting to harvest, pollination and disease resistance. Special greenhouse varieties have been bred to yield fruit in cooler environments, or with shorter days than the standard varieties. Some varieties are more disease resistant than the parent plants.

The following table, from the Organic Gardening Research Center in Manatawny, Pa., lists recommended food crops and their horticultural requirements. Our studies have shown that these recommendations are valid for solar greenhouses in Arkansas. Varieties that will grow best in winter are listed first and marked (W); other varieties for spring, summer, and fall are also listed. Those varieties that should be grown in spring and summer only are marked (S).

In the fall, some of these vegetables can be transplanted into the greenhouse from the garden, especially tomatoes, peppers, onions, and broccoli. Prepare for transplanting at least two weeks prior to the actual move by cutting the roots with a shovel midway between adjacent plants. This will encourage more root growth close to the plant, thus helping it survive the move.

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FOOD PLANTS FOR PASSIVE SOLAR GREENHOUSES

Plant	Varieties	Soil Temp.*	Location	Special Instructions
Tomato	Cherry types, especially "Sweet 100" (W), Big Boy (S), Better Boy (S), Beefsteak (S).	50	Full sun on trellis up back wall	Requires 20" of root depth, if in containers must be 12" or larger in diamater, trim suckers
Cucumbers	LeReine (S), European (S), Burpless types (S), Toska, Gourmet (S)	60	Full sun on trellis up back wall	Require hand pollination
Peas (Edible pod types)	Mammoth-melting (W), Sugar Snaps (W), Mighty Midget (W), Dwark White Sugar (W)	40	Shady, cool areas	Grow on teepee of four poles in back corners of greenhouse or on trellis up side walls.
Onions, leeks, chives, shallots, garlic	Any (W)	35	Cool, medium light toward sides of midsection of greenhouse	Garlic helps control insects, bulb growth is scant, for all, tops good in salads, space further apart than usual.
Cauliflower	Snowball (W), Super Snowball (W), Abuntia (W), Snowcrown (W), Snowking (W)	40	Cool, medium light	Reuire much space for the crop harvested, do well in pots, good for early transplanting to garden.
Cabbage	Dwarf Morden (W), Jersey Wakefield	40		Only one head harvested per plant
Chinese Cabbage	Burpee Hybrid (W), Michihli (W)	40	Cool, medium light	Excellent for fall-winter greenhouse, continuous harvest.
Collards	Vater (W), Georgia (W)	40	Same as above	Same as above.
Kale	Dwarf Blue Comet (W), Dwarf Blue Scotch (W)	40	Same as above	Same as above.
Kohlrabi	Early White Vienna (W)	40	Same as above	Same as above
Broccoli	Southern Comet (W), Calabrese (W), White Sprouting (W), Green Comet (W), Premium Crop F1.	40	Same as above	Same as above
Peppers	Almost all red, green or bell varities work	60	Warm, full light	Hand pollinate, do well in pots, careful not to overwater
Endive	Salad King (W), Broadleaved Batavin (W)	35	Cool, medium light	Good winter producers, may be grown under tomatoes or peas in back of greenhouse
Spinach	Monnopa (W), Bloomsdale (W), Perpetual, New Zeland	35	Cool, medium light	Same as above, continuous harvest
Swiss Chard	Vintage Green (W), Fordhook Giant (W), Lucullus (W), Ruby (W)	35	Cool, medium light	Tastes better after cool weather Good producer, continuous harvest
Radishes	White Chinese (W), China Rose (W), Summer Cross (W), Half Long (S), Yellow Gold (S), Icicle (S), Champion (S)	40	Anywhere	Double number of days to mature crop
Beans	Kentucky Wonder (pole) (S), Blue Lake (pole) (s), Tenderpod (bush) (S), Royalty (bush) (S)	60	Medium, light	Not good for midwinter crop, don't overeater; will easily rot. Watch for yellow bean beatles
Lettuce	Buttercrunch (W), Grand Rapids (W), Artic King (W), Tom Thumb (W), Green Ice (W), Salad Bowl (W), Great Lakes (W), Celtuce, Oakleaf, Bibb	35	Cool, medium light	Avoid head lettuce, watch for aphids, continuous harvest
Beets	Ruby Queen (W), Detroit Dark Red (W), Burpee Golden (W), Snow White (W), Asgrow Wonder (W)	40	Medium light, cool	Young foliage excellent as a green, plant farther apart than usual, require loose light soil
Carrots	Tiny Sweet (W), Short-n-Sweet (W), Little Finger (W), Golden Nugget (W)	40	High light, warm	Plant heavily then thin progressively, require loose, light soil and sand

*Minimum soil temperature for germination in °F

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Many crop varieties benefit from starting in pots or flats, then transplanting to the garden in spring. These include tomatoes, peppers, eggplant, melons, broccoli, and other cole crops such as cabbages.

Some of the warm weather crops will not germinate in the greenhouse but will grow there once started. You can get them going by keeping them in the house until they sproud, then moving them to the greenhouse.

Recent research at the Organic Gardening Research Center has shown considerable success with crops developed in China for growth through that country's damp, chilly, overcast winters. These various greens can be eaten fresh in salads or cooked in soups and casseroles and are very prolific in passive solar greenhouses.

CHINESE VEGETABLES

Siew Choy *(Brassica pekinensis* var. *cylindrica)*: leaves are wrinkled with celery-like midrib. About 8 inches tall. Pick outer leaves.

Seppaku taina (unk): grows bunched like celery, having broad, soft leaves on white stalks. Can be planted close together. Good eating even after hard freeze.

Bok choi *(Br. chinensis* var. *Chinensis)*: chinese cabbage. Will survive temperatures in the mid 20's. Pick regularly to prevent heat formation.

Choy sum *(Br. paracninensis, Bailey)*: flowering white cabbage, looks similar to broccoli. Eat flower stalks. Eat entire plant as salad or stir fry.

Dai gai choi *(Br. juncea* var. *rugosa)*: loose, upright head with curly leaves having a sweet, peppery flavor.

Gai choi *(Br. juncea* var. *foliosa)*: fast growing (space at 6 inch intervals), with mild mustard flavor. More leafy than Dai gai choi.

Komatsuna *(Br. pervidis Bailey)*: very cold tolerant, compact, resembles young chicory. Slow growing.

Kyo mizuna *(Br. juncea* var. *muttisecta)*: resembles fine endive. Fast growing. Mild and pleasing flavor for salads.

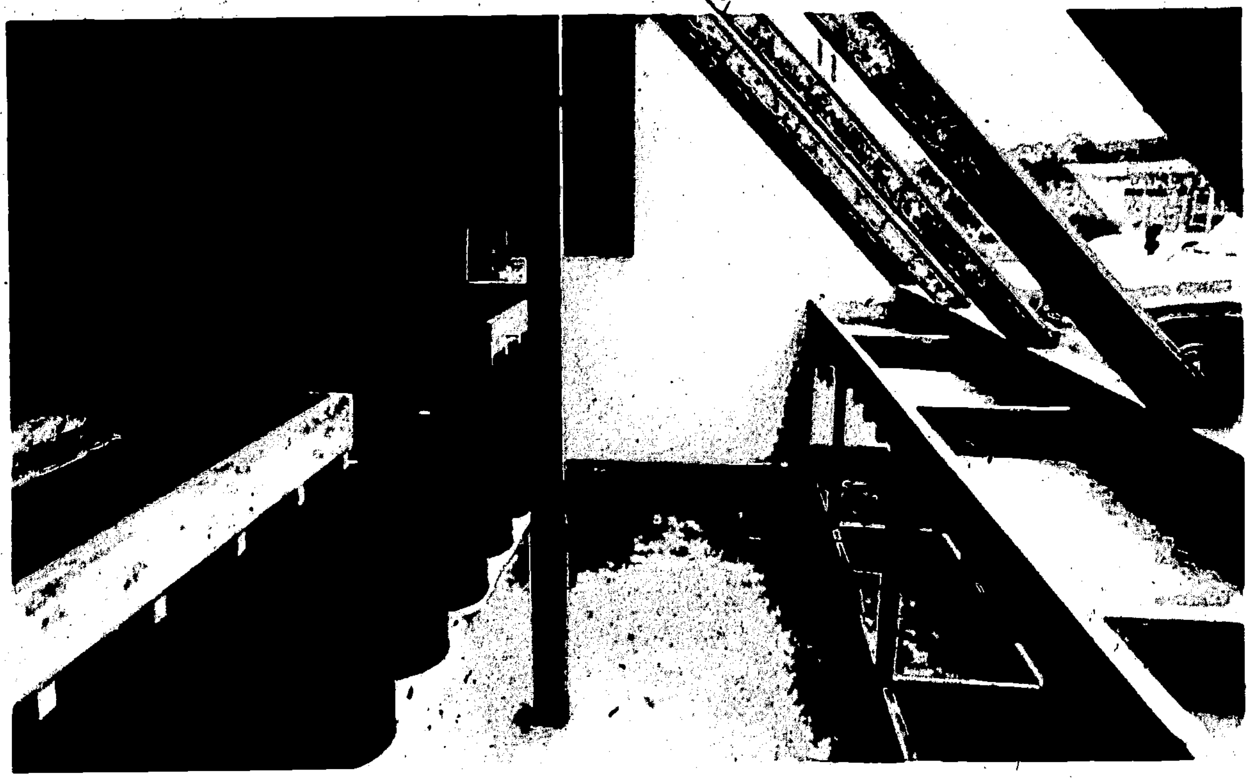
Shungi ku *(Chrysanthemum coronatium)*: young shoots excellent in salads. Continues to grow when clipped back.

3

The greenhouse environment changes with the seasons. In the winter it is cool but warmer than outside; in the summer it is warm but can be cooler and more shaded than outside. As in the outside garden, some crops do better in cool weather, others in warm weather. You can take advantage of the changing greenhouse environment by planting different crops in each season. Remember that it takes 1½ to 3 months between the planting and harvesting of most crops, so crops planted in the late winter will be harvested in the Spring. The following table gives some recommended crops to plant in each season.

PLANTS

Fall	**Cool weather crops for winter**
Oct.	lettuce, radishes, onions, herbs, broccoli, cauliflower, peas, spinach, beets, carrots
Nov.	chives, cabbage, swiss chard, onions, kohlrabi
Dec.	start seeds inside to germinate crops as in Oct. and Nov.
Winter	**Cool weather crops; early/spring crops and garden transplants; late**
Jan.	collards, spinach, cauliflower, broccoli, onions, swiss chard, cabbage, beets, flowers
Feb.	beans, lettuce, cabbage, herbs & peas in greenhouse, tomatoes, peppers, cucumbers, and others for garden
March	tomatoes, cucumbers, peppers, eggplant, peas, beans, cabbage, broccoli, cauliflower, spinach in greenhouse and for garden
Spring	**Warm weather crops for summer/and transplants for garden**
April	melons, squash, corn (transplant) and others as in March
May	Same as in April
June	tomatoes, cucumbers, peppers, eggplant, squash, melons
Summer	**Warm weather crops; early/cool weather crops for fall; late**
July	peas, carrots, onions, peppers, tomatoes, cucumbers, squash
Aug.	cabbage, broccoli, spinch, cauliflower, beets, peas, onions, herbs, radishes
Sept.	lettuce, chinese cabbage, swiss chard, kale, beets, broccoli, spinach



An existing concrete slab and a brick wall offer ideal conditions for heat storage in a solar greenhouse. A generous growing area is provided by the double-level plant bed along the knee wall and along the building wall on top of the barrels. The upper level bed along the knee wall should be built several inches below the sill so the plants will not touch the glazing, and the lower bed should be raised slightly off of the concrete floor to allow for drainage.

Because of the demands your crops will make on it, your greenhouse **soil** needs to be very rich. It is certainly possible to buy premixed (potting) soils, but the quantities required make this approach exceedingly expensive. Experience has shown that the types of chemical fertilizers used in agriculture tend to give poor results in greenhouses. Thus two basic approaches remain.

(1) A suitable soil can be obtained by mixing equal parts of good topsoil, sand, and a soil lightener such as perlite or peat moss. Additional nutrients can be added in the form of compost, or rotted manure.

(2) The best soil is perhaps an equal mixture of compost, sand, and whatever garden soil is available. The attractiveness of this system lies in recycling, through the compost, of kitchen and garden waste.

Soils can be contained in pots, raised beds, or ground-level beds. The use of numerous small pots on tables or benches is not recommended. These tend to dry out very easily and the roots can experience wide temperature shifts. The best approach seems to be a combination of beds toward the front of the greenhouse and pots and/or flats in the rear or on or over the heat storage containers.

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J. CONSTRUCTION METHODS

There are several factors to consider when designing a solar greenhouse, including what type of plants will be grown and how the greenhouse will be adapted to the house for easy access and heat distribution. There is no one way to build a solar greenhouse; rather, it should reflect the needs and resources of the owner.

The following construction methods are given for a greenhouse design that has performed well in Arkansas. The details may need to be modified to suit the particular conditions of each site.

1. PREPARING THE SITE

Before starting to dig the foundation, measure the wall of the house where the greenhouse is to be attached. It is very helpful to draw a plan and elevation of the proposed greenhouse on graph paper. Note any obstacles such as wires, electric or gas meters, or trees. Look at the line of the ground against the house and measure its slope. If you live in a suburb or city, make sure your lot line is not within five feet of the greenhouse. Check with your local government to see if you will need a building permit.

Clear the site of any unwanted shrubs, trees, or plants before you start working. To give you a good idea of the layout, place stakes in the ground where the walls will be located. Fig. J-1 indicates the equal lines of measurement to ensure that the foundation will be square.

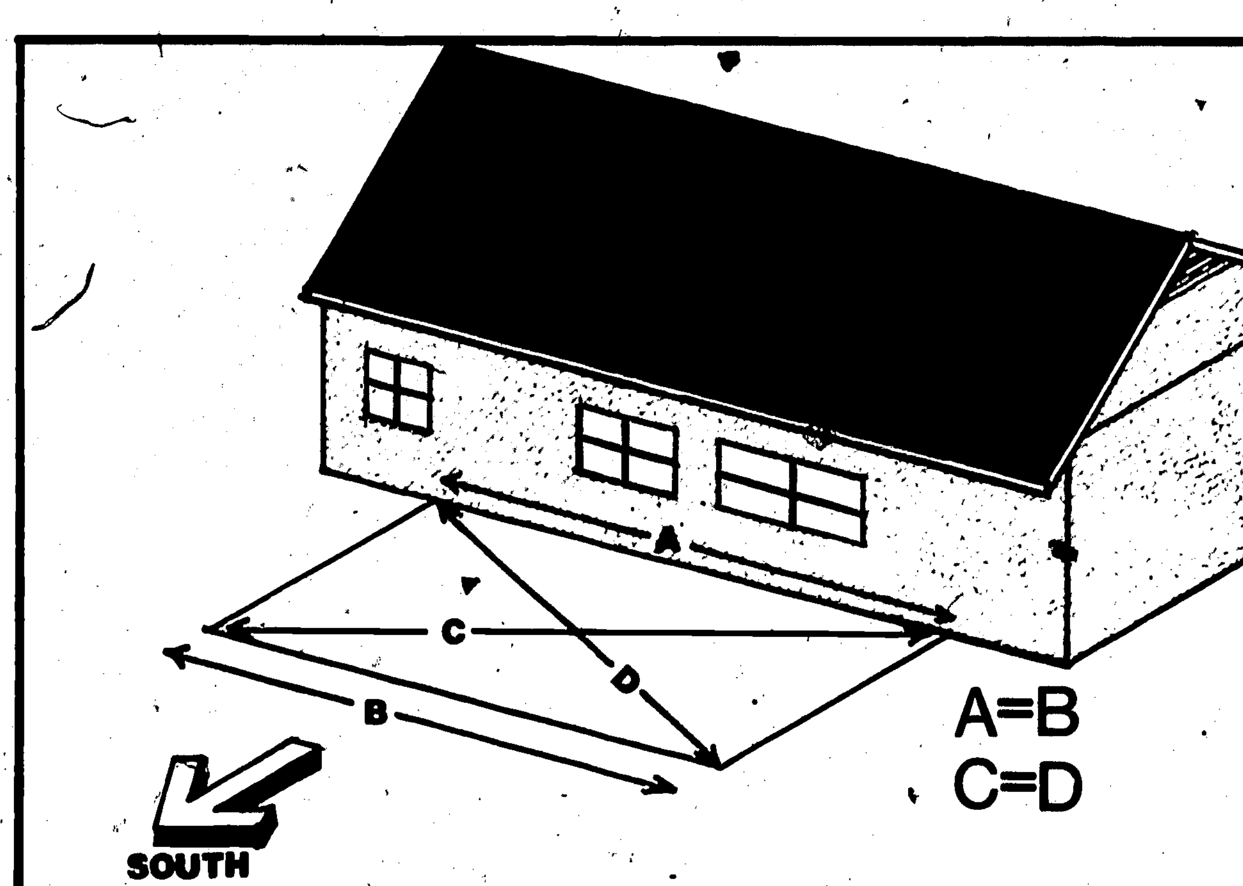

FIG. J-1

2. FOUNDATIONS

The foundation should evenly support the weight of the greenhouse and should be **square** and **level** so that the walls will fit together and attach to the house without gaps. Since the greenhouse itself is a lightweight structure, a conventional foundation, such as those for houses, is not needed. Whatever foundation is used, make sure it is **well insulated from the ground:** next to heat loss through the glazing, the foundation offers the greatest avenue for heat loss.

The sturdiest and most permanent foundation for sites that slope less than 24″ is a poured **concrete grade beam.** (Fig. J-2 and Fig. J-3) A grade beam is simply a continuous concrete footing that extends above the ground. First, dig a trench 10″ wide and 12″ deep around the perimeter. The bottom of the trench may slope with the ground, but the top of the grade beam should be 6″ above the highest corner of the ground and remain level around the entire perimeter. For example, if the ground slopes down towards the west a total of 24″, then the top of the grade beam will be 6″ above the ground on the east side and 18″ above the ground on the west side.

If the ground is level, you can use 2 x 6 boards to form the exposed sides of the beam. If the ground slopes, use ½″ plywood with 2 x 4 supports every 16″ to form the necessary height to keep the top of the grade beam level. Line the side and bottom of the trench with 2″ polystyrene foam insulation (bead board), then place two No. 4 reinforcing bars continuously

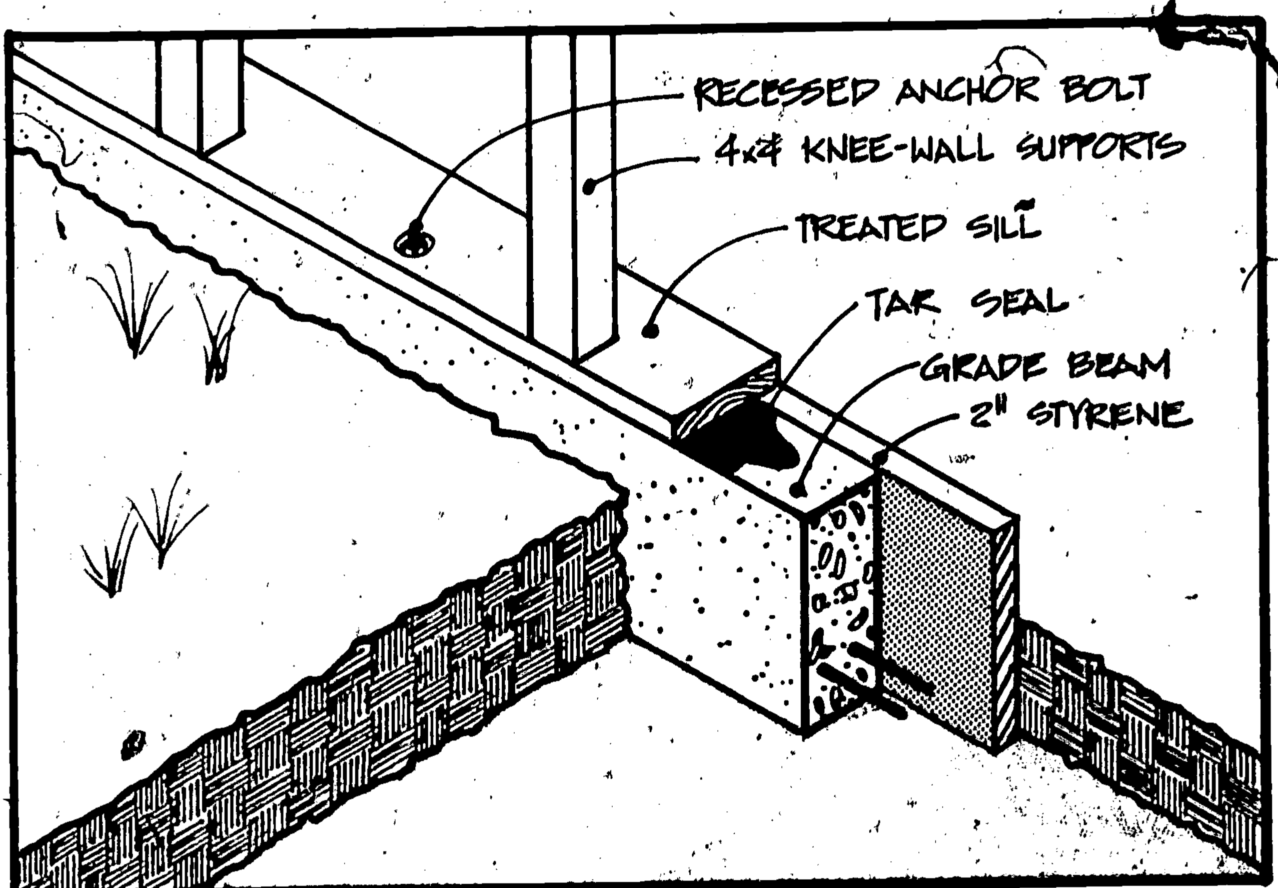

FIG. J-2

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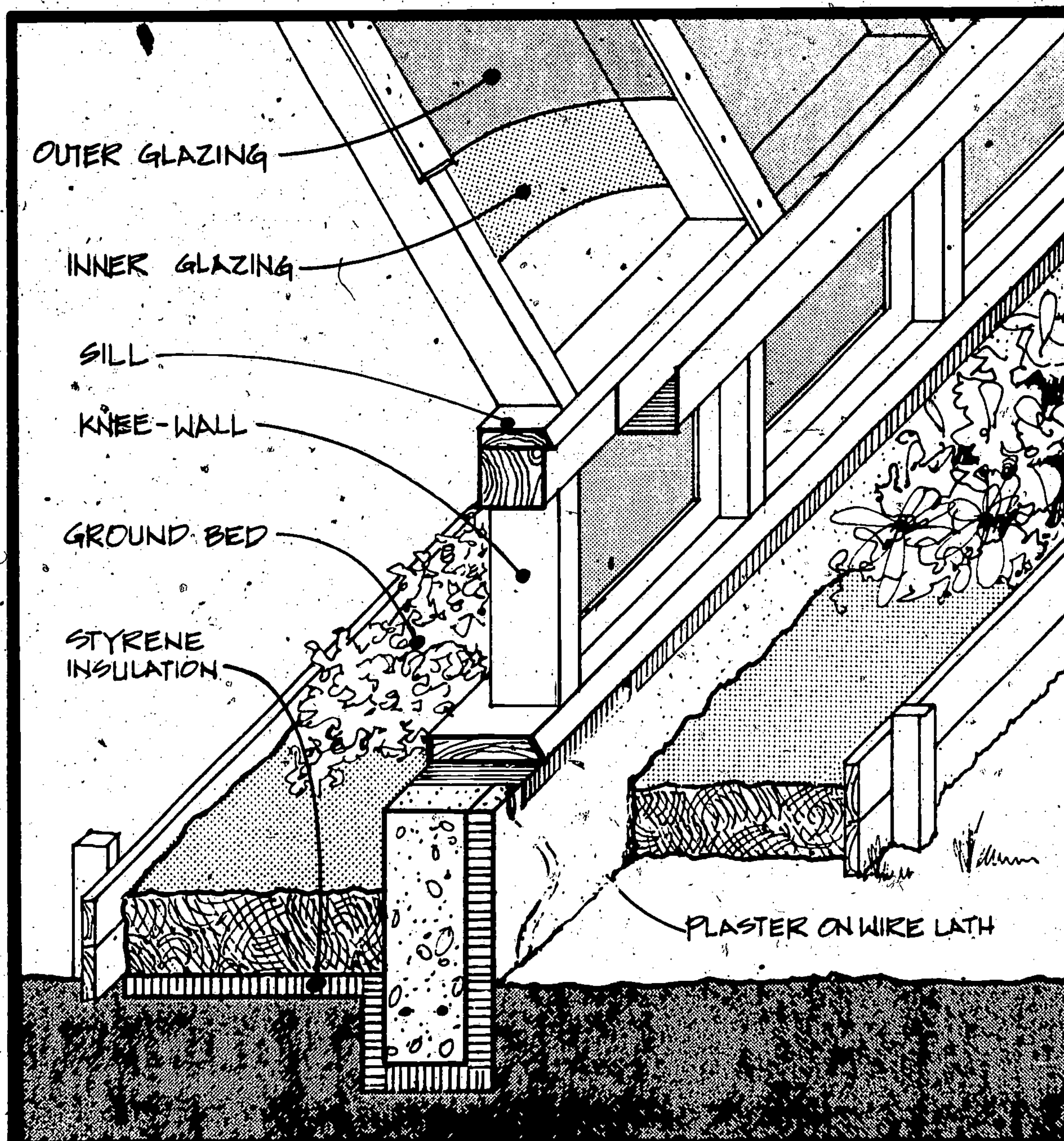

FIG. J-3

through the trench as indicated. If the foundation is small, you may want to use ready-mix concrete or make concrete from a mixture of one part cement, two parts sand, three parts gravel and enough water to mix. Be sure to place ½" x 8" anchor bolts every 4' into the top of the grade beam, with the threaded part extending 3" above the top of the beam. These are used to tie down the walls to the foundation.

Since both sunlight and ground moisture will deteriorate the bead board insulation, it is important to protect it with plaster or some other waterproof coating. An alternative insulation is Styrofoam (blue), which is more expensive but much more resistant to moisture and acids in the soil.

If the ground slopes more than 24", a grade beam may be impractical be-

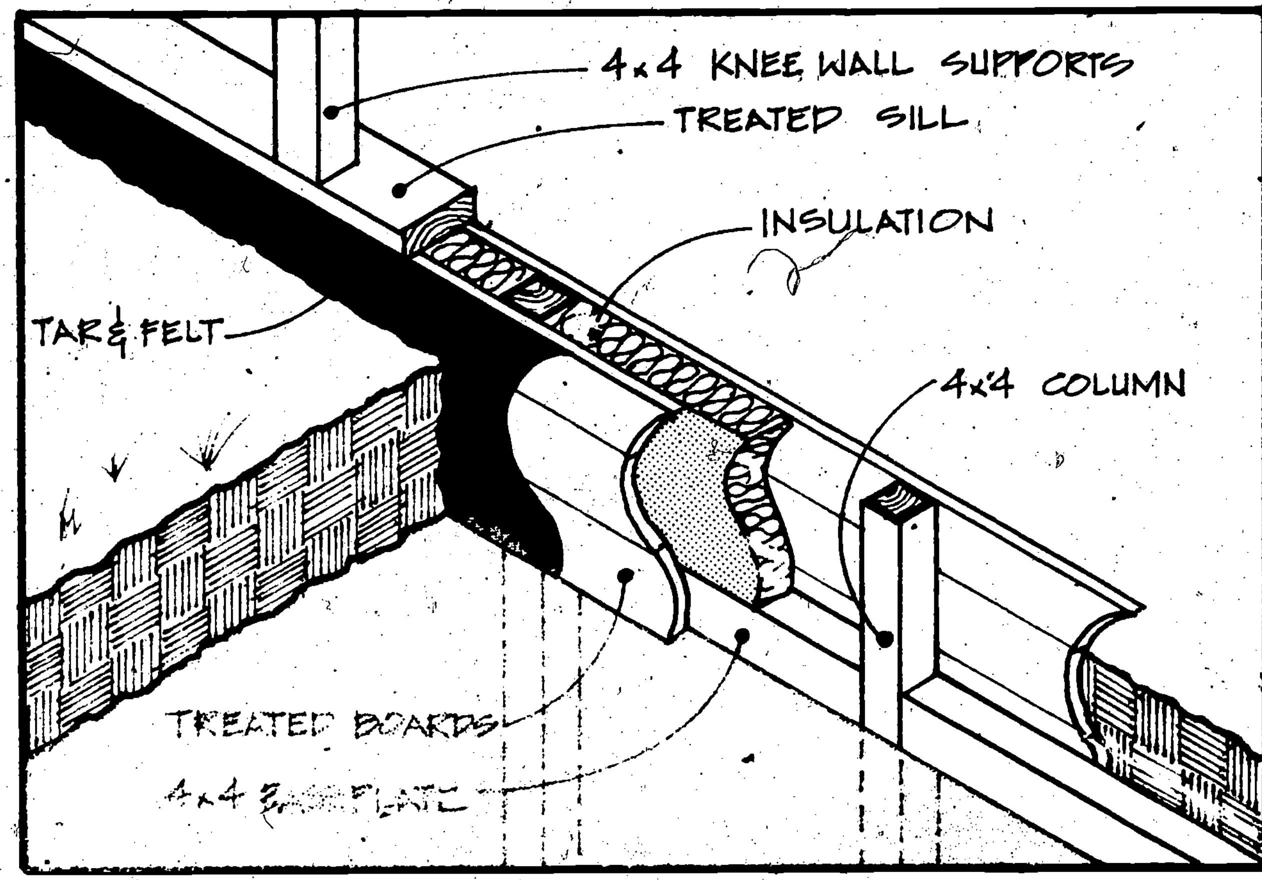

FIG. J-4

cause of the large amount of concrete and extensive forming necessary. For such steep slopes, a conventional concrete footing and block wall foundation is more appropriate. Details of this type of foundation can be found in any carpentry or house building book.

A less costly alternative to a concrete foundation is one that uses treated posts or railroad ties. These types of foundations have been used for greenhouses in rural areas that are not restricted by building codes.

Fig. J-4 shows a typical **post foundation**. Begin by digging a 12″ deep by 18″ wide trench around the perimeter. Set treated 4 x 4 posts in holes 3′ deep and 4′ apart in the bottom of the trench. Install the treated 4 x 4 baseplates between the posts, then nail treated boards or plywood to both sides of the posts to tie them together and form a cavity for the insulation. Waterproof the wooden sides with three layers of foundation coating (tar) and felt, then fill the cavities between the posts with insulation (fiberglass, cellulose, or styrene beads).

Oak railroad ties are common sawmill products in many parts of Arkansas and can be used to make perhaps the least costly foundation. The ground should be fairly level and, as shown in Fig. J-5, at least three courses of 8″ x 8″ oak ties should be used. Start by digging a 16″ deep by 18″ wide level trench around the perimeter. Place 4″ of pea gravel in the trench and lay the first course of ties after the bottoms have been mopped with tar. Using a sledge hammer, drive a ½″ x 3′ reinforcing rod or pipe through holes drilled in the ties every 4′. Each succeeding layer of ties is spiked to the one below it in a similar manner. Coat the outside

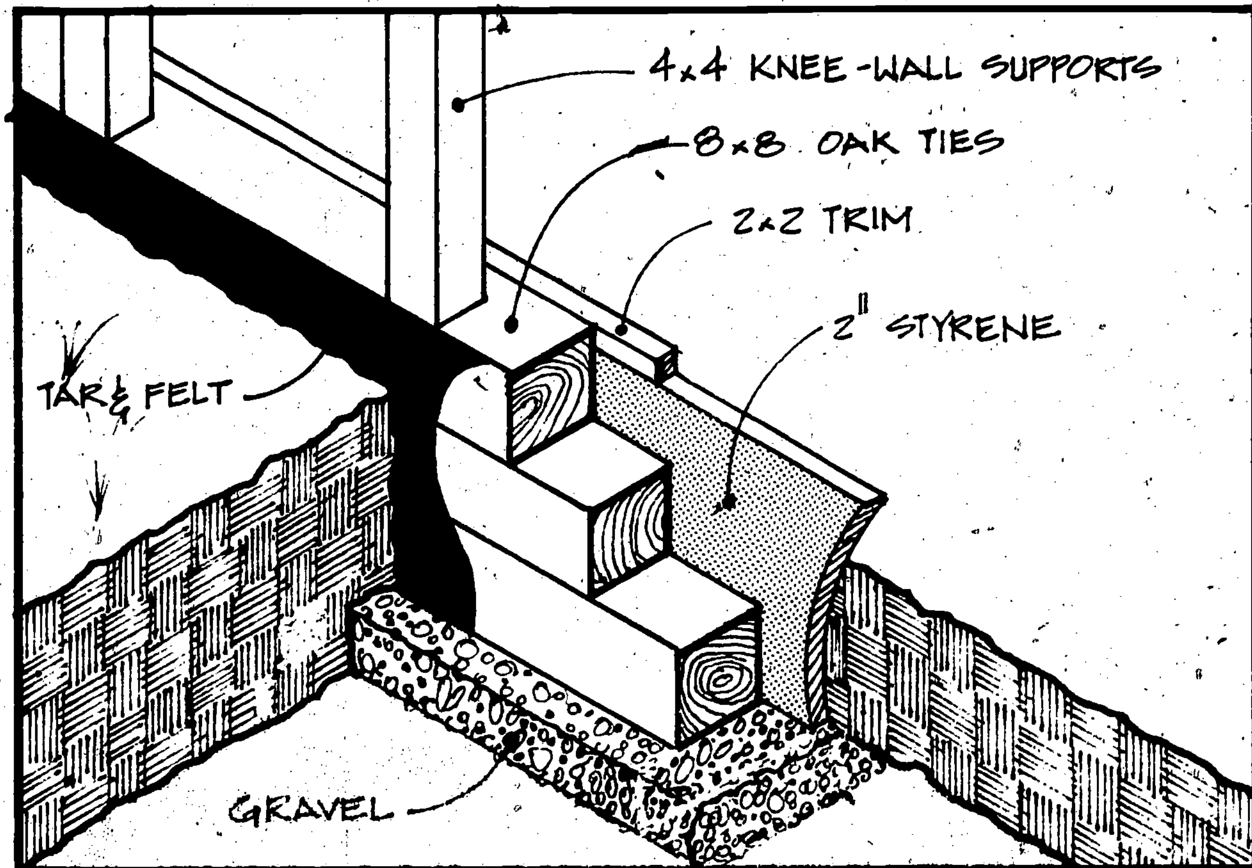

FIG. J-5

edge of the ties with three layers of tar and felt, then nail or glue on the 2″ bead board insulation.

Fig. J-6 and Fig. J-7 illustrate typical greenhouse details using tilted tempered glass panels (34″ x 76″) and a vertical **knee wall** with openable windows along its entire length. A knee wall with windows serves two important functions:

1. In summer, the knee wall windows are used as vents to allow a generous flow of air into the greenhouse. Along with smaller vents on the side walls or roof, these openings greatly reduce the amount of shading necessary to prevent overheating.

2. The knee wall makes possible a double-decked planting arrangement: one bed at ground level and one bed at the top of the knee wall. Light reaches the lower bed through the vertical windows while the upper bed receives light from the tilted glass panels. This arrangement enables the owner to grow about 40% more in the greenhouse than if just one bed were used.

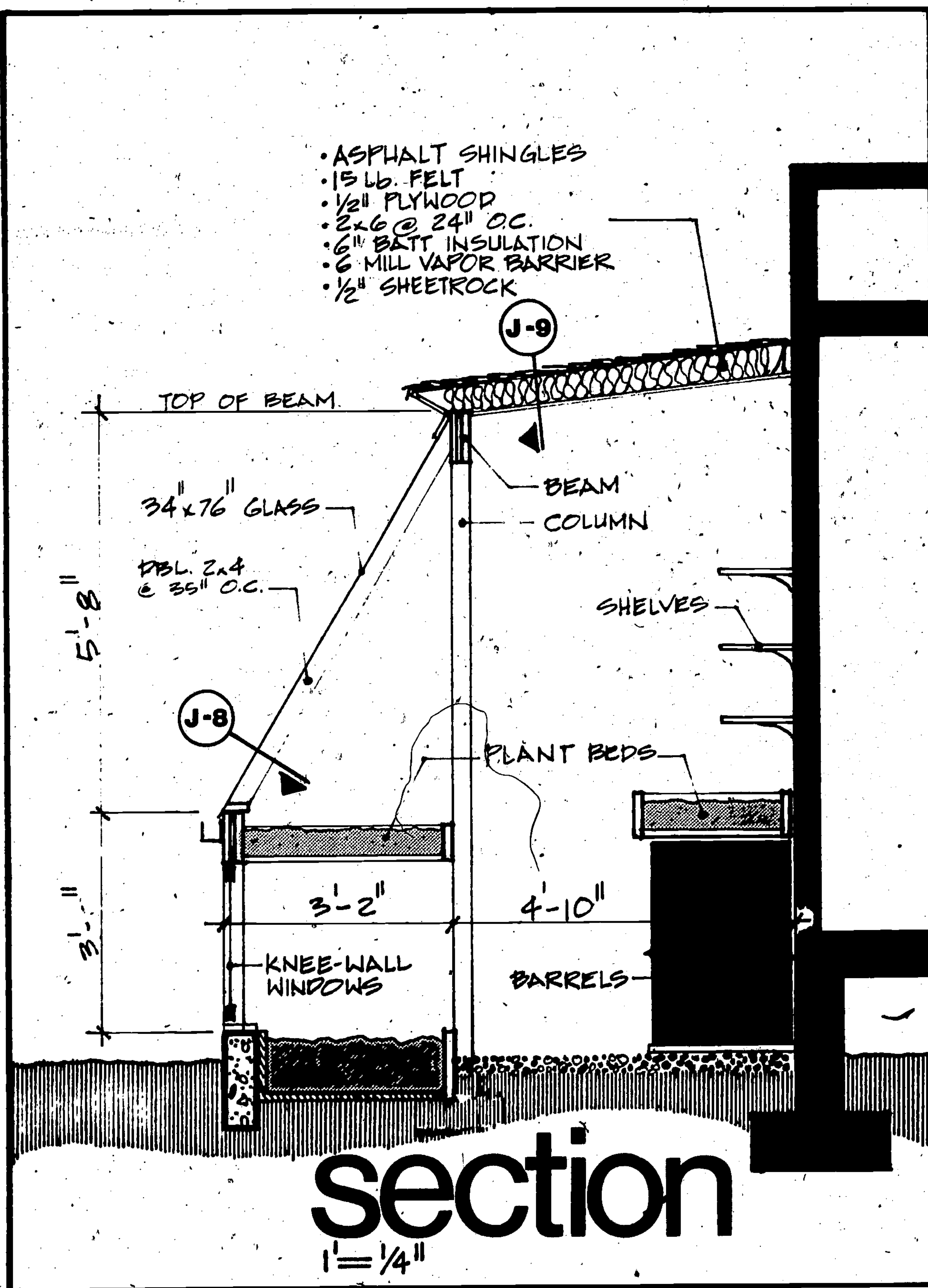
• ASPHALT SHINGLES
• 15 Lb. FELT
• 1/2" PLYWOOD
• 2x6 @ 24" O.C.
• 6" BATT INSULATION
• 6 MILL VAPOR BARRIER
• 1/2" SHEETROCK
J-9
TOP OF BEAM
BEAM
COLUMN
34"x76" GLASS
DBL. 2x4 @ 35" O.C.
5'-8"
SHELVES
J-8
PLANT BEDS
3'-2"
4'-10"
3'-"
KNEE-WALL WINDOWS
BARRELS
section
1'=1/4"

FIG. J-6

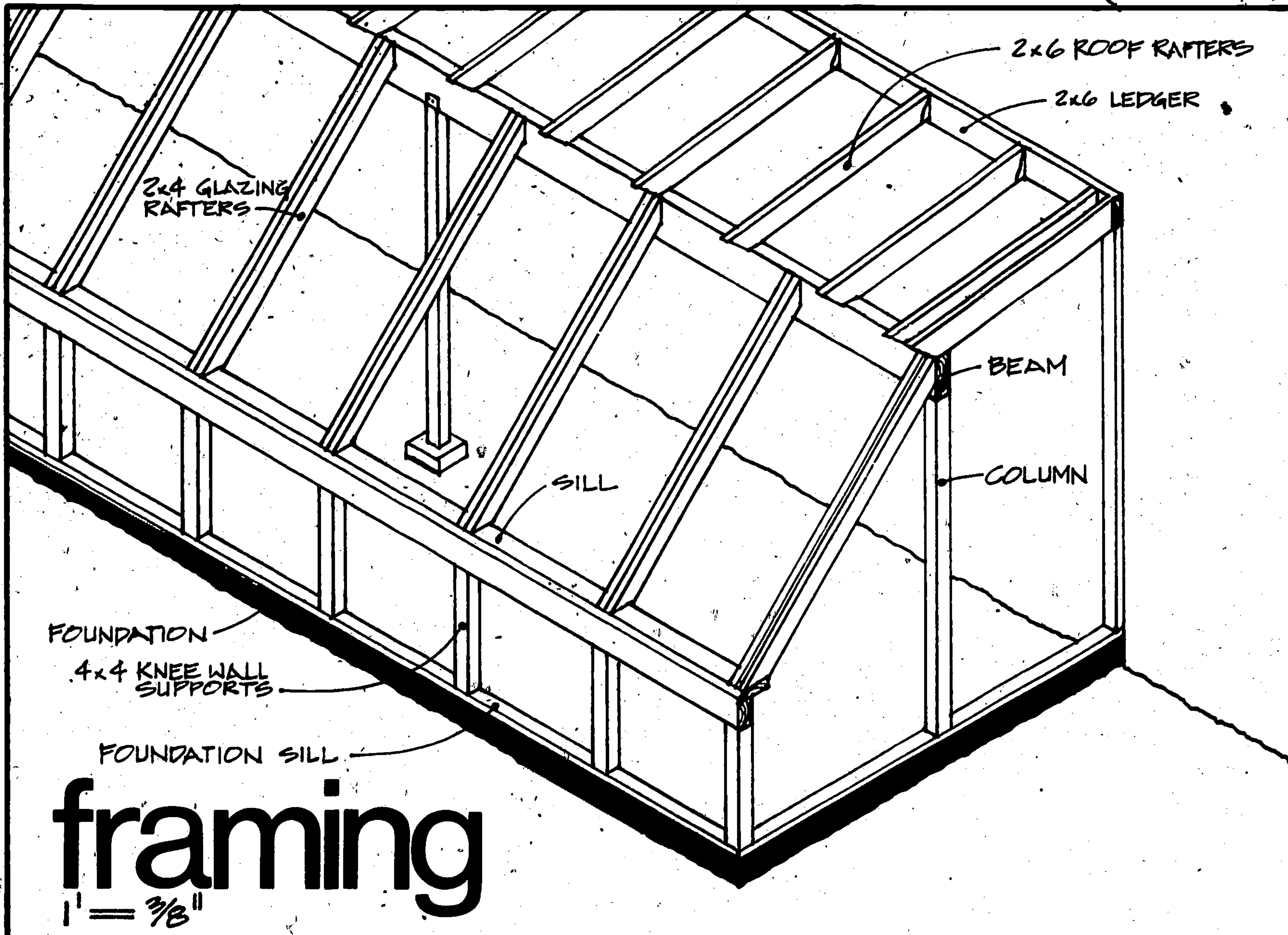
2x6 ROOF RAFTERS
2x6 LEDGER
2x4 GLAZING RAFTERS
BEAM
COLUMN
SILL
FOUNDATION
4x4 KNEE WALL SUPPORTS
FOUNDATION SILL
framing
1' = 3/8"

FIG. J-7

3. CONSTRUCTION SEQUENCE

A. Construct the **built-up beam** that will support the glazing rafters and the roof. If the greenhouse is less than 16′ long in an east and west direction, this beam can be made by bolting together two 2 x 10's with a layer of ½″ plywood in between. If the greenhouse is longer than 16′, then either a larger beam or an interior column will be necessary.

B. Place the beam in its correct location by supporting it with two 4 x 4 columns at each end. The ends of the beam should be plumb with the outside edge of the foundation. Brace the columns and beam with temporary diagonal braces until the roof rafters and walls are in place. Make sure the beam is level and is at the correct height above the foundation.

C. Nail or screw 2 x 6 **ledger plate** on the house wall. Hold a 2 x 6 board against the ends of the ledger and beam and trace their outlines with a pencil, then cut all the roof rafters to this pattern. Nail the pre-cut 2 x 6 roof rafters from the ledger to the beam on 24″ centers. There should be enough downward slope towards the south to allow rain to run off easily. Use **joist hangers** to connect the rafters to the ledger.

D. Build the **knee wall** on the ground, then tilt it into place on the foundation wall. Since the glazing rafters will be on 35″ centers, the 4 x 4 knee wall supports (mullions) should be on 35″ centers also. Knee wall windows can be made with 2 x 2 frames and double strenth glass. A brass piano hinge at the top of the windows allows them to swing outward so as not to disturb the plants and to remain open while it is raining. Screened frames can be placed in the openings in summer to keep out insects and can be removed in winter so that adequate sunlight can enter.

E. Determine the cutting pattern for the glazing rafters by holding a 2 x 4 against the end of the beam and the sill. After cutting the patterns, nail or screw together two of the pre-cut 2 x 4's to make each glazing rafter 3″ wide and 3½″ deep. Since these rafters will be exposed, be careful not to damage them during preparation or installation. Screw the glazing rafters into the beam and the sill with 4″ x ¼″ wood screws. Fig. J-8 shows the glazing details at the east and west ends of the greenhouse.

F. Frame the side walls with 2 x 4's on 24″ or 16″ centers. The connection or the wall studs to the roof rafters is shown in Fig. J-9. Wall vents are screened openings with insulated doors that swing inwards. The vent doors are made from a 2 x 2 frame with ¼″ plywood nailed to both sides and bead board insulation on the inside. Be sure to weatherstrip all vents, doors, and windows so they are air-tight when closed.

G. Paint the glazing rafters and the sill with two cots of clear marine varnish. When dry, apply a continuous bead of **clear silicone rubber** on the top edge of each rafter and beveled edge of the sill and then install the glass. Nail temporary wood blocks below the sill to prevent the glass from sliding off the rafters before the silicone rubber dries. After the rubber dries, remove the blocks and install the batten strips, which can be either 1 x 4 cedar or galvanized steel. Next, install the **gutter** with downspouts at each end. The gutter is very important because it prevents water from saturating the knee wall and lessening the chances for decay and leakage. The gutter can also be utilized to collect rain water for the plants.

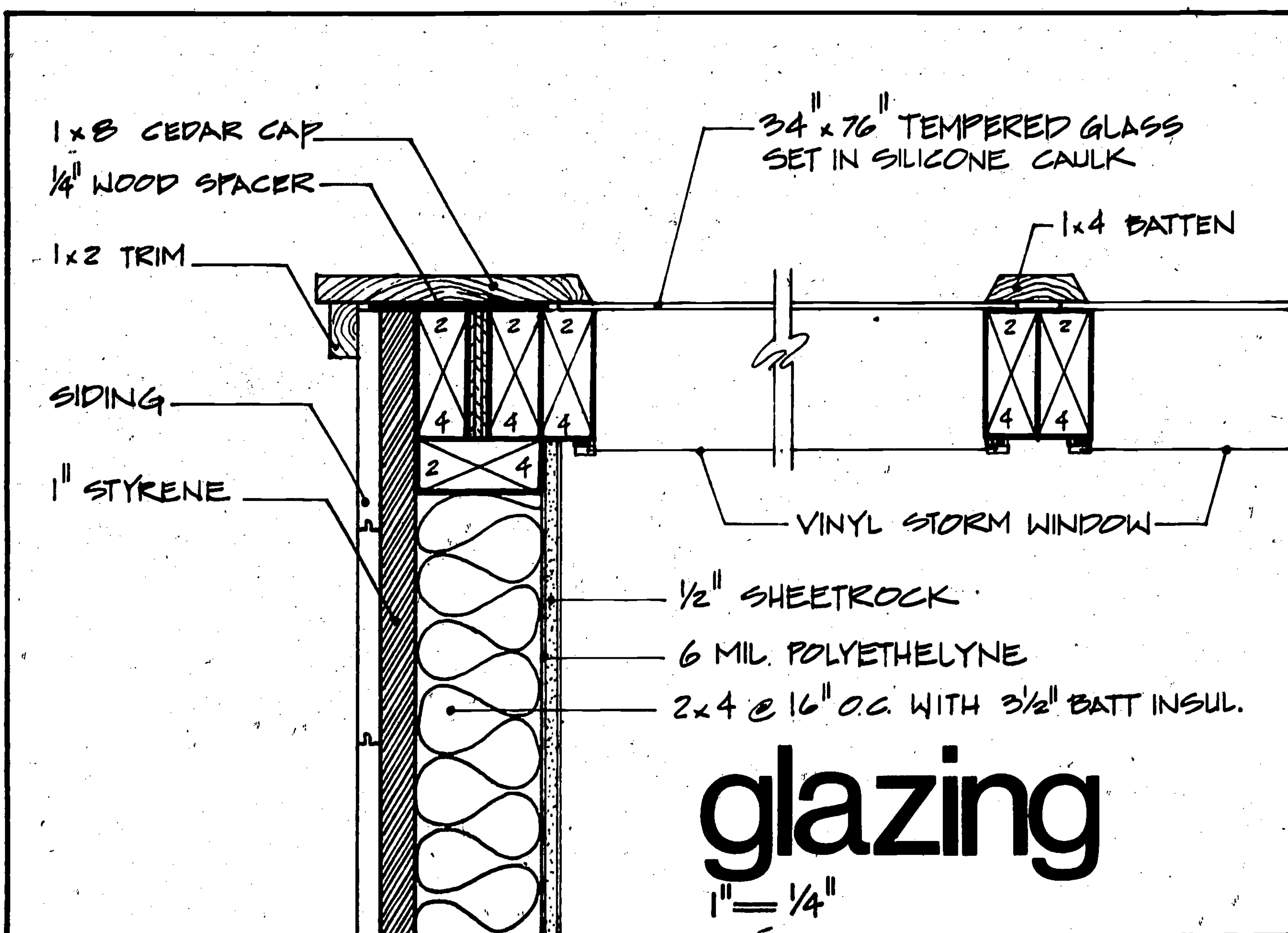
1x8 CEDAR CAP
1/4" WOOD SPACER
1x2 TRIM
SIDING
1" STYRENE
34" x 76" TEMPERED GLASS SET IN SILICONE CAULK
1x4 BATTEN
VINYL STORM WINDOW
1/2" SHEETROCK
6 MIL. POLYETHELYNE
2x4 @ 16" O.C. WITH 3 1/2" BATT INSUL.
glazing
1" = 1/4"

FIG. J-8

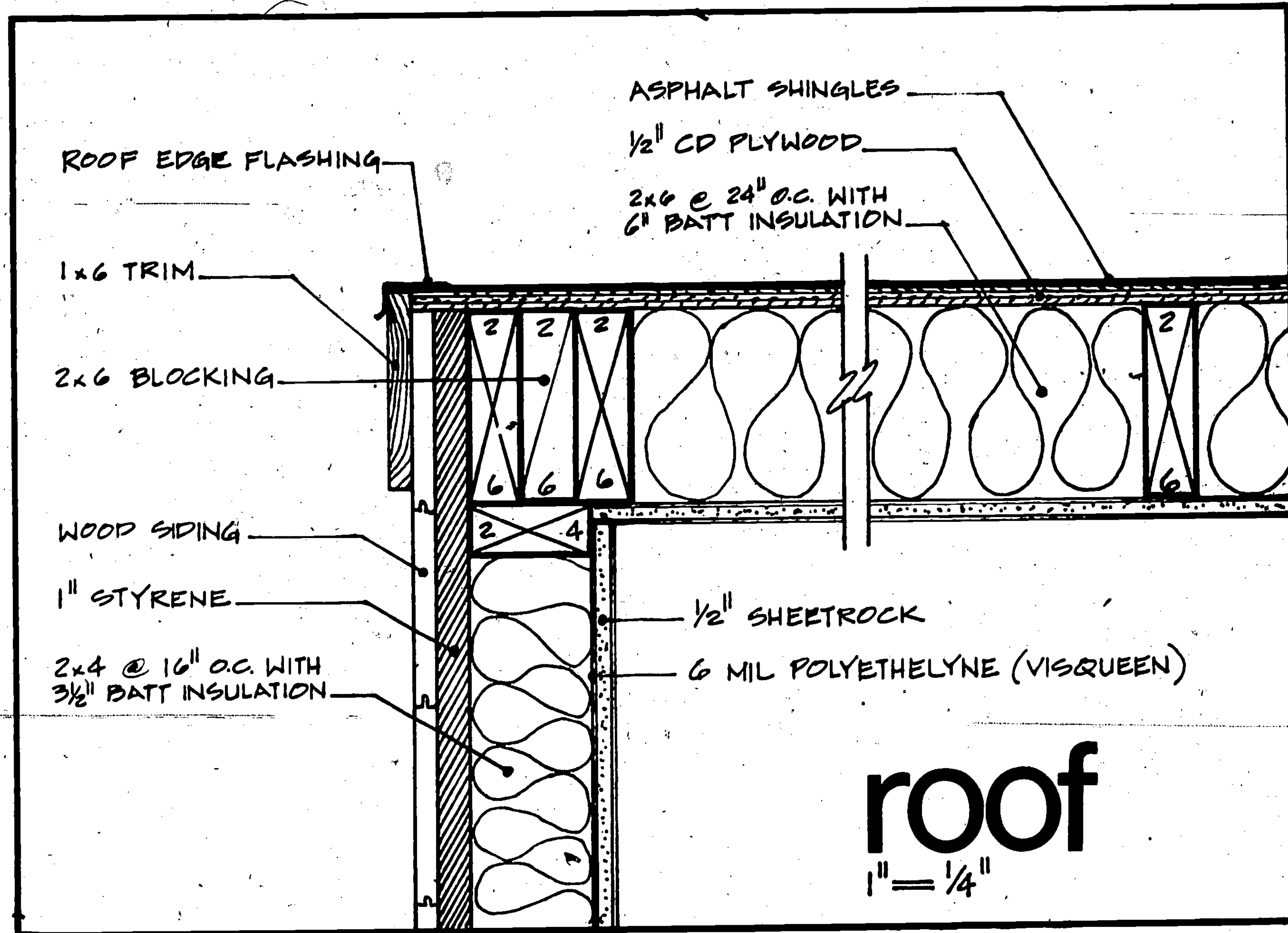
ASPHALT SHINGLES
1/2" CD PLYWOOD
ROOF EDGE FLASHING
2x6 @ 24" O.C. WITH
6" BATT INSULATION
1x6 TRIM
2x6 BLOCKING
WOOD SIDING
1" STYRENE
1/2" SHEETROCK
6 MIL POLYETHELYNE (VISQUEEN)
2x4 @ 16" O.C. WITH
3½" BATT INSULATION
roof
1" = 1/4"

FIG. J-9

H. Finish the outside of the roof with ½" CD plywood decking, 15 lb. felt, and asphalt shingles or roll roofing to match your existing house roof. Nail 1" bead board to the outside walls, then tape or caulk all the joints from the outside to prevent air leaks. Apply whatever siding material you desire to the bead board sheathing. The inside of the walls and roof are finished with fiberglass insulation (3½" in walls and 6" in roof), a 6 mil polyethylene vapor barrier, and ½" sheetrock (preferably the waterproofed type). Paint the walls and ceiling with two coats of white exterior latex or enamel. An alternative interior finish is ¼" masonite that has a plastic laminate surface on one side.

I. The framing for the beds may be treated with **copper naphthenate** to resist rotting; do not use creosote or pentachlorophenol (penta) to treat lumber in a greenhouse, because these substances are harmful to plants.

J. Place 4" to 6" of pea gravel on the floor and 55-gallon dark-painted barrels of water against the house wall. (See section on "Heat Storage") More planting beds and shelves can be placed above the barrels, making the total planting area at least equal to the floor area.

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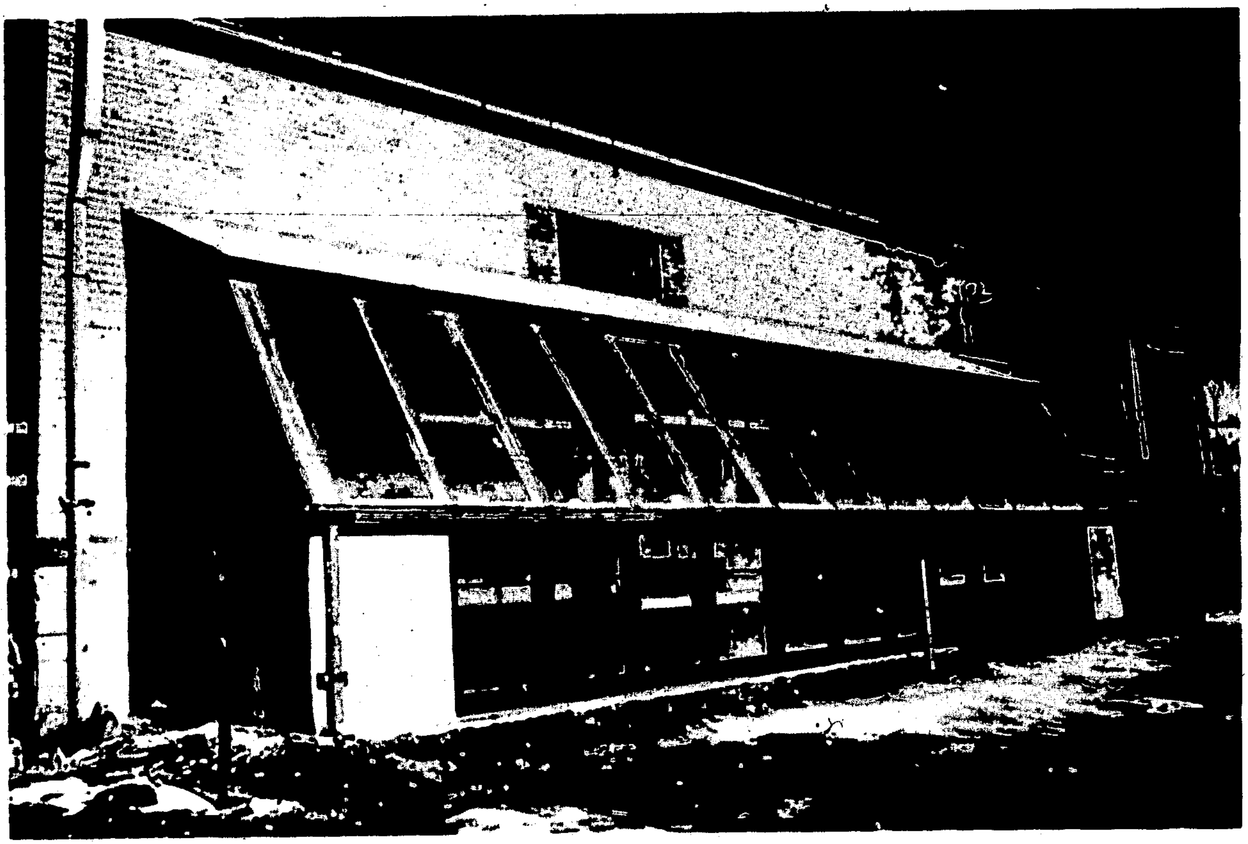
K. CASE STUDIES



Owner: Ozark Food Co-Op
Location: Fayetteville
Length: 40′ **Width:** 8′ **Area of Floor:** 320 sq. ft.
Tilted South Glazing: 366 sq. ft. **Type:** 34″ x 76″ tempered glass panels with an inner layer of 4 mil polyethylene in winter
Vertical South Glazing: 132 sq. ft. **Type:** 48″ x 34″ removable awning windows glazed with double strength glass and an inner layer of 4 mil polyethylene in winter
East Vents: 28 sq. ft. **Type:** a 3′ x 6′-8″ door with screen door and an upper 2′ x 4′ wall vent
West Vents: 12 sq. ft. **Type:** upper wall vent
Roof Vents: None
Openings to Building: 40 sq. ft. **Type:** 5′ x 8′ doorway (a 200 CFM thermostatically controlled blower also delivers air to the building)
Thermal Storage: Nine 55 gallon barrels of water (4140 lbs) and a 1′ thick brick wall (existing)
Planting Arrangement: Upper and lower shelves along south knee wall (80 sq. ft.) for flats and pots and 20 sq. ft. of ground level beds against the north wall
Shading: None at present. Although the vents along the knee wall provide much ventilation, it is felt that some shading will be necessary in summer

CONSTRUCTION

Floor: Earth
Foundation: Poured concrete grade beam (6″ x 18″) with 2″ bead board on the inside surface
Side Walls: ½″ plaster on metal lath, ½″ fiber board sheating, 2 x 4's on 24″ centers with 3½″ fiberglass, 4 mil polyethylene vapor barrier, ½″ sheetrock
Glazing Rafters: No. 2 pine 2 x 4's on 36″ centers; painted white
Roof: asphalt shingles, 15 lb. felt, ½″ CD plywood, 2 x 6's on 24″ centers with 6″ fiberglass batts, 4 mil polyethylene, ½″ sheetrock

COSTS

Materials: $1400 (Labor Cost: $1266)
Builder: Joe Henry

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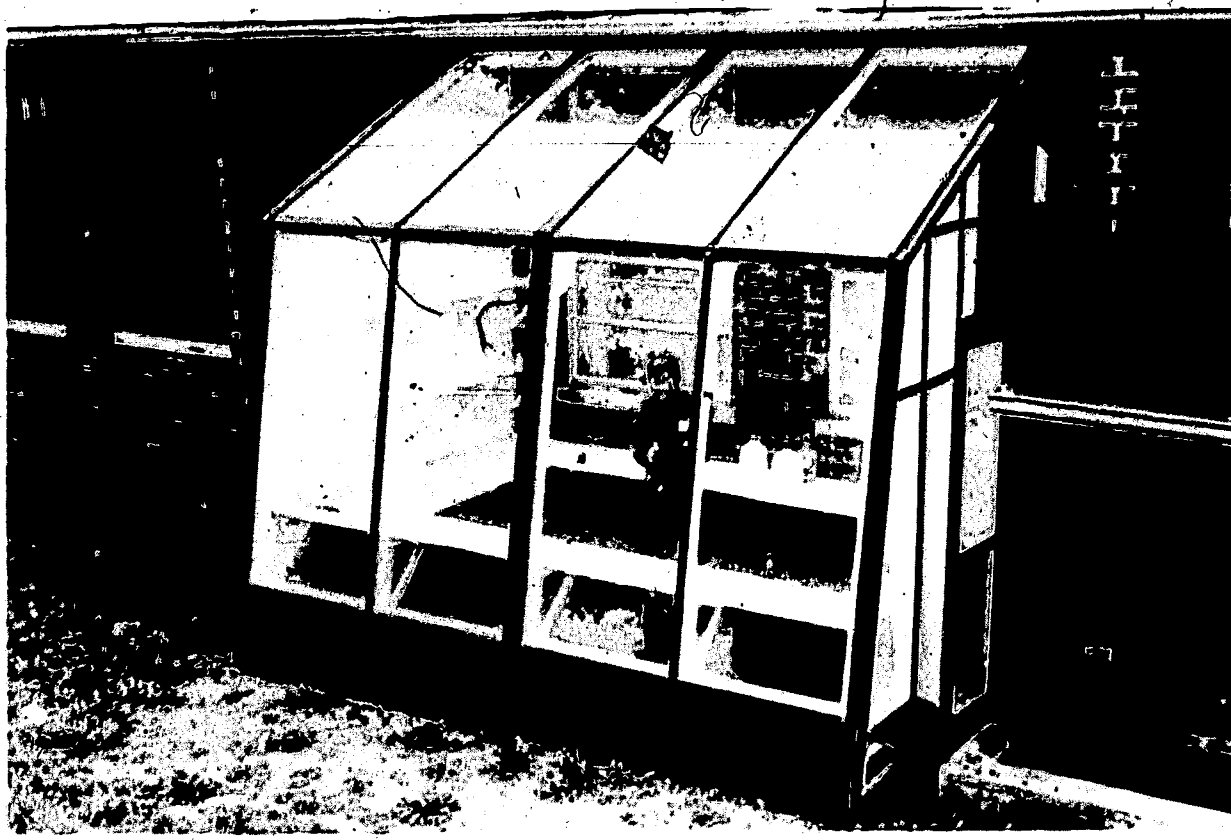

Owner: Northwest Arkansas Economic Development District, Inc.
Location: Harrison Senior Center, Harrison
Length: 12′ **Width:** 8′ **Area of Floor:** 96 sq. ft.
Tilted South Glazing: 72 sq. ft. **Type:** 34″ x 76″ tempered glass panels (single glazed)
Angle: 85°
Vertical South Glazing: None
Roof Glazing: 72 sq. ft. **Type:** 34″ x 76″ tempered glass panels (single glazed)
East Vents: 2.5 sq. ft. **Type:** upper (12″ x 20″) and lower (8″ x 12″) wall vents
West Vents: Same as east vents
Roof Vents: None
Openings to Buildings: 48 sq. ft. **Type:** Two 4′ x 6′ awning windows
Thermal Storage: Seven 55 gallon barrels of water
Planting Arrangement: removable flats on top of barrels; planting is done entirely in pots and seedling trays
Shading: None—the building is not used in summer

CONSTRUCTION

Floor: 4″ pea gravel
Foundation: 6″ x 18″ poured concrete grade beam, no insulation
Side Walls: 3/8″ plywood, 2 x 4's on 24″ centers with 3½″ fiberglass batts, ½″ bead board
Glazing Rafters: Double 2 x 4's on 34″ centers, plywood gussets at south roof edge
Roof: Same as tilted south glazing

COSTS

Materials: $780
Builder: Allen Grogan

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Owner: Pulaski County Council on Aging
Location: Community Center, Little Rock
Length: 27'-10" **Width:** 8' **Area of Floor:** 216 sq. ft.
Tilted South Glazing: 144 sq. ft. **Type:** 34" x 76" double glazed tempered glass panels
Vertical South Glazing: 81 sq. ft. **Type:** 34" x 36" awning windows with double strength glass and an inner layer of clear vinyl
East Vents: 8 sq. ft. **Type:** Upper wall vent
West Vents: 20 sq. ft. **Type:** 3' x 6'-8" door and screen door
Roof Vents: Four 12" diameter turbine ventilators with interior shutters
Openings to Building: 48 sq. ft.
Thermal Storage: Eighteen 55 gallon barrels of water (82566 lbs.) along north wall and south knee wall, an existing 1' thick solid brick wall and 162 cubic feet of soil (8000 lbs.)
Planting Arrangement: Upper and lower beds (24" wide and 12" deep) along the knee wall and a similar bed above the barrels on the north wall for a total of 162 sq. ft.

CONSTRUCTION

Floor: 4" of pea gravel
Foundation: An 8" x 18" poured concrete grade beam, with 2" bead board on the inside surface
Side Walls: 1 x 6 pine siding, 1" bead board, 2 x 4's on 16" centers with 3½" fiberglass batts, 4 mil polyethylene vapor barrier, and 3/8" plywood
Glazing Rafters: No. 2 double 2 x 4's on 36" centers
Roof: asphalt shingles, 15 lb. felt, ½" CD plywood, 2 x 6's on 24" centers with 6' fiberglass batts, 4 mil vapor barrier, 3/8" plywood

COSTS

Materials: $3000
Builder: George Flake (supervisor) and the Opportunity Industrialization Council weatherization staff

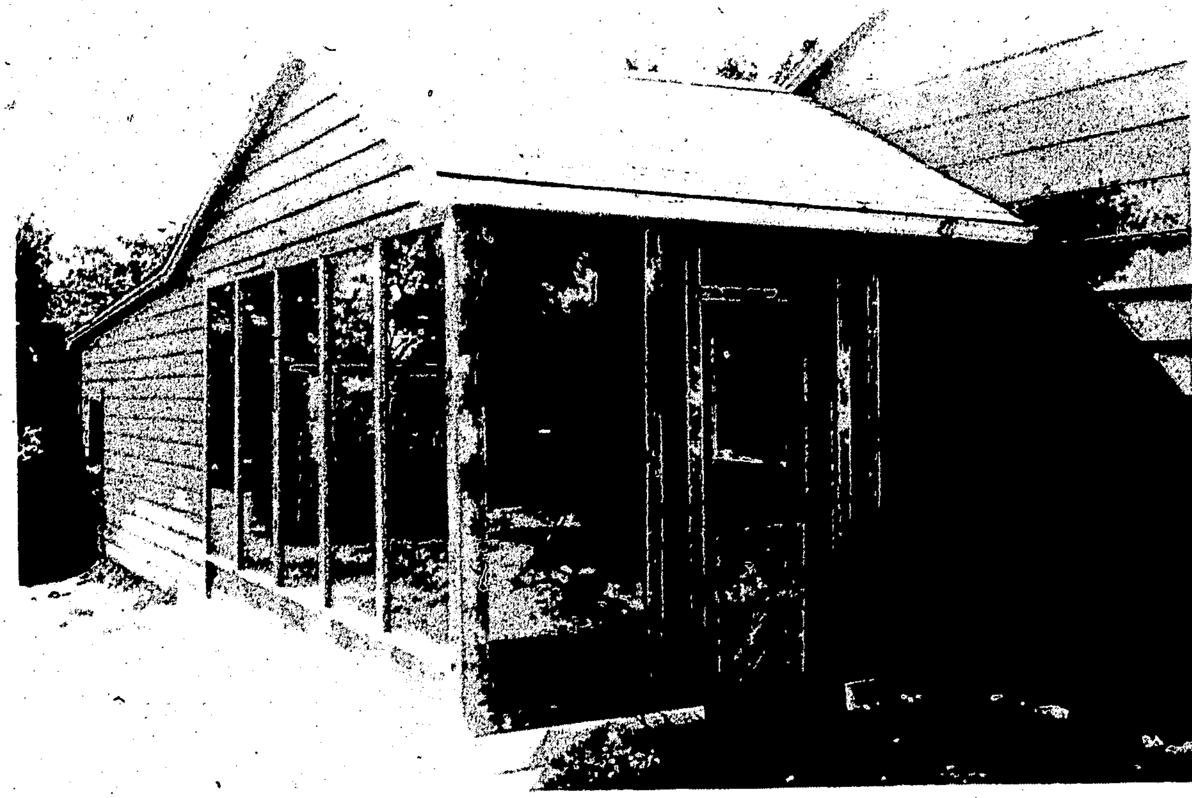
Owner: Sam and Helen Armstrong
Location: Rogers
Length: 27'-10" **Width:** 8' **Area of Floor:** 222 sq. ft.
Tilted South Glazing: 162 sq. ft. **Type:** 34" x 76" tempered glass panels with an inner layer of vinyl storm windows in winter
Vertical South Glazing: None
East Vents: 8 sq. ft. **Type:** 2' x 4' upper wall vent
West Vents: 20 sq. ft. **Type:** 3' x 6'-8" door with screen door
Roof Vents: None
Openings to House: 30 sq. ft. **Type:** a 3' x 6'-8" glass door and two 10 sq. ft. double hung wood windows
Thermal Storage: Fifteen 55 gallon barrels of water (6881 lbs.) stacked against the house wall
Planting Arrangement: 128 sq. ft. of shelves for trays and pots; upper and lower shelves along south knee wall and staggered shelves and hanging pots along the house wall
Shading: A polypropylene shade cloth rated at 50% light transmission

CONSTRUCTION

Floor: 4" pea gravel
Foundation: A 6" x 18" poured concrete grade beam with 2" bead board insulation on the outside surface
Side Walls: 1 x 8 pine siding, ½" fiberboard sheathing, 2 x 4's with 3½" fiberglass batts, 4 mil polyethylene vapor barrier, ½" sheetrock
Glazing Rafters: No. 2 pine double 2 x 4's on 36" centers
Roof: asphalt shingles, 15 lb. felt, ½" CD plywood, 2 x 6's on 24" centers with 6" fiberglass batts, 4 mil polyethylene vapor barrier, ½" sheetrock

COSTS

Materials: $800 **Labor Cost:** $800 (includes cost of building new door into house)
Builder: Joe Henry



Owner: Ralph Nesson and Kate Conway
Location: Fayetteville
Length: 16′ **Width:** 10′ **Area of Floor:** 160 sq. ft.
Vertical South Glazing: 90 sq. ft. **East:** 40 sq. ft. **Type:** 34″ x 76″ tempered glass panels
South Vents: 15 sq. ft. **Type:** 34″ x 12″ lower wall vents
East Vents: 26 sq. ft. **Type:** 3′ x 6′ x 8′ door and two 36″ x 12″ lower wall vents
West Vents: None
Roof Vents: None
Oenings to House: 20 sq. ft. **Type:** 6′ x 6′-8″ sliding glass door
Thermal Storage: Five 55 gallon barrels of water (2294 lbs.) and an existing 4″ concrete slab
Planting Arrangement: Flats on top of the barrels and shelves on north wall
Shading: None required for vertical glazing

CONSTRUCTION

Floor: Existing 4″ concrete slab (previously a garage)
Foundation: Existing edge of slab floor
Side Walls South and East: 4 x 4 cedar posts on 36″ centers with the tempered glass panels in between
Roof: Existing garage roof of 2 x 4 trusses on 24″ centers with 6″ fiberglass batts

COSTS

Materials: $500 **Labor Cost:** $800
Builder: Joe Henry

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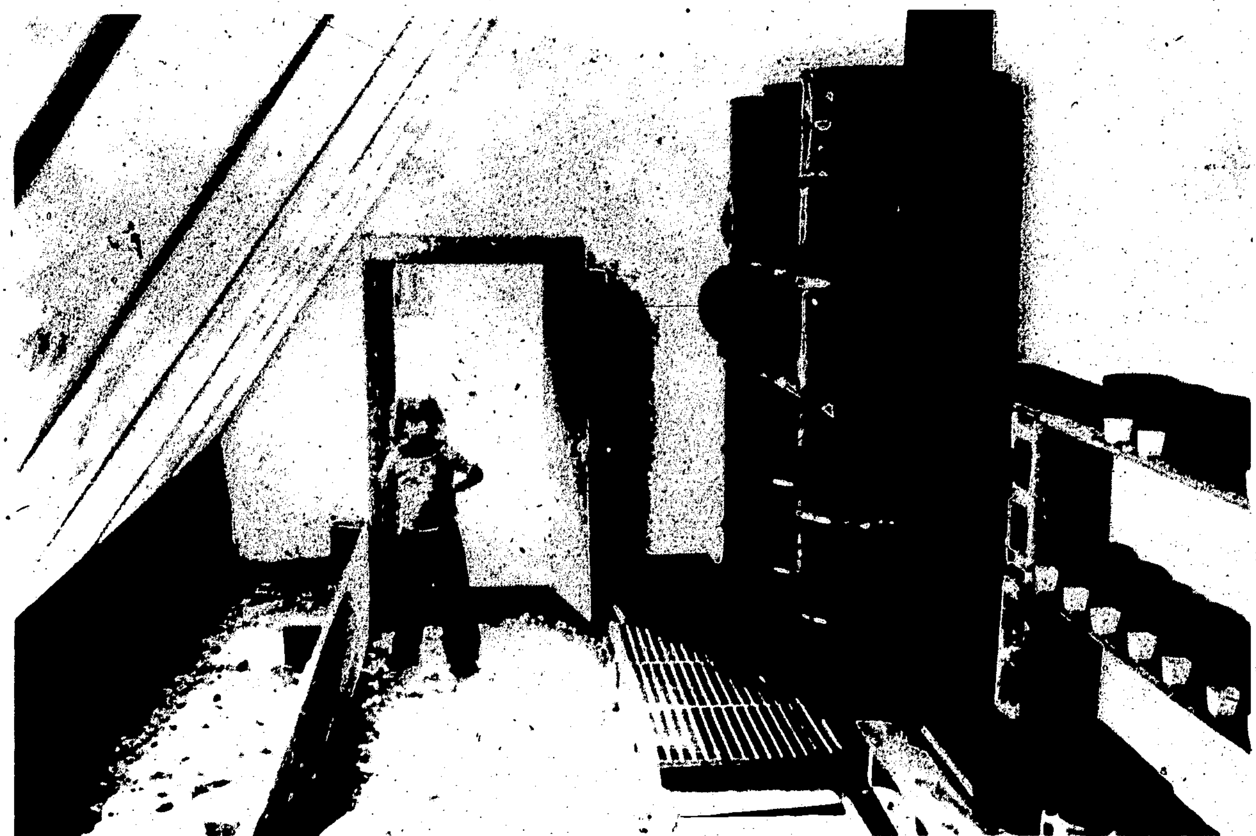

Owner: Office of Human Concern, Inc.
Location: Siloam Springs Child Development Center
Length: 18'-10" **Width:** 8'-6" **Area of Floor:** 144 sq. ft.
Tilted South Glazing: 108 sq. ft., 34" x 76" tempered glass panels with an inner layer of clear vinyl storm windows in winter
Vertical South Glazing: None
East Vents: 20 sq. ft. **Type:** 3' x 6'-8" door with screen door
West Vents: 12 sq. ft. **Type:** 3' x 4' kid's door
Roof Vents: Two 10' x 12" round thermal chiminies with interior shutters
Openings to House: One 350 CFM blower on a thermostat for air delivery and a 6" x 24" lower vent by return air
Thermal Storage: Nine 55 gallon barrels of water stacked against north wall
Planting Arrangement: 54 sq. ft. of south ground bed and 72 sq. ft. of stepped pallets (for seedling trays) against north wall
Shading: There is partial shading from nearby trees in summer

CONSTRUCTION

Floor: Earth
Foundation: 4 x 4 treated cedar posts every 3'; 1 x 6 cedar boards on each side with 3½" fiberglass insulation between posts. Tar and felt waterproofing
Side Walls: ½" plaster on metal lath, 1" bead board, 2 x 4's on 16" centers with 3½" fiberglass, 6 mil polyethylene vapor barrier, 1" bead board, and ½" plaster on metal lath
Glazing Rafters: Double 2 x 4's (No. 2 pine) on 36" centers
Roof: Asphalt shingles, 15 lb. felt, ½" CD plywood, 2 x 6's on 24" centers with 6" fiberglass, 6 mil polyethylene vapor barrier, ½" plaster on metal lath

COSTS

Materials: $750
Builder: Joel Davidson, Steve Mescha, and Robert Knapp of the Office of Human Concern

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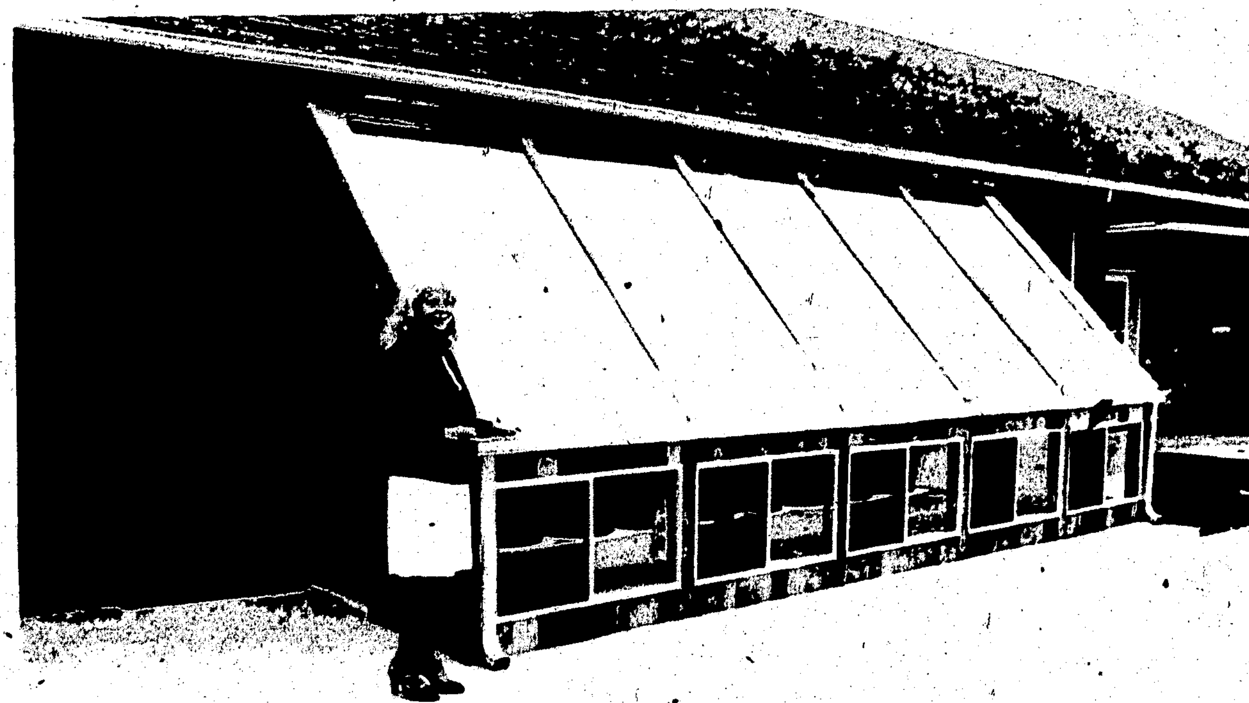


Owner: Sebastian County Roads Department
Location: Road Maintenance Building, Greenwood
Length: 20'-7" **Width:** 8'-6" **Area of Floor:** 160 sq. ft.
Tilted South Glazing: 160 sq. ft. **Type:** 46" x 91" tempered glass panels with an inner layer of 6 mil polyethylene in winter
Vertical South Glazing: 50 sq. ft. **Type:** 3' x 2'-6" aluminum sliding glass windows for a total vent area of 25 sq. ft. (screened in summer)
East Vents: 8 sq. ft. **Type:** 2' x 4' upper wall vent (with screen)
West Vents: 20 sq. ft. **Type:** 3' x 6'-4" door with screen door
Roof Vents: None
Openings to House: One 350 CFM dust fan on a thermostat delivers air to an office area through two 8" diameter ducts. Return air is from one 12" diameter duct
Thermal Storage: Ten 55 gallon barrels of water (4565 lbs.), existing brick wall, 4" concrete slab floor, and 2500 lbs. of soil in planting beds.
Planting Arrangement: Upper and lower beds along south knee wall (33 sq. ft. each) and a bed above the barrels along the north (existing) wall for a total of 105 sq. ft. of planting beds
Shading: a polypropylene shade cloth rated at 50% light transmission is secured to the outside of the tilted glazing in summer

CONSTRUCTION

Floor: Existing 4" concrete slab
Foundation: Two courses of 4 x 4 cedar posts attached to existing slab with lag bolts every 4'
Side Walls: ¼" masonite siding, 1" bead board, 2 x 4's on 16" centers with 3½" fiberglass, 6 mil polyethylene vapor barrier, ½" sheetrock
Glazing Rafters: No. 2 pine double 2 x 4's on 48" centers
Roof: asphalt shingles, 15 lb. felt, ½" CD plywood, 2 x 4's on 24" centers with 3½" fiberglass, 6 mil polyethylene vapor barrier, 1" bead board, ½" sheetrock

COSTS

Materials: $848 (barrels and some lumber supplies were donated)
Builder: Monica Rojek of Community Energy Futures, Inc. (supervisor) and the Sebastian County Roads Department staff

III. SOLAR AIR HEATERS

A. FUNDAMENTALS

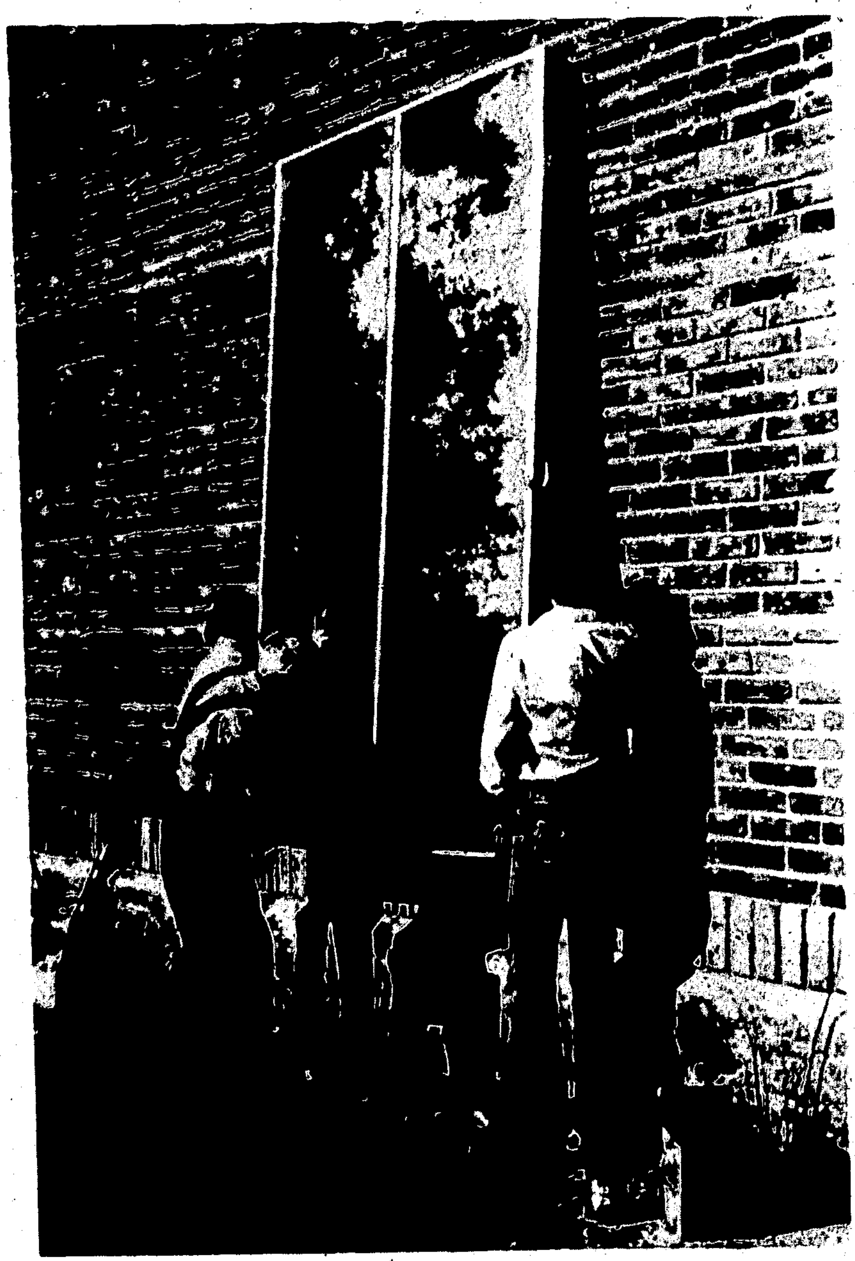
Solar air heaters are simple devices that utilize solar energy to help heat buildings in winter. Air heaters are probably the lowest costing and most efficient solar device you can build to reduce home energy costs.

The basic principles of all solar air heaters are the same. A black-painted piece of metal, called the **absorber,** is mounted within a shallow frame. Next, the frame is covered by a sheet glazing (glass or fiberglass), which faces south. As sunlight passes through the glazing and strikes the absorber, it causes the black absorber to get hot; much hotter than it would if there were no glazing. Air is drawn from inside the house, across the absorber, where it picks up heat, and then back into the house. During its circuit, the air will rise in temperature anywhere from 20° F to 30° F. The frame, the absorber, and the glazing make up what is called a **solar air collector.**

Most solar air heaters built in Arkansas are active collectors; that is, they use an electrical fan (blower) that is thermostatically controlled to blow air across the absorber when it is hot enough to produce heated air. Solar air heaters can also be passive, relying only on the principal of **gravity convention** or **thermosiphoning,** which is the natural movement of air due to differences in temperature. As the sun heats the absorber, the air around it gets hot, causing it to expand and rise out of the collector and into the house through an upper vent, thus drawing cooler room air into the collector through a lower vent. Although active solar air heaters require electricity to operate, they are still very simple and generally will deliver more BTU's per dollar than passive solar air heaters.

Solar air heaters can be further categorized as either **modular** or **site built.** Modular solar air heaters refer to small (usually 4′ x 8′) units that provide heat for a room that is used in the daytime. Site-built solar air heaters operate the same as modular air heaters, but they are larger (8′ x 8′ or bigger) and are more economically built in place at the site. Typically, site-built solar air heaters cover most of the south wall of a home to provide a large portion of the heating needs. Since large amounts of heat are produced, ducts are often used to distribute the heat to various rooms, and sometimes thermal storage systems, such as rock beds, are utilized to store excess heat for use at night and on cloudy days.

New Life Farm, Inc. (Drury, MO 65638) has built many site-built solar air heaters throughout the Ozarks. Their manual, "Simple Solar Air Heaters," by Ron Hughes, ($3.50) is an excellent reference for learning the many different possibilities for adapting air heaters to homes and other buildings.



The Office of Human Concern (OHC) of Rogers has conducted twenty solar air heater workshops for individuals, vo-tech schools and community agencies throughout Arkansas. The 4' x 8' collector shown here is being installed by local residents onto a community center in Gravette.

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Construction of the O.H.C. solar air heater requires only simple carpentry skills. In the photo above, the absorber (aluminum roofing) is being fitted within the collector frame during a construction workshop in Blytheville.

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B. MODULAR SOLAR AIR HEATERS

Modular air heaters have been ideal for the purposes of several community agencies in Arkansas who have built and installed over 100 units on the homes of elderly, low-income families during the past two years.

The first modular solar air heater in Arkansas, and the standard by which most others have been built, was developed by Joel Davidson and Bill Brown of the Office of Human Concern (OHC) in Rogers. They saw a need for air heaters as the next logical step to reduce fuel consumption in homes that had already been weatherized. Their objectives were to design a low-cost solar air heater that could be:

1. Built in quantity with simple carpentry tools and skills.

2. Assembled easily and cheaply by using standard 4 x 8 components for the glazing, absorber, and backing.

3. Delivered and installed in less than a day.

4. Completely automatic.

5. Durable enough to last at least 10 years without maintenance.

Figure B-1 illustrates the construction of the collector, which is mounted either vertically or horizontally against the south wall of the house. The area between the absorber and the glazing is a dead air space which is vented in summer by thermostatic vents to prevent overheating. The air flows through a 1½" x 24" air gap behind the corrugated aluminum absorber. (The depth of 1½" includes the depth of the corrugations.) A 200 CFM squirrel-cage blower pushes the air in a U-shaped path around a center baffle for a total air run of 16 feet.

Jim Free, of the Crowley's Ridge Development Council in Jonesboro, has designed a variation of the OHC

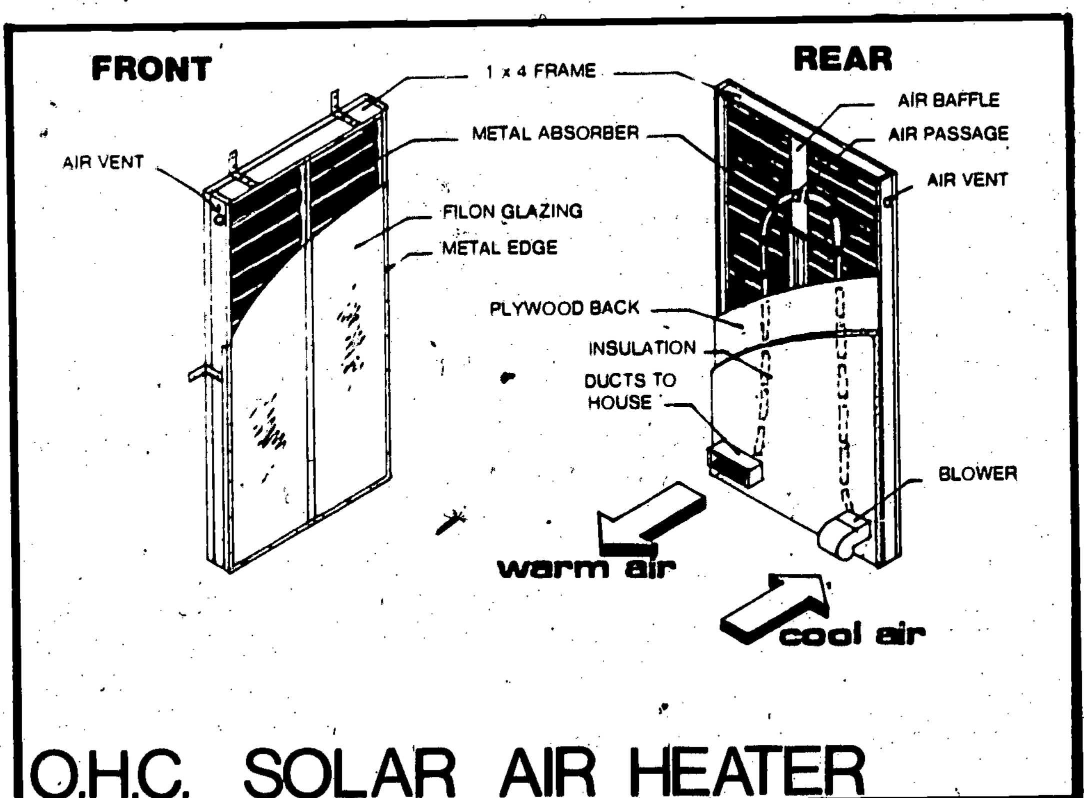

FIG. B-1

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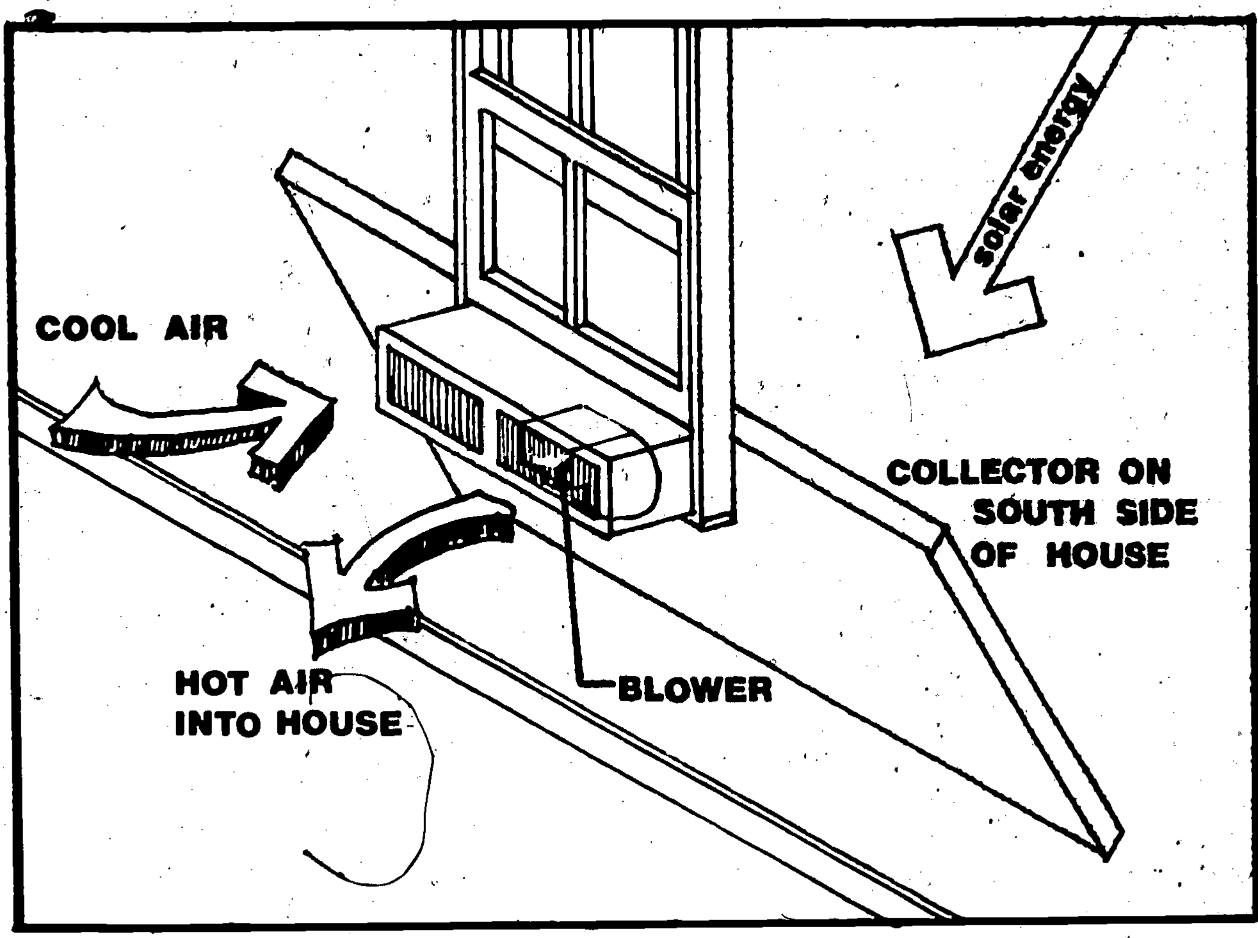

FIG. B-2

collector. Air is blown both in front of and then behind the absorber for a total run of 32 feet. To compensate for the increased distance of air flow, the air gap has been increased to about 1-½″ on each side of the absorber. Jim recommends a 200 to 350 CFM blower.

Another modular solar air heater based on the OHC model has been developed by Peter Scholls of the Crawford-Sebastian Community Development Council in Van Buren. This unit is identical to the OHC version except that a 10″ propeller-type duct fan instead of a squirrel cage blower is used. The duct fan has the advantage of fitting flush within the wall for more quiet and unobtrusive operation. Since propeller-type fans have less power than squirrel cage blowers to force air through the collector, the duct fan requires a higher CFM rating of 425 to 600.

Each of these three collectors costs about $110 if the components are bought at wholesale prices and about $150 if the materials are bought at retail prices, as they would be for homeowners who wish to build one or more units for themselves. A free, illustrated, step-by-step manual on construction, operation, and performance of the OHC collector is available from the Office of Human Concern, P.O. Box 756, Rogers, Arkansas 72756. A similar construction guide of Jim Free's collector design is available from the Crowley's Ridge Development Council, Jonesboro, Arkansas.

Larry Bueg, of the Energy Center, Inc. in Lowell, recently designed a 4′ x 8′ modular solar air heater that is quite different from any built in Arkansas. As shown in Figure B-2, this unit mounts directly into the lower part of a south window, eliminating the time and expense of putting ducts through the wall. Instead of being mounted flush against the wall, this collector has brackets which can adjust the collector to the optimum angle for solar collection in winter.

The absorber, which also serves as the insulation and back of the collector, is a 4' x 8' x 1" sheet of rigid, high-temperature fiberglass. Black aluminum foil covers the fiberglass to serve as the heat-absorbing surface. Galvanized steel baffles create a serpentine air flow in front of the absorber. Total length of air run is 32', with an air gap of 2".

The manifold that projects through the window is divided into two halves, one side serving as the air intake into the collector and the other side housing a small squirrel cage blower. Unlike the arrangements in the previously mentioned collectors, this blower pulls instead of pushes air through the collector.

It was found that much more air is delivered to the room when the blower is mounted on the delivery side of the manifold rather than the intake side.

The collector is framed in sheet metal with a fiberglass glazing, making it very lightweight and weatherproof. In summer, the unit can be easily removed from the window and stored in the garage or, better yet, can be utilized as a solar food dryer. The collector can be fitted to a cabinet with vertically arranged screen trays upon which the food is placed. Solar heated air is blown through the cabinet, thus drying large quantities of food very rapidly. Arkansas families who traditionally use canning as a means of preserving food could instead use such a device to solar dry their food, saving much time and energy. Also, dried foods have superior taste and nutritional value over canned foods.

C. PERFORMANCE

There is an urgent need to compare the performance of these collectors in side-by-side tests so that effective improvements can be made in their design. To date, all the design criteria have been based on research and demonstration projects by the San Luis Valley Solar Energy Association (P.O. Box 1284, Alamosa, CO 81101) and the Small Farm Energy Project (P.O. Box 736, Hartington, NB 68739). These two non-profit organizations have developed the rules-of-thumb for solar air collector design that have been used successfully throughout the country.

Although precise scientific measurements have not been made to compare performance among the air heaters, studies have been done to assess the general effectiveness of the OHC collector. The following is an excerpt from the OHC air heater manual that describes the results of tests conducted from October 10, 1979 to February 26, 1980:

"Ten homes occupied by low-income elderly people in Benton, Carroll and Madison Counties were fitted with solar air heaters in September of 1979. Seven of the homes were heated with natural gas and three of the homes were heated with propane. (Wintertime) fuel consumption for each home from 1977 to 1980 was obtained from fuel suppliers (Arkansas Western Gas and Sungas).

In the test homes, the dollar savings (caused by the air heaters) ranged from 6.3% to 13.44%, with an overall average of 9.87%. It is expected that this figure will increase with the use of the larger blower (200 CFM) and the addition of an adjustable thermostat that will extend the daily hours of operation."

The decision to change to a 200 CFM blower was a result of the tests conducted in January of 1980 by Dr. Thomas Rokeby, a consulting engineer who is director of the solar poultry house project at the University of Arkansas in Fayetteville. He tested several different sizes of blowers to determine air flow characteristics of the air heater and concluded that the larger blower would increase heat production by about 38%.

More tests were performed on the OHC air heater in December of 1980 by Russ Garton and Steve Metcalf, graduate students in mechanical engineering at the University of Arkansas in Fayetteville. They determined the average efficiency of the collector to be 48.5%, which is very good when compared to similar air heaters built by the Small Farms Energy Project and others.

For Little Rock, a vertical south-facing surface will receive an average of 152,140 BTU/ft² total solar radiation during the heating season (November to March). Therefore, a collector of 32 square feet and 45% efficiency would deliver:

$$152{,}140 \text{ BTU/ft}^2 \times 32 \times .45 = 2{,}190{,}816 \text{ BTU}$$

The value of 2,190,816 BTU's of heat for houses that use electricity, natural gas or propane to heat their homes in 1981 is:

Electricity
2,190,816 BTU = 641 Kilowatt/Hours
At 6¢ per KWH, you save
.06 × 641 = $38.46

***Natural Gas**
2,190,816 BTU = 2.12 MCF
At 3.50 per MCF, you save
2.12 × 3.50 × 1.30 = $9.65

***Propane Gas**
2,190,816 BTU = 23.8 GAL
At .80 per gallon, you save
23.8 × .80 × 1.30 = $24.75

*Whereas electrical heating is 100% efficient, you only get about 70% of the BTU's available in each unit of gas (the rest goes up the flue). So an efficiency factor of 1.30 is included in the value of each unit of gas that is saved by solar energy.

If you spend $150 to build an air heater and take the 40% federal tax credit, the actual cost is only $90. With prices of electricity, natural gas and propane rising dramatically, an investment in an air heater will pay for itself in two to five years.

D. DESIGN METHODS

The basic rules of the thumb for designing solar air heaters are:

1. The baffle layout in the collector should be such that no single **air run**, the distance between the inlet and the outlet, exceeds 32 feet.

2. The "delivered" air flow should equal 3 CFM per square foot of collector. The **delivered** (or actual) air flow is the fan's rated capacity (CFM) after it has gone through the collector. This capacity will be less than the **free air** rating of the fan because of the resistance encountered in the collector. The average air flow reduction, called the **static pressure drop**, across a typical solar air heater is rated at .5 on an instrument that measures pressure change in inches of water in a column. Most fan and blower CFM ratings are given for both "free air" conditions

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and over a range of pressure drops. ratings are given for both "free air" conditions and over a range of pressure drops.

For example, the delivered ~~air flow~~ through a 32-square-foot collector should be: 3 CFM × 32 = 99 CFM. Since it is assumed that the pressure drop will be about .5 inches, the rating for the fan at a pressure drop of .5 inches should be at least 99 CFM. Most squirrel cage blowers with a free air rating of 200 CFM will have a delivered air flow of 100 CFM at a pressure drop of .5 inches.

3. The air gap is a function of the air flow (cubic feet per minute) and the air velocity (feet per minute). The assumed optimal air flow is 800 FPM (Feet Per Minute). Divide the free air CFM rating by 800 FPM to get the area (in square feet) of the air gap cross-section. The gap is then found by dividing the cross section area by the width of the collector air way in one direction of air flow.

For example, the free air rating for a 32-square-foot collector was determined to be 200 CFM. So:

200 CFM ÷ 800 FPM =
.25 square feet or 36 square inches.

Since the air way width is 24 inches, the gap is

36 ÷ 24 = 1.5 inches.

If corrugated roofing is used as the absorber, as in the OHC collector, the depth of the corrugations must also be counted as part of the air gap.

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IV. BATCH SOLAR WATER HEATERS

A. INTRODUCTION

Historically, solar water heating has been the most practical and widespread of all solar applications. The amount of effort that people have spent on solar water heating has been proportional to the availability of fossil fuels and the severity of the climate. Evidence of solar water heating methods dates back thousands of years to the early days of the Greek and Roman civilizations. Today, the countries of Japan and Israel obtain a large percentage of their hot water needs from the sun; also, the majority of companies in the solar industry are exclusively involved with solar water heating systems.

Although solar water heaters are common in many parts of the world and are even required by law in a few American cities, they are not prevalent in Arkansas. One reason for this is that most Arkansans, like most Americans, believe that all solar water heaters are complex and expensive. It is true that most commercially available systems cost from $1500 to $3000, which makes them unaffordable for most residents, even considering the 40% federal tax credit. But there are simple, owner-built solar water heating systems, called **batch water heaters**, that cost less than $300 and have been demonstrated in Arkansas to save about 50% of the yearly hot water costs for a typical household.

A recent publication titled "Solar Hot Water," by Nicholas Brown, explains a wide variety of owner-built solar hot water systems and how they can be built using common plumbing supplies and off-the-shelf components. This booklet is available free from the Arkansas Energy Office and should be read prior to this report by those unfamiliar with solar water heating concepts. This retrofit guide focuses on batch solar water heaters because they offer the most potential for immediate and widespread use on homes in Arkansas.

When most people think of solar water heating, they think of solar collectors mounted on rooftops. Flat plate collector systems have received most of the solar publicity and are the predominant method of solar water heating today. However, the batch solar water heater is far more simple to build and operate and, with the advent of new designs, can be as effective as a flat plate collector system.

The operation of a batch solar water heater is very simple: no pumps, no heat exchangers, no controls or other moving parts. The sun shines through a glass cover onto black metal tanks inside an insulated box, heating the water in the tanks. Thus, the heat collection and storage functions of the water heater are integrated.

The cold water line in the house is

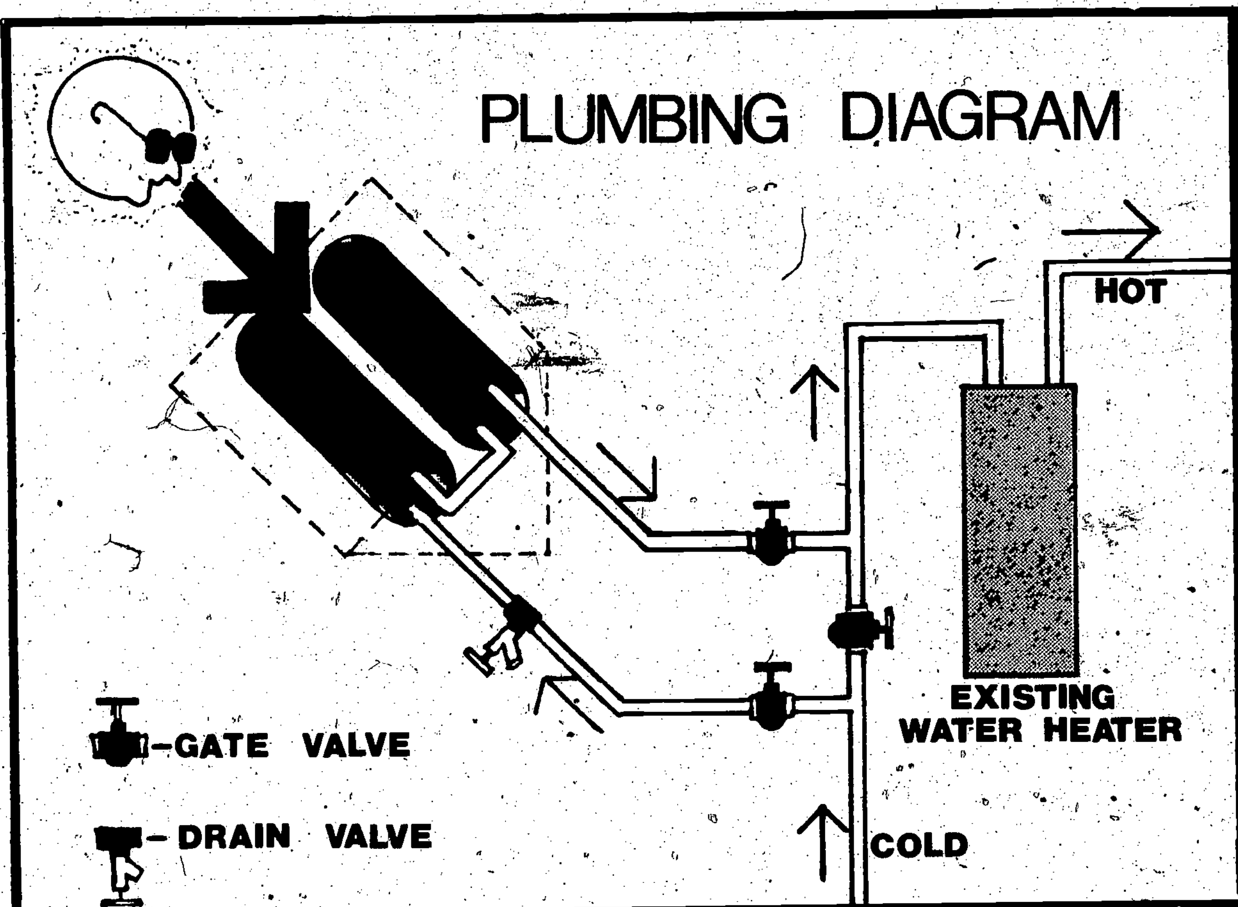

FIG. A-1

plumbed to the tanks so that water must pass through the tanks before it enters the conventional hot water heater in the house (Fig. A-1); hence, the term "preheater" is sometimes used to describe batch solar water heating systems.

In winter, the tanks may be drained to prevent the water from freezing. However, recent designs employ insulated shutters that are closed over the tanks at night to extend the effective period of operation.

Many people have trouble believing that such a simple concept can work very well, but batch heaters have been shown to be the most effective solar heating system on a BTU per dollar basis. Currently, most operating batch water heaters are home-built systems constructed from inexpensive materials such as recycled water heater tanks. In most cases, the batch solar water heater will be the cheapest solar water heater for homeowners to build and operate. However, it also has good potential for production by local plumbing businesses for new or existing homes, schools, and commercial buildings.

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B. BRIEF HISTORY

Originally, batch water heaters were nothing more than a black-painted tank of water exposed to the sun. The name comes from the fact that all the water is heated at once, in a batch. These simple heaters were built by the thousands in California and Florida in the late 1800's when heating fuel was scarce and expensive. The tanks supplied hot water by late afternoon and only during the warmer months, but could cut hot water bills by 75% in the summer and 25-50% year round.

In 1891, a patent was awarded for the "Climax" solar water heater, which was the first commercially made batch water heater to enclose the tank inside a glass-covered box. The glass served to trap heat radiating from the tank, and performance was dramatically improved over the bare design. Batch water heaters performed well in those early days but gradually disappeared as artificially cheap natural gas and electricity became available. Ken Butti and John Perlin describe this history in their book, *The Golden Thread*.

F. A. Brooks tested several batch water heaters in 1936 at the University of California. He demonstrated that tanks in glazed insulated boxes are capable of producing hot water at over 120° F. He also proved the effectiveness of using these tanks in series as opposed to one tank. As hot water is drawn out of the upper part of the tank, cooler water enters from the other end and mixes with the solar heated water, causing it to cool rapidly. But with three separate tanks, it takes much longer for the incoming water to mix, and more hot water can be delivered. Brooks concluded that batch water heaters were effective solar energy absorbers but were poor for storing hot water overnight.

Batch water heating design was largely forgotten in this country until 1972, when Steve Baer, a solar researcher in Albuquerque, New Mexico, built and tested his "breadbox" water heater (Fig. B-1). The breadbox (so called because it looks like one) added insulated shutters which, when opened, reflected additional solar energy onto the tanks and, when closed at night, insulated the tanks to prevent rapid heat loss. On a clear February day with an average outside (ambient) temperature of 40° F, 60 gallons of water in two tanks in the breadbox were solar heated initially to 140° F and were lowered to only 107° F after 35 gallons were drawn.

In 1979, Allen Grogan, of Northwest Arkansas Economic Development District, Inc. in Harrison, designed a two-tank batch water heater. Several units were built as part of a CETA training program and installed on the homes of low-income, elderly residents. Although no scientific monitoring has been done, the owners have experienced a reduction in their fuel bills. However, the design called for 5-foot wide fiberglass, which must be ordered in quantity and makes it impractical for individuals who wish to build just one unit.

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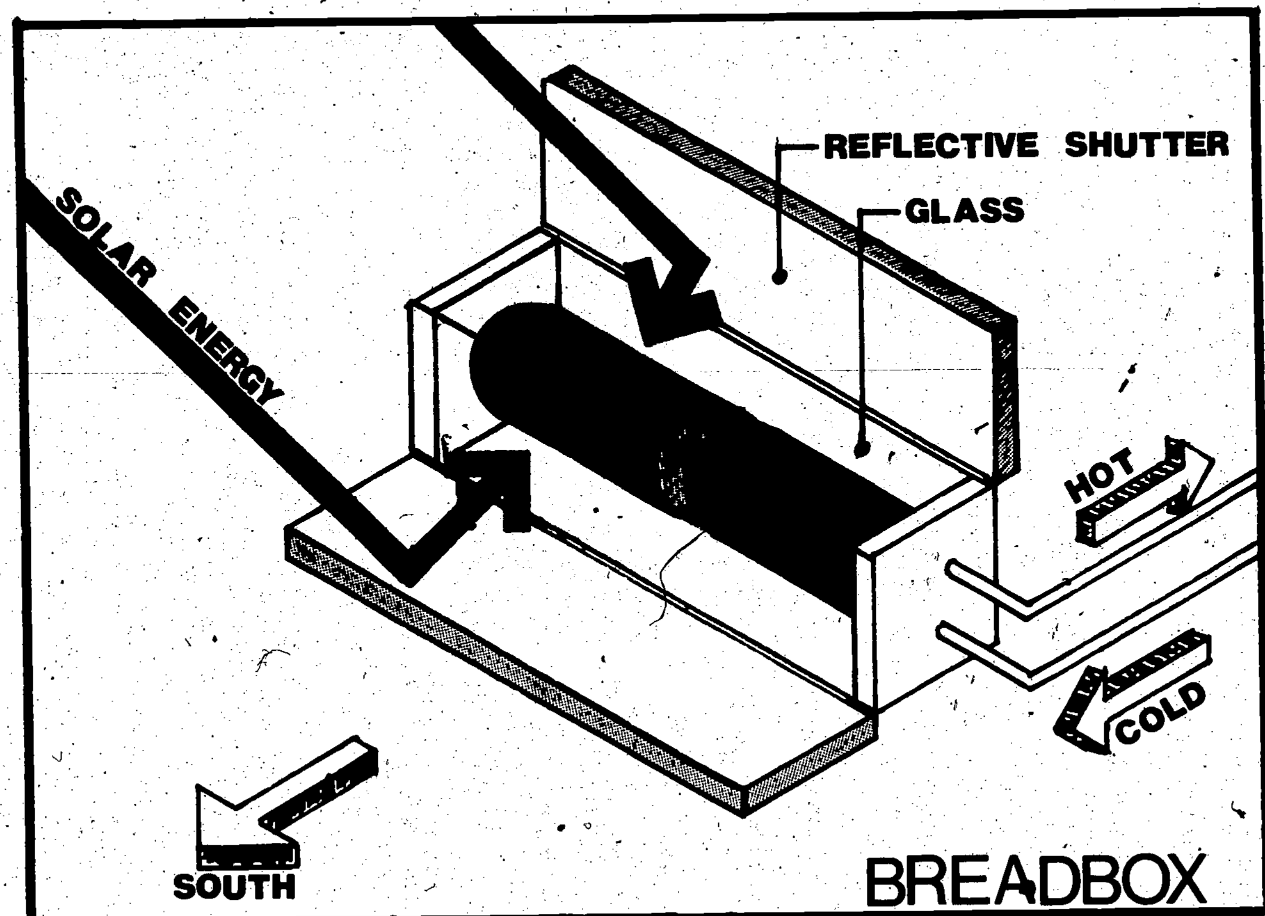


FIG. B-1

C. A NEW DESIGN

As with solar greenhouses and solar air heaters, it is very important to design owner-built solar water heaters to use only standard, locally available materials that require a minimum of modification to assemble. The main components of the batch heaters are the absorber (tanks), the glazing and the box. They need to be matched in size so there is little or no waste of materials.

Considering that previous batch solar water heater designs required custom glazing, I designed a batch water heater that uses a standard tempered glass panel (34″ x 76″) as the primary component. This glass panel is the main element in the design, around which all other parts are built because:

1) It is kept in stock as a standard replacement for sliding glass doors and can be bought locally throughout Arkansas. ($20-29 for single pane or $60-65 for double pane)

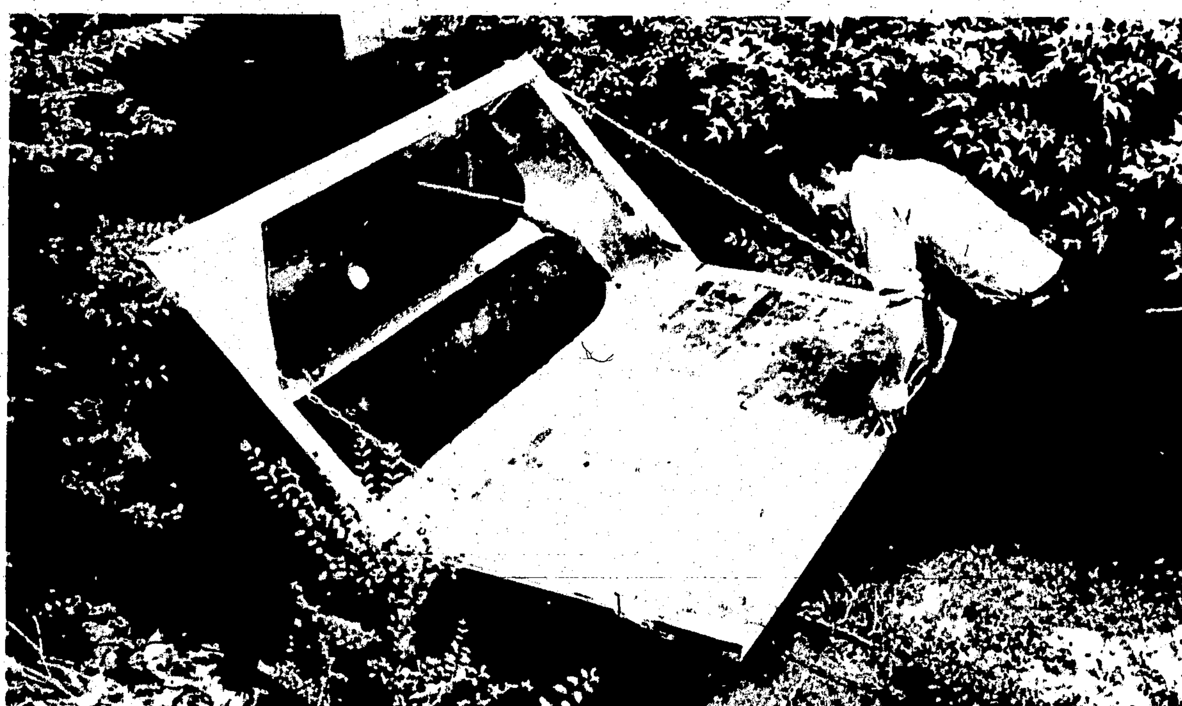
2) It is long enough and wide enough to enclose two typical recycled gas or electric water heater tanks.

3) It will not degrade under sunlight.

4) It has a very high impact strength to resist damage by hail and other objects.

The tanks are mounted within an insulated plywood box. The box is then mounted on a wooden stand at an angle of 45° from horizontal. This is the optimum angle to collect solar

This new batch water heater design, called the **Sun Mummy**, uses only three sheets of plywood to construct. The insulated cover (shown closed) has a continuous piano hinge along the bottom for easy opening and closing.



When opened, the tanks of water are heated by direct sunlight and by reflected sunlight from the cover. The length of the chains on each side of the heater can easily be adjusted to re-position the cover as the seasons change.

energy on a year-round basis. An adjustable insulated plywood cover is hinged to the box to reflect additional energy onto the tanks during the day and is closed at night to store the heat. Total materials for the collector cost about $175. The cost of pipe and fittings to connect the collector to the existing water heater usually runs about $30-50.

Community Energy Futures, Inc., (C.E.F.) a non-profit energy research and training agency, has built and tested several prototype units of this design in Blytheville, Little Rock, and Dumas. Preliminary performance tests by Aviv Goldsmith of C.E.F. indicate that these water heaters would be effective in Arkansas for 7-10 months out of the year and have a pay-back time of less than two years for most homes.

D. PERFORMANCE

The May-June 1981 issue of *New Shelter* magazine gave the results of extensive, year-long tests on five different types of home-built solar water heaters. Systems included in the study were batch, thermosyphon, drain down, drain back and phase change. The systems were compared for their performance in BTU's per square foot, cost per BTU, return on investment and ease of construction. The summary of the results states:

"Without a doubt, the batch heater seems the best choice of the solar systems. It's simple and inexpensive; it offers a very high return and a low cost-per-BTU; and it pays for itself quickly. It's also architecturally flexible: if you have a sunny wall, you can integrate the heater into your home's siding, giving the system a pleasing "built-in" appearance. Or, if your home faces the wrong way, you can build a free-standing version, such as the one we showed in our October 1980 issue. Once the conservation measures are in place, a batch heater can cut your remaining water-heating cost by a full third, saving a total (conservation plus solar) of $289 per year. At this rate, the combined return on investment is 65 per cent per year, with a pay back of just a year-and-a-half. You can't do much better than that. . . .For families in most parts of the nation, the batch heater offers the best combination of low cost, ease of assembly and high performance. It gets our highest recommendation. It worked well for us here in Pennsylvania, and it should work even better for those of you who live in the South, Southwest, or along the West Coast. You get more sun than we do, and you can operate your batch heater year-round without fear of freezing."

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E. LIMITATIONS

Batch solar water heaters are generally the first option to consider when choosing among solar hot water heaters, but there may be good reasons why they are not suitable to everyone's needs:

1) There may not be shade free areas on the south side of the house to accommodate the heater.

2) Although batch heaters operate well without a shutter, maximum performance is obtained only when the owner can open and close the cover on a daily basis. To most people, this is very little effort. But it may be difficult or impossible for some elderly or handicapped persons. In case the batch water heater is impractical, the next type of solar water heating system to consider is a recirculating system. For specifics on this system, refer to the Arkansas Energy Office's publication, "Solar Hot Water," by Nicholas Brown.

NOTE: It is foolish to consider any solar hot water system unless you have already employed conservation measures on your existing hot water system. Turning down the temperature control on your water heater to 120° F and installing pipe and water heater insulation, flow restrictors, and a timer on your electric water heater will save far more energy per dollar invested than any solar system.

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APPENDIX A—GLOSSARY

Absorber Plate—A black surface that absorbs solar radiation and converts it to heat; a component of a flat-plate collector.

Absorptance—The ratio between the radiation absorbed by a surface and the total energy falling on that surface. A flat black surface, such as used in solar collectors, has a high absorptance.

Absorption Chilling—Solar assisted; An air-conditioning method that uses solar heated liquid to activate the chilling process.

Active System—A solar heating and/or cooling system using mechanical methods of heat distribution.

Air-Type Collector—A solar heat collector designed to use air as heat-transfer fluid.

Alternating Current (AC)—Electric current which changes its direction of flow at regular intervals, normally making 60 cycles per second. AC is easier to transmit than direct current and is also more easily changed to higher or lower voltages. Household current is AC.

Ambient Temperature—Surrounding temperature, as temperature around a building.

Ampere (AMP)—The unit of rate of flow in an electric circuit.

Ampere-Hour—Unit of electrical charge, equalling the quantity of electricity flowing in one hour past any point of a circuit carrying a current of one ampere. Storage batteries are rated in ampere-hours to show the quantity of electricity that can be used without discharging the battery beyond safe limits.

Angle of Incidence—The angle at which radiant energy strikes a surface, measuring from the path of the energy to a line perpendicular to that surface at the point of impact. The angle of incidence determines the percentage of direct sunshine interrupted by a surface. The sun's rays that are perpendicular to a surface are said to be "normal" to that surface.

Auxiliary System (Back Up)—A supplementary heating unit to provide heat to a space when its primary unit cannot do so. This usually occurs during periods of cloudiness or intense cold, when a solar heating system cannot provide enough heat to meet the needs of the space.

Azimuth—The angular distance between true south and the point on the horizon directly below the sun.

Berm—A mount of earth either abutting a house wall to help stabilize temperature inside house, or positioned to deflect wind from house.

British Thermal Unit (BTU)—The quantity of heat required to raise the temperature of 1 pound of water 1 degree F°. One BTU = 252 calories.

Calorie—The quantity of heat needed to raise the temperature of one gram of water one degree Celsius.

Caulking—Making an airtight seal by filling in cracks around windows and doors.

Centrifugal Pump—A high speed pump that drives water with a rotating impeller.

Clerestory—Vertical window placed high in wall near eaves, used for light, heat-gain, and ventilation.

Closed Loop—System in which heat-transfer liquid from collectors circulates through a heat exchanger immersed in heat-storage liquid, passing its heat to heat-storage liquid while remaining isolated from it.

Coefficient of Performance—Ratio of heat output to energy use of a heating or cooling device.

Coefficient of Heat Transmission—The rate of heat loss in BTU's per hour through a square foot of wall or other building surface when the difference between indoor and outdoor air temperatures is one degree Fahrenheit.

Collection—The act of trapping solar radiation and converting it to heat.

Collector—Any of a variety of devices used to absorb solar radiation and convert it to heat.

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Collector Efficiency—Ratio of collector heat output to amount of solar radiation that strikes collector apperture.

Collector Tilt—The angle between the horizontal plane and the solar collector plane.

Collector, Solar—A device for capturing solar energy, ranging from ordinary windows to complex mechanical devices.

Combined Energy System—A plan that utilizes several sources of energy in the most efficient way.

Concentration Collector—Device that uses reflectors to concentrate direct solar rays onto a narrow absorber area to produce intense heat.

Conduction—The flow of heat due to temperature variations within a material (solids, liquids or gases).

Conductance—The rate of heat flow (in BTU's per hour) through an object when a 1° F. temperature difference is maintained between the sides of the object.

Conductivity (k-Value)—A measure of the ability of a material to permit conduction heat flow through it.

Conifers—Species of trees which usually keep their leaves in the autumn, including the evergreens.

Convection, Natural—Heat transfer through a fluid (such as air or liquid) by currents resulting from the natural fall of heavier, cool fluid and rise of lighter, warm fluid.

Cooling Season—Portion of year (usually June to September) when outdoor heat makes indoor cooling desirable to maintain comfort.

Converted Heat—Heat which is transferred from one position to another, driven by the change in a gas's density that accompanies a change in temperature.

Cord—A unit of volume measurement - 4 x 4 x 8 feet, generally used to measure quantities of wood cut for fuel.

Cover Plate—A sheet of glass or transparent plastic placed above the absorber in a flat-plate collector. (See Absorber and Collector.)

Creosote—An oily, odorous distillate of wood tar that may collect on the walls of a chimney as a result of incomplete combustion. Also used to treat lumber to resist moisture.

Dead Air Space (Vapor Barrier)—A confined space of air. A dead air space tends to reduce both conduction and convection of heat. This fact is utilized in virtually all insulating materials and systems, such as double glazing, beadwall, fiberglass batts, rigid foam panels, fur and hair, and loose-fill insulations like pumice, vermiculite, rock wool and goose down.

Deciduous—Species of trees which shed their leaves in the autumn.

Degree-Day—An indication of heating needs, based on the difference between the average daily temperature and an assumed steady indoor temperature of 65° F. A 24-hour period with an average temperature of 60° F rates five degree-days; a daily average of 60° F rates 65 degree-days. Degree-days are then totaled to obtain seasonal or yearly heating needs.

Demand Load—Domestic water heating needs to be supplied by solar or conventional energy.

Demand Time—Occurs when energy is needed, as heat is at night.

Density—The mass of a substance which is expressed in pounds per cubic foot.

Design Temperature—A designated temperature close to the most severe winter or summer temperature extremes of a climate, used in estimating a house's heating or cooling requirements.

Desiccant—A coarse, salty or sandy substance such as calcium oxide or sulfuric acid that is used to absorb moisture, both in liquid and vaporous forms.

Differential Thermostat—Automatic device that responds to temperature differences (between collectors and heat storage, for example) in regulating operation of an active solar system.

Diffuse Radiation—Solar radiation, scattered as it passes through atmospheric molecules, water vapor, dust, and other particles, so that it appears to come from entire sky, as on a hazy or overcast day.

Direct Current (DC)—Electric current which flows in one direction. Generators produce DC current.

Direct-Gain—Passive solar heating system in which the sun penetrates and warms the interior structure directly. (A window on the south side, for example.)

Direct Radiation—Radiation that comes directly from sun, as opposed to diffuse or reflected radiation.

Domestic Water Pressure—The pressure of the potable water within the building from sources not related to the solar domestic hot water system.

Double-Glazed—Covered by two panes of glass or other transparent material.

Double Wall Separation—Heat exchangers utilizing non-potable heat transfer fluids are separated from the potable water system by use of two walls between the fluids.

Drain Down—Function of an open-loop solar water system in which all water drains out of the collectors when a freeze threatens.

Efficiency—A measure of how much of the energy applied to a device is utilized in useful work.

Emittance—A measure of the ability of a material to give off thermal radiation.

Energy—The ability to do work. Units of energy are: kilowatt hour (KWH); British thermal unit (BTU); and horsepower-hour (hph)

Eutectic Salts—Substances that melt readily at low temperatures (as low as 80° to 90° F) and, in so doing, store large quantities of latent heat, which they release when cooling and resolidifying.

Equinox—Either of the two times during a year when the sun crosses the celestial equator and when the length of day and night are approximately equal. These are the autumnal equinox on or about September 22 and the spring equinox which is on or about March 22.

Evaporative Cooling—Evaporating water cools and humidifies surrounding air; house air is circulated over water as technique to cool indoor air in dry-climate areas.

Flat Black Paint—Nonglossy paint with a relatively high absorptance.

Flat-Plate Collector—Device that employs a planar absorber plate to collect solar radiation and convert it to heat, without assistance of devices to concentrate sun's rays.

Flow Rate—The pounds of heat-transfer fluid which pass over or through an absorber plate per hour.

Forced Convection—The transfer of heat by the flow of fluids (such as air or water) driven by fans, blowers, or pumps.

Freon—A volatile chemical substance capable of boiling (becoming lighter) at low temperatures.

Galvanic Corrosion—The condition caused as a result of a conducting liquid making contact with two different metals which are not properly isolated physically and/or electrically.

Galvanized Steel—Steel which has been sprayed, immersed, or electrically coated with rust resistant zinc.

Getters (Sacrificial anodes)—A column or cartridge containing an active metal which will be sacrificed to protect some other metal in the system against galvanic corrosion.

Glazing—A covering of transparent or translucent material (glass or plastic) used for admitting light. Glazing retards heat losses from reradiation and convection. Examples: windows, skylights, greenhouse and collector coverings.

Glazing, Double—A sandwich of two separated layers of glass or plastic enclosing air to create an insulating barrier.

Gravity Convection—The natural movement of heat that occurs when a warm fluid rises and a cool fluid sinks under the influence of gravity. (See Convection.)

Greenhouse Effect—Ability of glass or clear plastic to transmit shortwave solar radiation into a room or collector and to trap long-wave heat emitted by room or collector interior.

Header—The pipe that runs across the edge of an array of solar collectors, gathering (or distributing) the heat transfer fluid from or to the risers in the individual collectors. This in-

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sures that equal flow rates and pressure are maintained. (See Risers.)

Heat Capacity—(Volumetric)—The number of BTU's a cubic foot of material can store with a one degree increase in its temperature.

Heat Distribution—The act of conveying solar heat from collectors to storage and from storage (or collectors) to areas of the building where heat is needed.

Heat Exchanger—Device consisting of a long coil of metal pipe or a multifinned radiator used to transfer heat from one fluid inside to another outside, without bringing the two fluids into direct contact.

Heat Gain—An increase in the amount of heat contained in a space, resulting from direct solar radiation and the heat given off by people, lights, equipment, machinery and other sources.

Heat Loss—A decrease in the amount of heat contained in a space, resulting from heat flow through walls, windows, roof and other building envelope components.

Heat Storage—A device or medium that absorbs collected solar heat and stores it for use during periods of inclement or cold weather.

Heat Storage Capacity—The amount of heat which can be stored by a material.

Heating Season—Portion of year (usually October to May) when outdoor cold makes indoor heating necessary to maintain comfort.

Heat-Recovery Device—A device, designed for installation in a fireplace, through which house air or household water is cycled to reclaim fire's heat before it can escape through chimney.

Heat Storage—Medium that absorbs collected solar heat and holds it until it is needed to heat house interior.

Heat-Transfer Fluid—Air or liquid used to carry solar heat from collectors to heat storage.

Horsepower—A measure of the rate of doing work, equal to 33,000 foot pounds or 754.2 watts.

Humas—Organic matter (animal and plant) in a state of decomposition, forming an essential element of all fertile soils.

Hybrid System—Solar heating system that combines active and passive techniques.

Indirect-Gain System—Passive solar heating system in which sun directly warms a heat storage element in one area of the building, and heat is then distributed from that element to the rest of the building by natural convection, conduction, or radiation.

Infiltration—The uncontrolled movement of outdoor air into the interior of a building through cracks around windows and doors or in walls, roofs and floors. This may work by cold air leaking in during the winter, or the reverse in the summer.

Infrared Radiation—Electromagnetic radiation from the sun that has wavelengths slightly longer than visible light.

Insolation—Or incident solar radiation: amount of direct, diffuse, and/or reflected solar radiation striking a given surface per hour.

Insulation—Materials or systems used to prevent loss or gain of heat, usually employing very small dead air spaces to limit conduction and/or convection.

Inverter—A device for converting direct current (DC) into alternating current (AC).

Isogonic Chart—Shows magnetic compass deviations from true north.

K-Value—BTU/hr/ft²/F° per inch. (See Conductivity.)

Kilowatt—A unit of power equal to 1,000 watts.

Kilowatt-Hour (KWH)—The amount of energy equivalent to 1 kilowatt of power being used for one hour; 3,413 BTU.

Langley—A measure of solar radiation; equal to one calorie per square centimeter.

Life Cycle Costing—A method of cost analysis in which operating, maintenance, fuel, and other ownership costs are estimated for predicted lifetime of a device and considered along with initial cost; often used to compare costs of solar heating or cooling systems and conventionally fueled systems.

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Liquid Type Collector—A solar heat collector designed to use a liquid as heat transfer fluid.

Magnetic South—"South" as indicated by a compass; changes markedly from one location to another because of latitudinal relationship to Earth's magnetic fields.

Microclimate—Climate of a very small area, such as a building site, formed by unique combination of topography, exposure, soil, and vegetation of site. Microclimate may contrast sharply with macroclimate (regional climate) in which it is situated.

Movable Insulation—Insulation placed over windows when needed to prevent heat loss or gain and removed for light, view, venting, or heat.

Natural Convection—(See Gravity Convection.)

Open Loop—System in which heat-transfer liquid from collectors feeds directly into heat-storage liquid.

Open System—An assembly of natural and architectural components which converts solar energy into usable or storable thermal energy (heat) without mechanical power.

Orientation—Alignment of a building along a given axis to face a specific direction, such as along an east-west axis to face south.

Parabolic Reflector—Reflector designed in the shape of a parabola to focus extra sunlight onto absorber of a concentrating collector.

Passive System—A solar heating and/or cooling system using natural means of heat distribution. Generally, building's structure itself forms solar system.

Payback Period—Period of time a solar heating or cooling system takes to return its entire initial cost through fuel savings.

Percentage of Possible Sunshine—Percentage of daylight hours during which direct sun is bright enough to cast a shadow.

Potable Water—Water suitable for people to drink.

Pyranometer—An instrument for measuring solar radiation. (See Solar Radiation.)

Radiation—The direct transport of energy through space by means of electromagnetic waves.

Reflectance—The ratio or percentage of the amount of light reflected by a surface to the amount incident. The remainder that is not reflected is either absorbed by the material or transmitted through it. Good light reflectors are not necessarily good heat reflectors.

Reflected Radiation—Solar radiation reflected off surrounding objects so it appears to come from them, as in reflection off a white wall or a car window.

Refrigerant—A volatil substance, such as ammonia, used for obtaining and maintaining low temperatures, as in a refrigerator.

Reradiation—Radiation resulting from the emission of previously absorbed radiation.

Resistance or R-Value—Capability of a substance to impede the flow of heat. Used to describe insulative properties of construction materials.

Resistance Heating—A standard method of converting electricity into heat for the purpose of home heating.

Retrofit—To add a solar heating or cooling system to an existing building.

Risers—The flow channels or pipes that distribute the heat transfer liquid from the headers across the face of an absorber plate. (See Header.)

R-Value—(See Resistance.)

Seasonal Efficiency—The ratio, over an entire heating season, of solar energy collected and used to the solar energy striking the collector.

Selective Surface—Specially adapted coating with high solar radiation absorptance and low thermal emittance, used on surface of an absorber plate to increase collector efficiency.

Sensor—Device that detects changes in heat and relays information to differential thermostat.

Shading Coefficient—The ratio of the solar heat gain through a specific glazing system to the total solar heat gain through a single layer of clear double-strength glass.

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Skydome (Sky vault)—The visible hemisphere of sky, above the horizon, in all directions.

Skylight—A clear or translucent panel set into a roof to admit sunlight into a building.

Solar Attitude—The angle of the sun above the horizon.

Solar Constant—The amount of radiation or heat energy that reaches the outside of the earth's atmosphere.

Solar House—House that derives at least 40 to 50% of its annual heating (or cooling) from the sun.

Solar Radiation (Solar Energy)—Electromagnetic radiation emitted by the sun.

Solar Rights (Sun Rights or Solar Access)—A legal issue concerning the right of access to sunlight.

Solar Window—Openings that are designed or placed primarily to admit solar energy into a space.

Space Heating—Heating of the air inside a building. ("Space cooling" is the converse.)

Specific Heat (Cp)—The number of BTU's required to raise the temperature of one pound of a substance 1°F in temperature.

Stagnation Temperature—High temperature range 300 to 400 degrees F; reached inside a collector on clear, sunny days when the heat transfer fluid isn't circulating through the collector.

Standby Heat Loss—Heat lost through storage tank and piping walls. (Rate of heat loss differs from standing still and when moving.)

Storage Mass—(See Heat Storage.)

Sun Path Diagram (Solar Window)—A circular projection of the sky vault, similar to a map, that can be used to determine solar positions and to calculate shading.

Sun Tempering—Designing a house to derive some of its heat directly from the sun (though not necessarily enough to qualify as a solar house).

Temperature Zones—Areas controlled to maintain different temperatures within a house.

Thermal Mass—The amount of potential heat storage capacity available in a given assembly or system. Drum walls, concrete floors and adobe walls are examples of thermal mass.

Thermocirculation or Thermosiphoning—The convective circulation of fluid which occurs when warm fluid rises and is displaced by denser, cooler fluid in the same system.

Thermal Radiation—Electromagnetic radiation emitted by a warm body. (See Infrared Radiation.)

Thermistor—Sensing device which changes its electrical resistance according to temperature. Used in the control system to generate input data on collector and storage tank temperatures.

Time Lag—The period of time between the absorption of solar radiation by a material and its release into a space. Time lag is an important consideration in sizing a thermal storage wall or Trombe wall.

Tilt Angle—Angle at which a collector is tilted upward from horizontal for maximum solar exposure.

Translucent—The quality of transmitting light but causing sufficient diffusion to eliminate perception of distinct images.

Transmittance—The ratio of the radiant energy transmitted through a substance to the total radiant energy incident on its surface. In solar technology, it is always affected by the thickness and composition of the glass cover plates on a collector and to a major extent by the angle of incidence between the sun's ray and a line normal to the surface.

Trickle Type Collector—A collector in which the heat transfer fluid flows in open channels on the absorber.

True South—South with reference to the stars, not to a compass. Opposite to the Pole Star, which lies to the true north of Earth.

Tube-in-Plate Absorber—A metal absorber plate in which the heat-transfer fluid flows through passages formed in the plate itself.

Tube Type Collector—A collector in which the heat transfer liquid flows through metal tubes that are fastened to the absorber plate by solder, clamps, or other means. (See Collector.)

Ultraviolet Radiation—Electromagnetic radiation with wavelengths slightly shorter than visible light.

Unglazed Collector—A collector without a cover plate.

U Value (Coefficient of heat transfer)—The number of BTU's that flow through one square foot of roof, wall or floor in one hour, when there is a 1° F difference in temperature between the inside and outside air, under steady state conditions. The U value is the reciprocal of the resistance or F-factor.

Vapor Barrier—A component of construction which is impervious to the flow of moisture and air and is used to prevent condensation in walls and other locations of insulation.

Volt—The unit of pressure in an electric circuit.

Water Wall—An interior wall of water-filled containers constituting a one-step heating system which combines collection and storage.

Watt—The unit of rate at which work is done in an electrical circuit, equal to the rate of flow (amperes) multiplied by the pressure of that flow (volts).

Weatherstripping—Narrow or jamb-width sections of thin metal or other material to prevent infiltration of air and moisture around windows and doors.

GLOSSARY REFERENCES

Homeowners Guide to Solar Heating
Lane Publishing Company
Menlo Park, CA

Installation Guidelines for Solar DHW Systems
U.S. Department of Housing and Urban Development
Second Edition

Producing Your Own Power
Carol Stoner
Rodale Press
Emmaus, PA

APPENDIX B — SOLAR REFERENCES

1. Solar Greenhouse Design and Construction

The Solar Greenhouse Book
James McCullagh
Rodale Press
33 E. Minor Street
Emmaus, PA 18049 $8.95 328 pages

The most comprehensive book to date on the design, construction, and management of various solar greenhouses throughout the country.

The Food and Heat Producing Solar Greenhouse
Rich Fisher and Bill Yanda
John Muir Publications
P.O. Box 613-R
Santa Fe, NM 87501 $9.50 161 pages

The classic beginner's book on solar greenhouses, with good advice on plant management, space utilization, and construction details.

The Complete Greenhouse Book — Building and Using Greenhouses From Cold Frames to Solar Structures
Peter Clugg and Derry Watkins
Garden Way Publishing
Charlotte, VT 05445 $8.95 285 pages

Provides criteria for design of all types of greenhouses, with emphasis on solar structures. Excellent sections on plant diseases, soils, and growing conditions, with many fine drawings and photographs.

The Passive Solar Energy Book
Edward Mazria
Rodale Press
33 E. Minor Street
Emmaus, PA 18049

An excellent resource of passive solar fundamentals, including step-by-step design methods for solar greenhouses. Used as a textbook for many solar courses.

Proceedings of the Conference on Energy Conserving, Solar Heated Greenhouses, 1977
John Hayes and Drew Gillet, Eds.
Marlboro College
Marlboro, VT 05344 $9.00 282 pages

A survey of innovative solar greenhouse projects by greenhouse owners, university researchers, and representatives of community groups. Most papers include illustrations and photographs on greenhouse design and construction, and a few papers address production methods.

2. Plant Management

Biological Management of Passive Solar Greenhouses
National Center for Appropriate Technology
P.O. Box 3838
Butte, Montana 59701

An excellent annotated bibliography on solar greenhouse production methods, biological pest control, and horticulture. Also includes a unique resource list of individuals and groups experienced in construction and management of passive solar greenhouses, and a list of companies which sell beneficial insects.

The Survival Greenhouse
James B. DeKorne
Walden Foundation
P.O. Box 5
El Rito, NM 87530 $7.50 165 pages

The author describes two years' experience **growing vegetables, rabbits,** and **fish** in an underground solar greenhouse. The book contains one of the few honest assessments of hydroponic systems, both chemical and organic.

How to Grow More Vegetables Than You Even Thought Possible on Less Land Than You Can Imagine
John Jeavons
Ecology Action of the Midpeninsula
2225 El Camino Road
Palo Alto, CA 94306 $4.00 81 pages

A step-by-step description of the French Intensive method of gardening which can appreciably increase crop yields. Especially appropriate for greenhouses where growing space is limited.

The Secret Life of Plants
Peter Tompkins and Christopher Bird
Avon Books, 1973
959 Eighth Avenue
New York, NY 10019 $1.95 416 pages

Has very little to do with greenhouses but is an astonishing account of the physical, emotional, and spiritual relations between plants and people. Highly recommended for anyone who grows plants.

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Horticultural Management of Solar Greenhouses in the Northeast
The MEMPHREMAGOG Group
P.O. Box 456
Newport, VT 05855

This manual was written to share the successes and failures that many solar greenhouse owners have had growing food crops. Provides basic information on how best to use these structures to produce food.

Organic Gardening Under Glass
George and Katy Abraham
Rodale Press
33 E. Minor Street
Emmaus, PA 18049 $8.95 308 pages

Though written for the hobbyist who is using a conventional structure, most of the information is also applicable to solar greenhouse growing. For a range and depth of coverage, this book on organic gardening is hard to beat.

Summary of Cool Weather Crops Tested 1979-80 For Solar Structures
Organic Gardening and Farming Research Center
RD 1
Kutztown, PA 19530

This new report presents the results of extensive testing of vegetables, herbs, and flowers in solar greenhouses. Includes pest management, harvesting techniques, and recipes.

3. Seed Sources

BULBS
Van Bourgondien
245 Farmingdale Rd.
P.O. Box A
Babylon, NY 11702

HERBS
Meadowbrook Herb Garden
Wyoming, RI 02898

Well Sweep Herb Farm
317 Mt. Bethel Rd.
Port Murray, NJ 07865

ORIENTAL VEGETABLES
A World Seed Service
c/o J.L. Hudson Seedsman
P.O. Box 1058
Redwood City, CA 94064

*Burgess Seed & Plant Co.
Box 2000
Galesburg, MI 49053

*Burpee, W. Atlee Co.
300 Park Ave.
Warminster, PA 18974

Comestock, Ferre & Co.
263 Main St.
Wethersfield, CT 06109

DeGiorgi Co., Inc.
Council Bluffs, IA 51501

Demonchaux Co., Inc.
225 Jackson
Topeka, KS 66603

Ferndale Gardens
702 Nursery Lane
Fairbault, MN 55021

Fruitland Nursery
307 Whitley Dr.
Fruitland, ID 83619

Grace's Gardens
Autumn Lane
Hackettstown, NJ 07840

*Gurney Seeds & Nursery Co.
2nd & Capitol Sts.
Yankton, SD 57078

Henry Field Seed & Nursery Co.
Shenandoah, IA 51602

*Herbst Brothers Seedsman, Inc.
100 N. Main St.
Brewster, NY 10509

Japonica Nursery
P.O. Box 236
Larchmont, NY 10538

*Johnny's Selected Seeds
Albion, ME 04910

*Joseph Harris Co., Inc.
Morelon Farm
Rochester, NY 14624

Kitazawa Seed Co.
356 W. Taylor St.
San Jose, CA 95110

LeJardin du Gourmet
W. Danville, VT 05873

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Nichols Garden Nursery
1190 N. Pacific Highway
Albany, OR 97321

*Park, Geo. W. Co., Inc.
Greenwood, SC 29646

Radhey Shian & Co.
Seed Growers & Merchant
Kutabkhana Sabzimandi
Bareilly, India

Redwood City Seed Co.
P.O. Box 361
Redwood City, CA 94064

Richter, Otto & Son
Goodwood, Ontario
Canada LOC 10A

Seedway, Inc.
Hall, NY 14463

Shumway, R. H. Co.
Rockford, IL 61101

Stokes Seeds, Inc.
Box 548
Buffalo, NY 14624

Sutton Seeds
Reading, England

Thompson & Morgan, Inc.
P.O. Box 24
401 Kennedy Blvd.
Somerdale, NJ 08083

Tsang & Ma International
1556 Laurel St.
San Carlos, CA 94070

Dr. Yoo Farm

The above seed sources are reprinted from:
Organic Gardening
Research Center
RD 1
Kutztown, PA 19530

*Offer soil test kits

4. Movable Insulation and Shading Methods

Solar Control and Shading Devices
Olgyay and Olgyay
Princeton University Press, 1957
Princeton, NJ

Design with Climate
Victor Olgyay
Princeton, University Press, 1963
Princeton, NJ

These two books are classics in the field of passive solar design, even though they were written before energy became an issue in building design. They contain more valuable information on solar control which can never go out of date.

Selecting and Growing Shade Trees
U.S. Department of Agriculture
Washington, D.C.

Thermal Shutters and Shades
William Shurcliff
Brick House Publishing
3 Main Street
Andover, MA 01810 $12.95 238 pages

Movable Insulation
William K. Langdon
Rodale Press
Emmaus, PA

The most complete books to date on home-made and commercially available insulating devices for windows and greenhouses.

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APPENDIX C — SOLAR AIR HEATER REFERENCES

Solar Air Heater Manual
Joel Davidson
Office of Human Concern, Inc.
P.O. Box 756
Rogers, AR 72756

Simple Solar Air Heaters
Ron Hughes
New Life Farm, Inc.
Drury, MO 65638

Project Focus #3
Solar Vertical Wall Collector
Small Farm Energy Project
P.O. Box 736
Hartington, NB 68739

Solar Air Heater Manual
Jim Free
Crowley's Ridge Development Council, Inc.
Jonesboro, AR

Air Flow Tests of Solar Air Heater
Dr. Thomas Rokeby, P.E.
Agricultural Engineering Department
University of Arkansas
Fayetteville, Arkansas 72701

Solar Survey
National Center for Appropriate Technology
P.O. Box 3838
Butte, MT 59701

Evaluation of the OHC Solar Air Heater
Russ Garton and Steve Metcalf
Department of Mechanical Engineering
University of Arkansas
Fayetteville, AR 72701

Low Cost Solar Collector
Bill North
San Luis Valley Solar Energy Association
P.O. Box 1284
Alamosa, CO 81101

"Walls of Warm Air"
Joe Carter
New Shelter Magazine, May/June 1980

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APPENDIX D — SOLAR WATER HEATER REFERENCES

"Heating Water in a Breadbox"
Allen Van Fleet
Alternative Sources of Energy; April 1977

"Sun on Tap"
Frederic Langa
New Shelter; May/June 1981

"Breadbox Designs"
Jeff Reiss and David Bainbridge
Alternative Sources of Energy; Oct. 1978

Solar Hot Water
Nicholas Brown
Arkansas Energy Office

Solar Energy and Its Use for Heating Water
F.A. Brooks
U.C. Berkeley Agricultural Experimental Station
Bulletin 602

Hand Made Hot Water Systems
Srt Sussisman and Richard Fraizer
Garcia River Press
P.O. Box 527
Point Arena, CA 95468

Sunspots
Steve Baer
Zomeworks Corp.
P.O. Box 712
Alburquerque, NM 87103

Build Your Own Solar Water Heater
Steve Campbell
Garden Way Publishing
Charlotte, VT 05445

APPENDIX E — SOLAR PERIODICALS

Solar Living & Greenhouse Digest
P.O. Box 10010
Phoenix, AZ 86016 *$10/bi-monthly*

Solar Living & Greenhouse Digest
P.O. Box 10010
Phoenix, AZ 86016 $10/bi-monthly

Solar Age
P.O. Box 4934
Manchester, OH 03108 $20/bi-monthly

Alternative Sources of Energy
Milaca, MN 56363 $15/bi-monthly

New Shelter
Rodale Press
33 E. Minor Street
Emmaus, PA 18049 $9.00 monthly

Mother Earth News
P.O. Box 70
Hendersonville, NC 27891 $15.00 Monthly

Solar Utilization News
P.O. Box 3100
Estes Park, CO 80517 $10/bi-weekly

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APPENDIX F — SOLAR INFORMATION SOURCES

Arkansas Energy Office
1 Capitol Mall
Little Rock, AR 72201
(800) 482-1122 or (501) 371-1370

Southern Solar Energy Center
61 Perimeter Park
Atlanta, GA 30341

Solar Energy Research Institute - SERI
Information Systems Division
1617 Cole Boulevard
Golden, CO 80401

The National Solar Heating and Cooling
Information Center
P.O. Box 1607
Rockville, MD 20850
(800) 523-2929

The National Center for Appropriate
· Technology
P.O. Box 3838
Butte, MT 59701
(406) 404-4572

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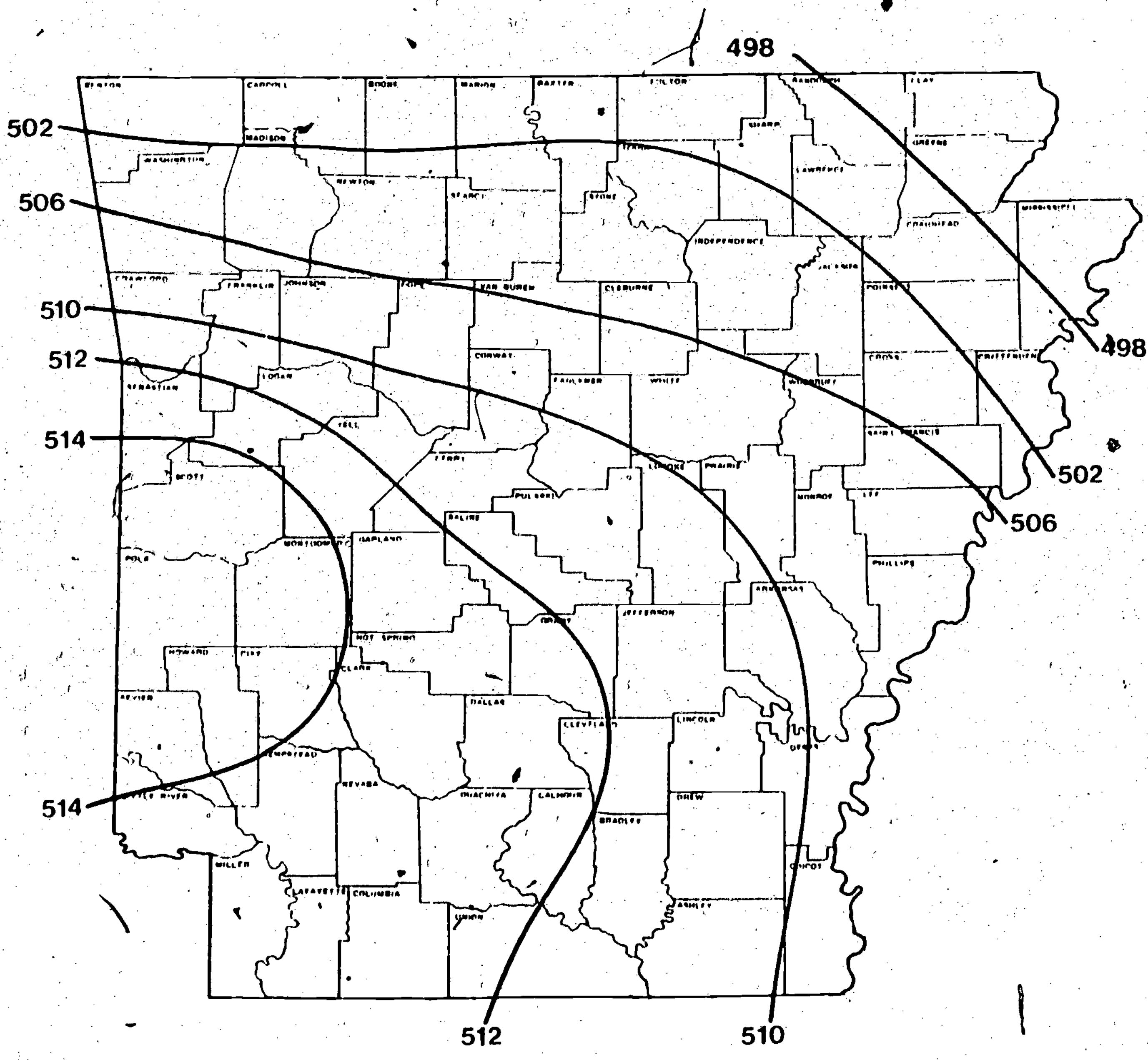
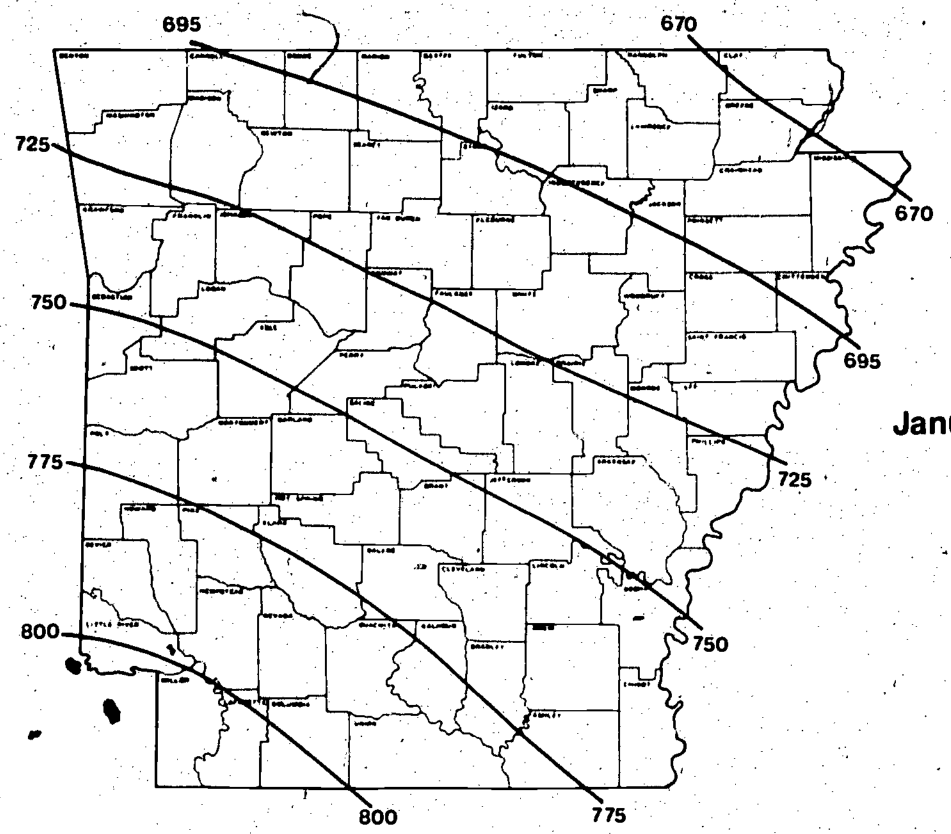
APPENDIX G — SOLAR RADIATION DATA

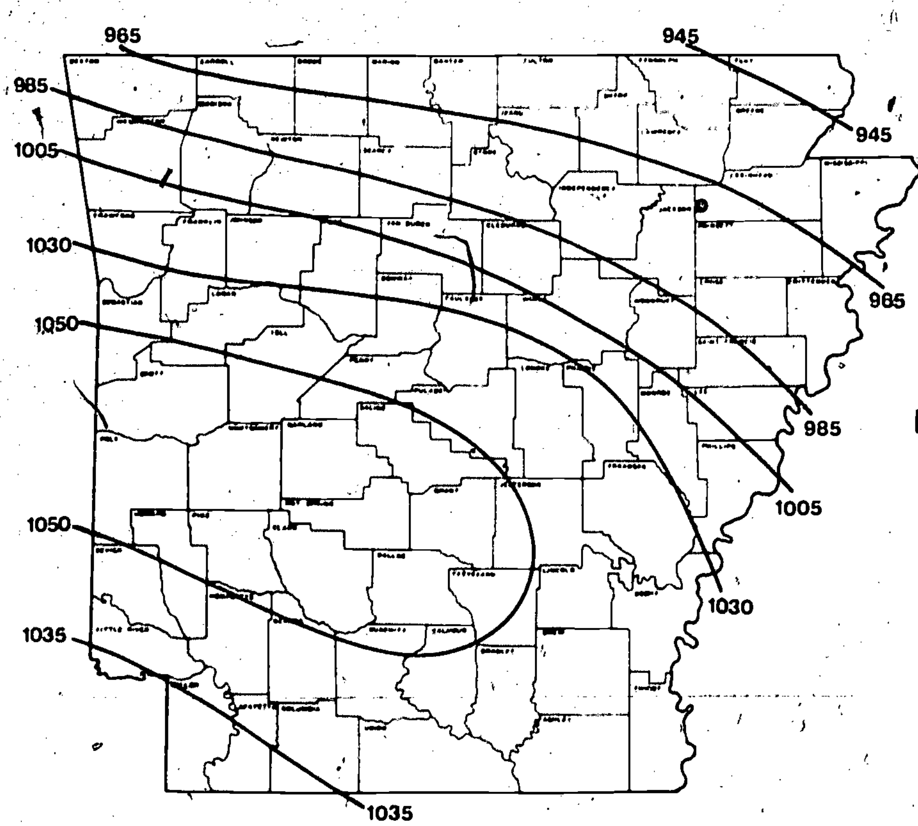


Mean Annual Total Solar Radiation
(Thousands of Btu's per Ft²)

Mean Daily Solar Radiation (BTU/ft²)



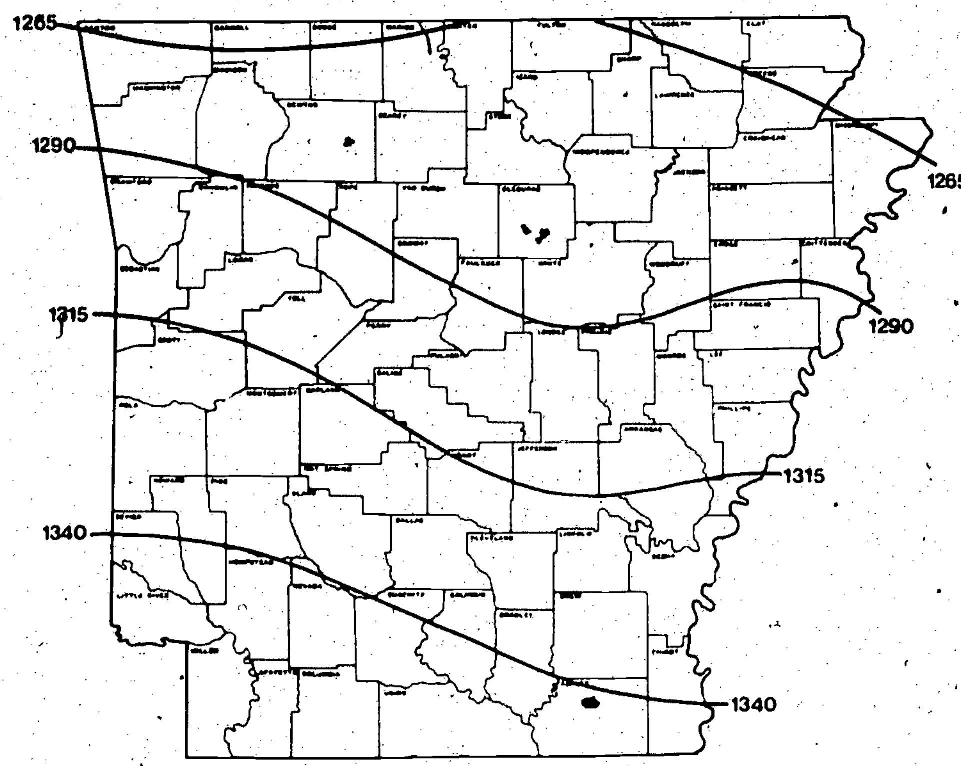
January



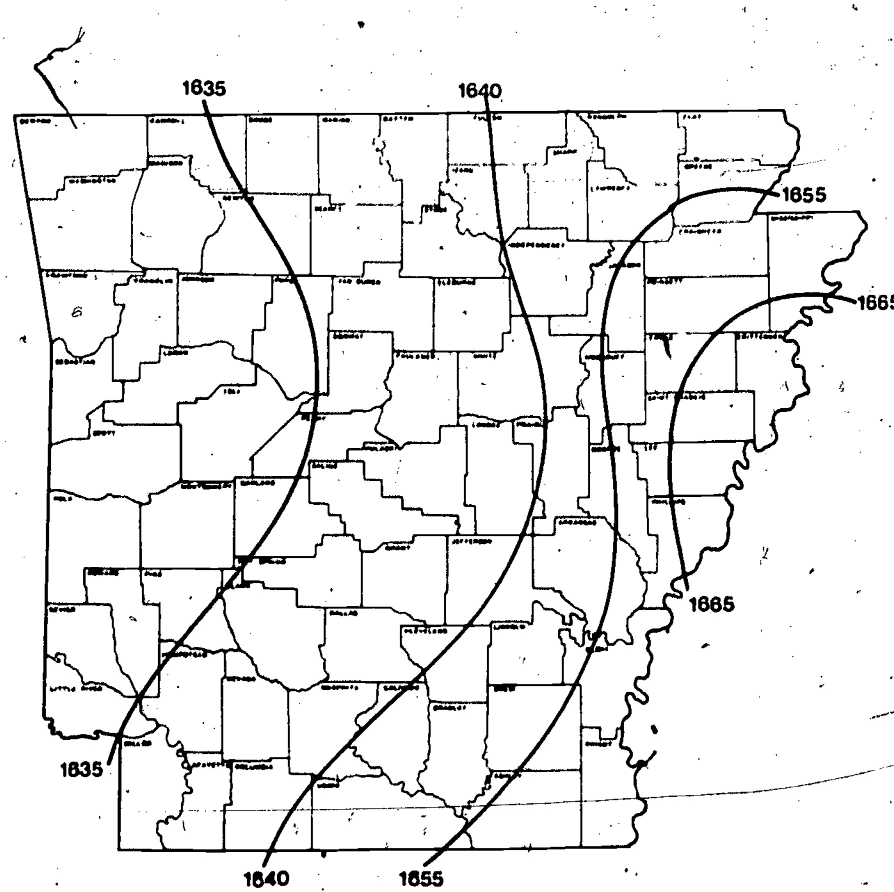
February

89

Mean Daily Solar Radiation (BTU/ft²)

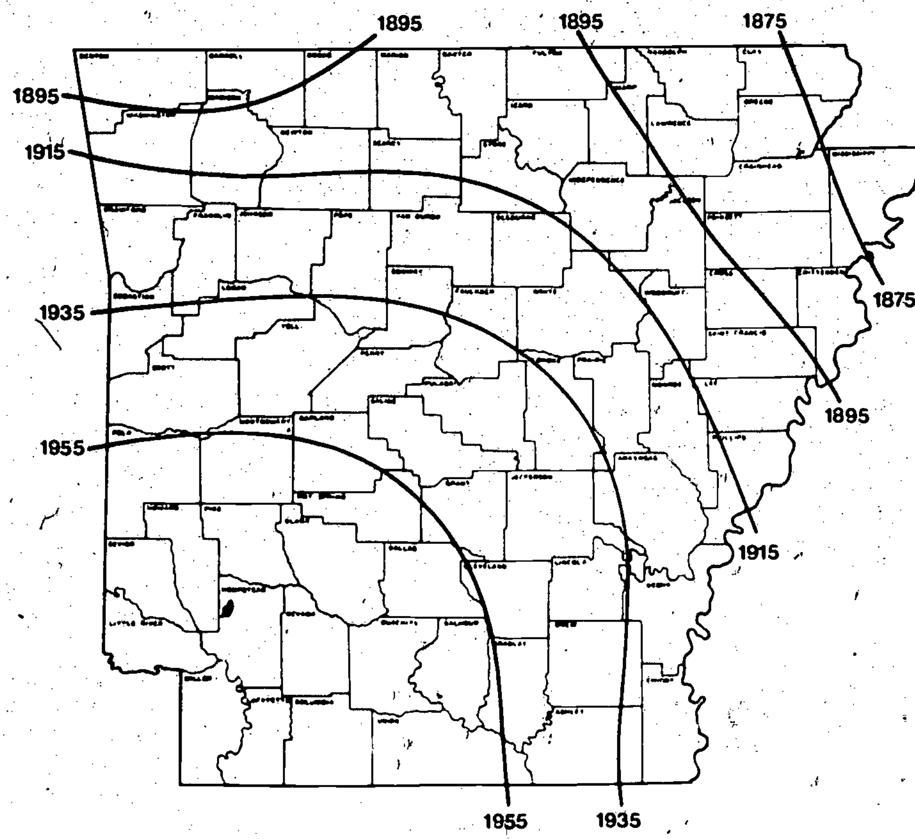


March

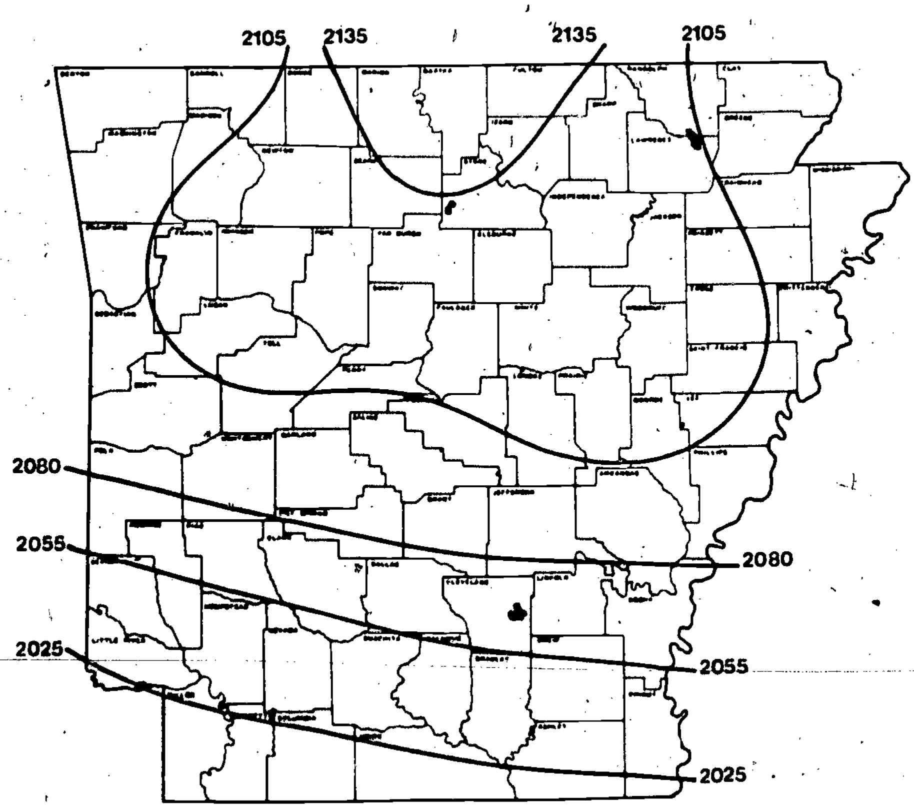


April

Mean Daily Solar Radiation (BTU/ft²)



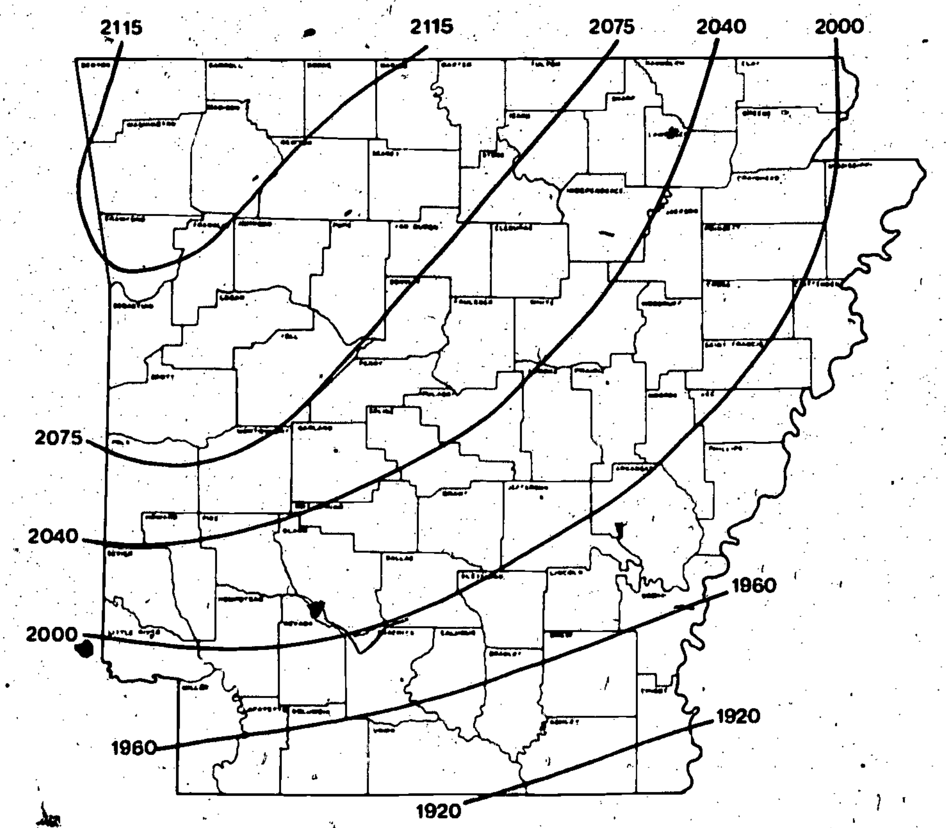
May



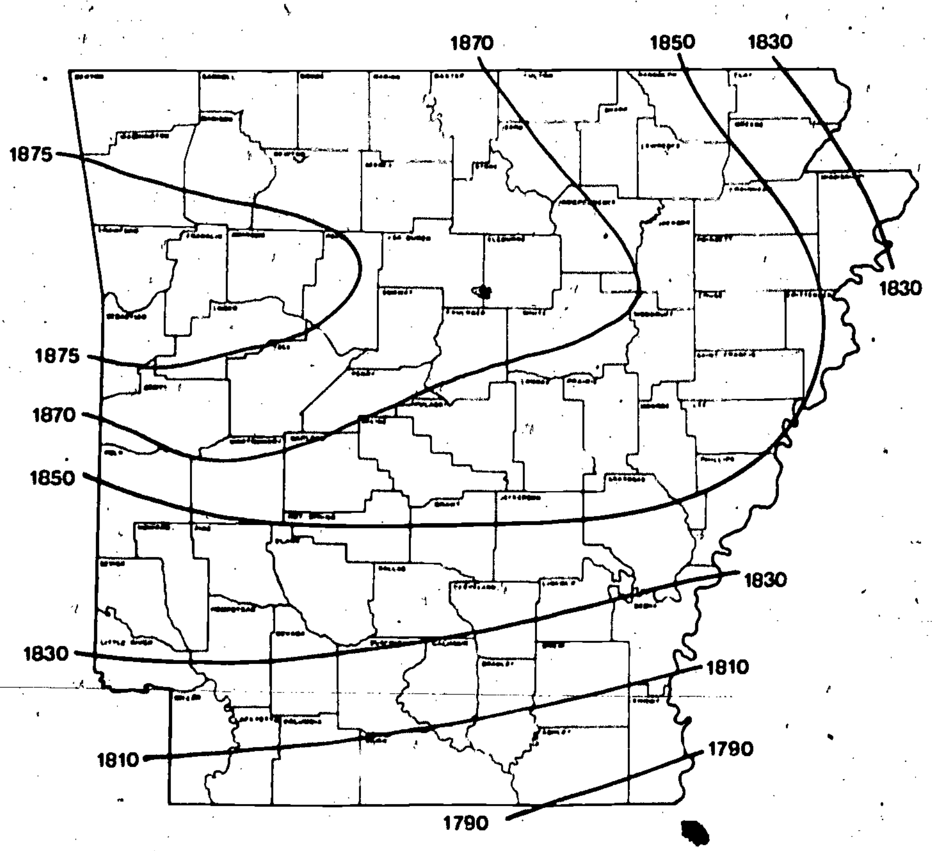
June

9 i

Mean Daily Solar Radiation (BTU/ft²)



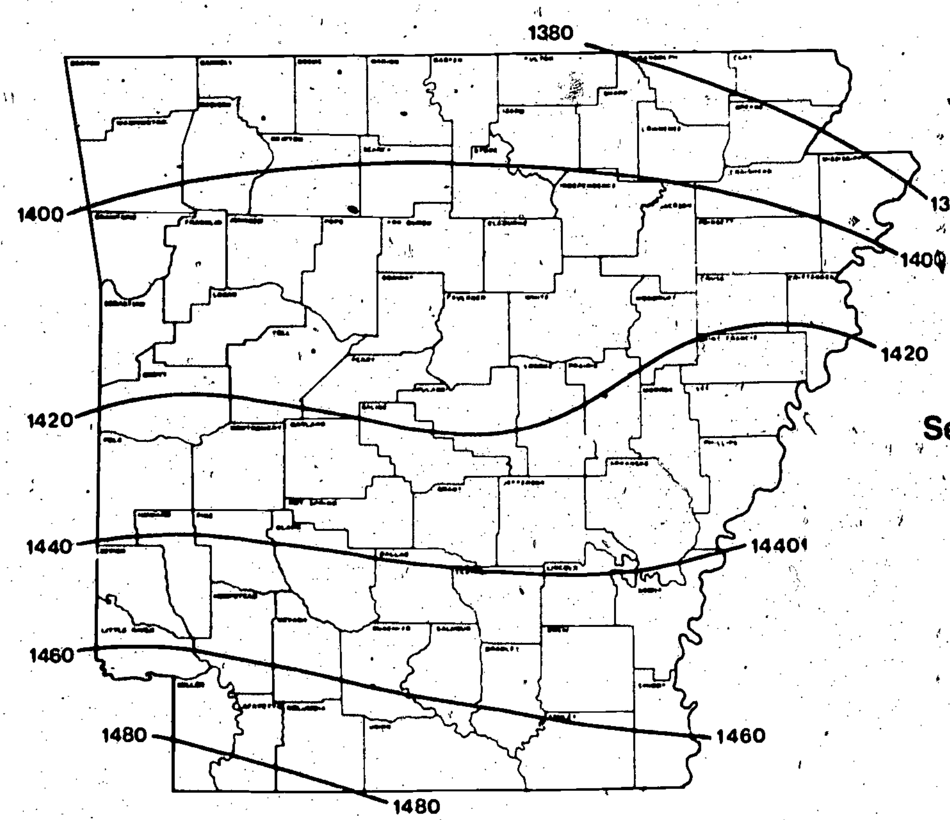
July



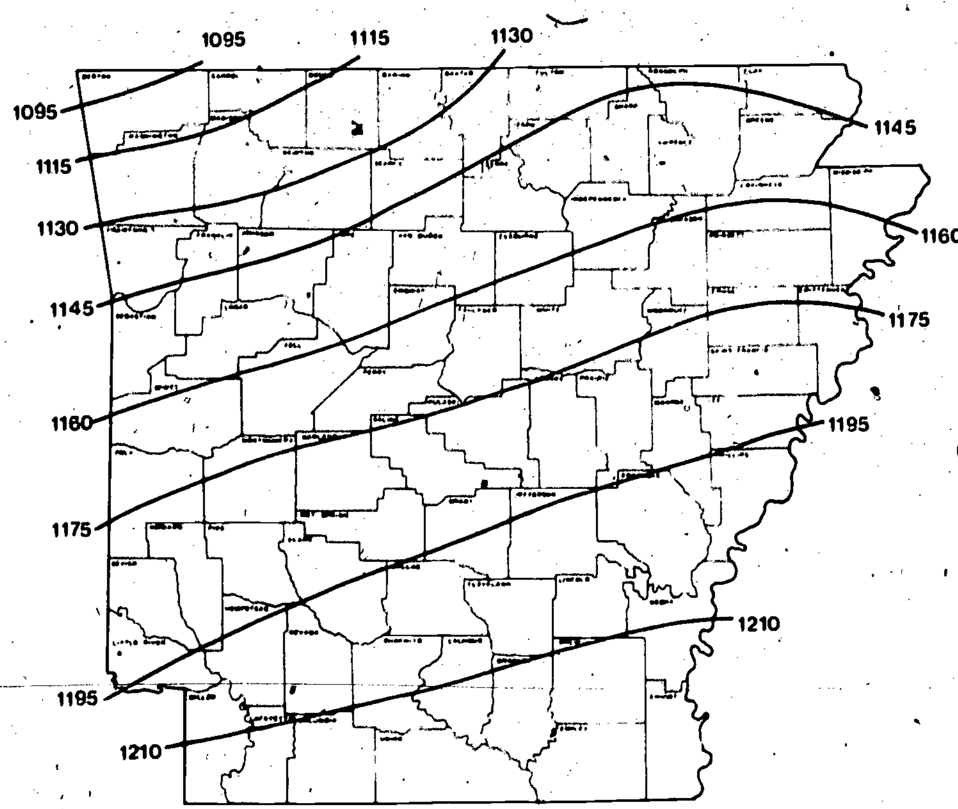
August

92

Mean Daily Solar Radiation (BTU/ft^2)



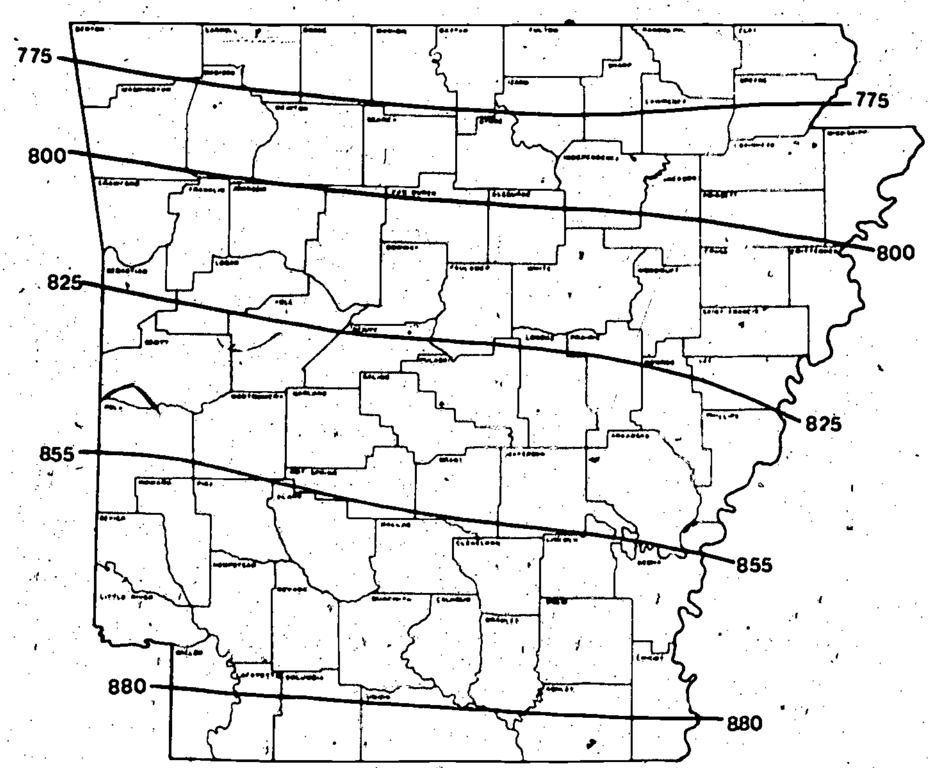
September



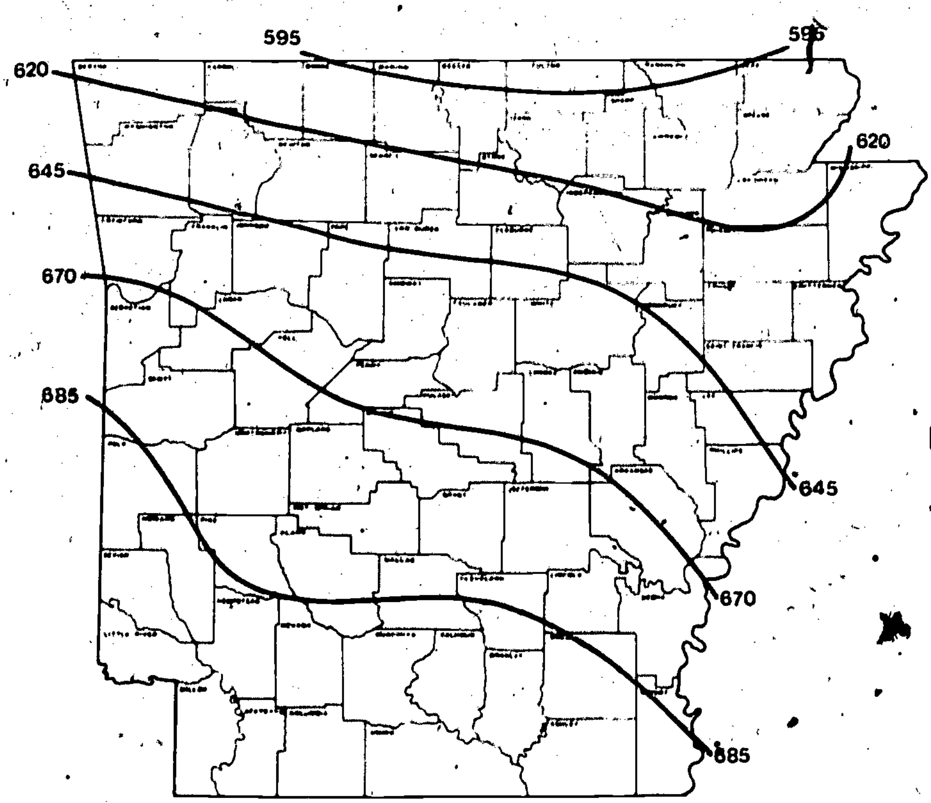
October

93

Mean Daily Solar Radiation (BTU/ft²)



November



December

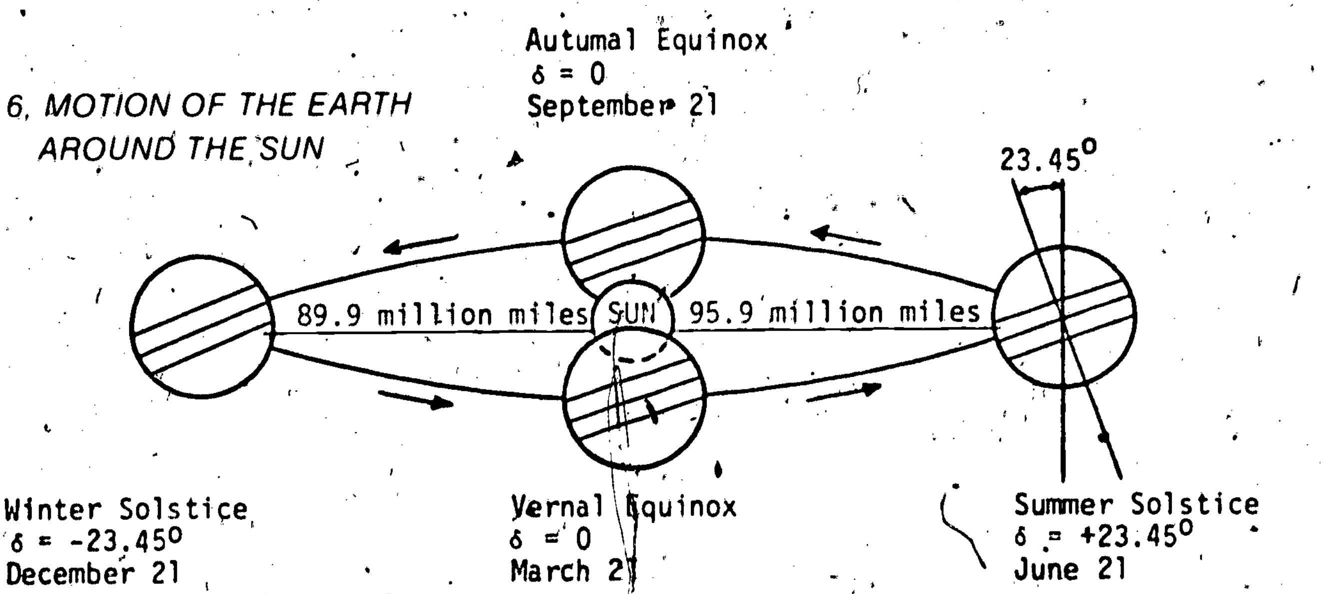
EVALUATION OF SOLAR RADIATION MAPS

The general trend of the solar radiation maps shows the effect of latitude on the values. The winter months (January, February, December) as well as the spring and fall months (March, April, May, and September, October, November) generally show the radiation values increasing in a southerly direction. The month of April is an exception. The contour lines for April show only a 30 Btu's/ft² day variation across the state. The contour lines for April tend to show a north-south pattern with the highest values being in the eastern part of the state, along the Mississippi River.

Contrary to the winter, spring, and fall months, the summer months (June, July, August) show the solar radiation values increasing with increasing latitude. In other words, there is more radiation in the northern part of the state than in the southern part. One cause for this inversion is that cloud cover is greater in the southern part of the state, brought about by moisture from the Gulf of Mexico. Information from the National Weather Service for the years 1960 through 1969 do, in fact, show slightly higher percentages of cloud cover in the summer months for Jackson, Mississippi, and Shreveport, Louisiana, than for Little Rock, Arkansas, Tulsa, Oklahoma, and Springfield, Missouri.

Another reason for the solar radiation inversion is the position of the earth in relation to the sun during the summer months. (See Figure 6.) The declination angle of the earth reaches its maximum positive value of 23.45° on June 21, the summer solstice. At this time, the North Pole can receive sunshine 24 hours a day, but the radiation intensity on clear days is weak because of the steep angle of the sun's rays at that point.

FIG. 6, MOTION OF THE EARTH AROUND THE SUN



On the other hand, the latitude near the Tropic of Cancer can receive only about 12 hours of sunshine each day, but the radiation on clear days is stronger because the sun's rays there are perpendicular to the earth's surface and have less atmosphere to pass through. The two factors of angle of the sun and length of daily sunshine tend to balance each other at the two extremes, so their predicted radiation totals for clear days in summer are about equal.

The highest clear-day radiation values in summer in the northern hemisphere occur between the North Pole and the Tropic of Cancer, with radiation values decreasing towards each extreme. This peak clear-day radiation value occurs north of the state of Arkansas during the summer solstice. Therefore, during the summer months, the northern portions of the state would be expected to receive more solar radiation, based solely on clear-day predicted values.

Generally speaking, the variation in the peak radiation on clear days and the cloud pattern over the state combine to account for the inversion effect during the summer months with the southernmost portion of the state receiving slightly less solar radiation.

TILT FACTORS

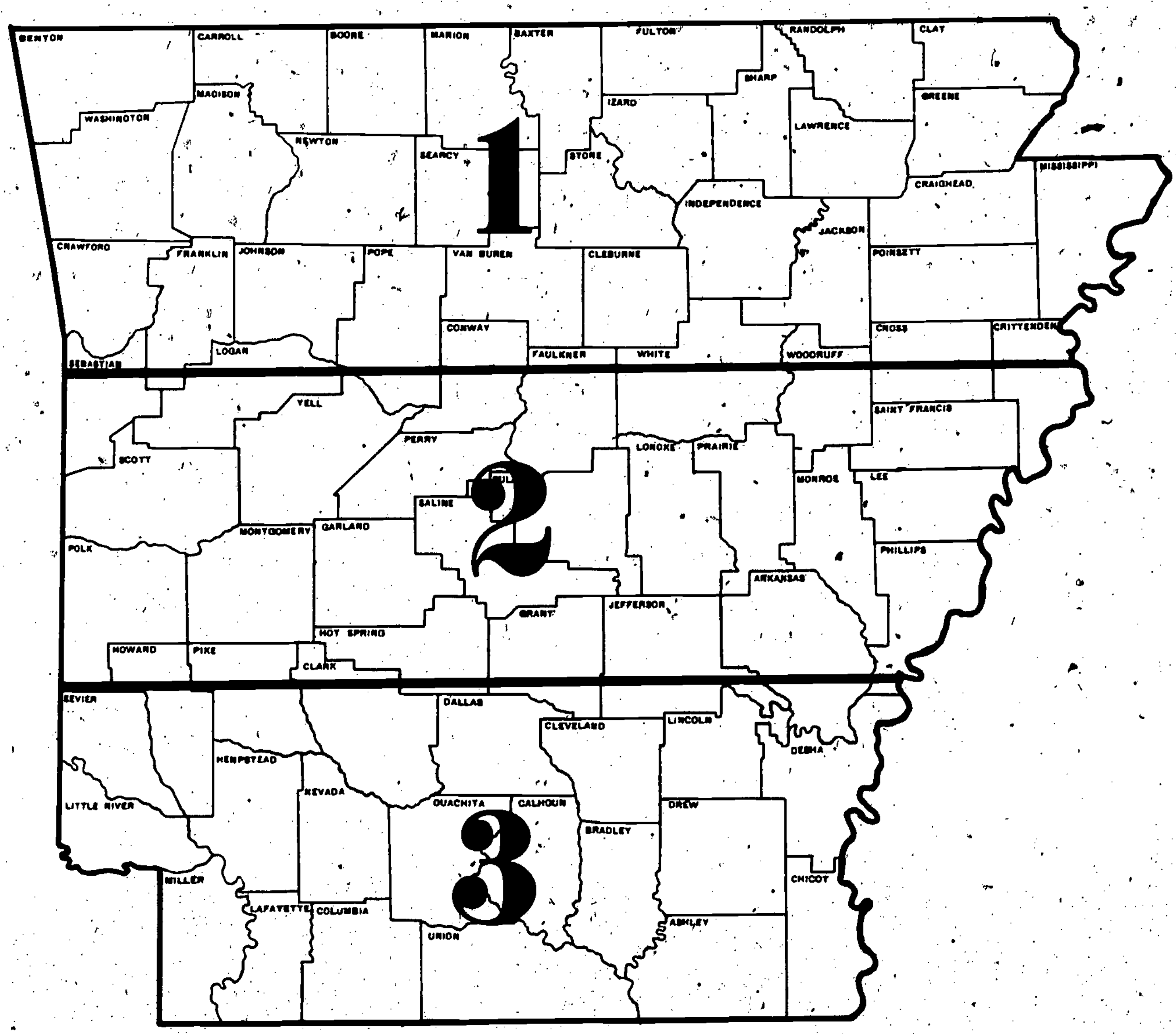
The solar radiation maps can be used to find the total and beam solar radiation on surfaces other than horizontal by using tilt factors. Tilt factors are simply coefficients which enable us to predict solar radiation levels on a surface of any angle or orientation once the horizontal radiation is known.

Equations for tilt factors are dependent upon latitude, so their value generally will increase from north to south. In order to simplify calculations and to minimize the effect of latitude on the tilt factors, the state has been sectioned into the three regions indicated in Figure 7.

Tilt factors for each of the three regions have been calculated for south-facing tilted and vertical surfaces, and for east, west, and north. The tilt factor used to find the total solar radiation is $\bar{R}_B$. Tilt factors for each region are given on pages 89 - 91, followed by step by step methods for using the tilt factors, along with example calculations.

Tilt Factor Regions

FIG. 7.



TILT FACTORS FOR REGION 1

VERTICAL SURFACES

MONTH	Southeast and Southwest $\overline{R}_T$	Southeast and Southwest $\overline{R}_B$	East and West $\overline{R}_T$	East and West $\overline{R}_B$	North $\overline{R}_T$
JAN	1.11	1.49	.72	.74	.33
FEB	.95	1.14	.70	.69	.31
MAR	.77	.81	.67	.63	.31
APR	.62	.54	.64	.58	.31
MAY	.53	.38	.63	.54	.33
JUN	.47	.30	.62	.53	.33
JUL	.49	.33	.62	.53	.32
AUG	.57	.46	.64	.56	.30
SEPT	.70	.68	.66	.61	.31
OCT	.88	.99	.69	.66	.30
NOV	1.05	1.37	.71	.72	.33
DEC	1.16	1.62	.73	.76	.33

TILTED SOUTH-FACING SURFACES

TILT	20°		35°		50°		65°		VERTICAL	
MONTH	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$
JAN	1.31	1.62	1.46	1.95	1.54	2.16	1.54	2.22	1.36	1.98
FEB	1.21	1.40	1.30	1.59	1.32	1.68	1.28	1.65	1.06	1.35
MAR	1.11	1.22	1.14	1.29	1.11	1.28	1.02	1.17	.78	.83
APR	1.03	1.07	1.00	1.03	.92	.93	.80	.77	.54	.40
MAY	.98	.97	.91	.88	.81	.73	.67	.55	.42	.19
JUN	.95	.93	.87	.81	.75	.65	.61	.46	.36	.12
JUL	.96	.94	.88	.84	.77	.68	.63	.49	.37	.14
AUG	1.01	1.02	.96	.95	.86	.83	.73	.66	.47	.29
SEP	1.08	1.15	1.07	1.17	1.02	1.11	.92	.98	.66	.62
OCT	1.18	1.33	1.25	1.48	1.25	1.52	1.19	1.46	.97	1.15
NOV	1.27	1.55	1.41	1.84	1.47	2.01	1.45	2.04	1.26	1.78
DEC	1.33	1.69	1.51	2.08	1.60	2.32	1.61	2.41	1.44	2.19

TILT FACTORS FOR REGION 2

VERTICAL SURFACES

MONTH	Southeast and Southwest $\bar{R}_T$	Southeast and Southwest $\bar{R}_B$	East and West $\bar{R}_T$	East and West $\bar{R}_B$	North $\bar{R}_T$
JAN	1.07	1.43	.71	.72	.33
FEB	.94	1.09	.70	.67	.30
MAR	.75	.78	.67	.62	.31
APR	.61	.52	.64	.57	.31
MAY	.51	.36	.62	.54	.32
JUN	.46	.29	.61	.52	.33
JUL	.48	.31	.62	.53	.33
AUG	.56	.44	.63	.56	.30
SEPT	.69	.66	.65	.60	.31
OCT	.87	.96	.69	.65	.29
NOV	1.03	1.31	.71	.71	.32
DEC	1.12	1.55	.72	.74	.33

TILTED SOUTH-FACING SURFACES

TILT	20°		35°		50°		65°		VERTICAL	
MONTH	$\bar{R}_T$	$\bar{R}_B$	$\bar{R}_T$	$\bar{R}_B$	$\bar{R}_T$	$\bar{R}_B$	$\bar{R}_T$	$\bar{R}_B$	$\bar{R}_T$	$\bar{R}_B$
JAN	1.29	1.58	1.43	1.90	1.50	2.09	1.49	2.13	1.30	1.89
FEB	1.22	1.40	1.31	1.58	1.33	1.66	1.29	1.63	1.07	1.33
MAR	1.11	1.21	1.13	1.27	1.09	1.25	1.00	1.14	.76	.79
APR	1.03	1.06	.99	1.02	.91	.91	.79	.75	.53	.37
MAY	.96	.97	.90	.87	.79	.72	.66	.53	.40	.17
JUN	.94	.92	.86	.80	.74	.64	.60	.44	.35	.10
JUL	.95	.94	.88	.83	.76	.67	.62	.47	.37	.13
AUG	1.00	1.01	.95	.94	.85	.81	.72	.64	.46	.27
SEPT	1.07	1.14	1.06	1.15	1.01	1.09	.90	.95	.65	.59
OCT	1.18	1.32	1.24	1.45	1.24	1.49	1.18	1.42	.95	1.10
NOV	1.27	1.52	1.40	1.79	1.45	1.95	1.43	1.96	1.24	1.70
DEC	1.32	1.65	1.48	2.02	1.56	2.24	1.57	2.31	1.39	2.09

TILT FACTORS FOR REGION 3

VERTICAL SURFACES

MONTH	Southeast and Southwest $\overline{R}_T$	Southeast and Southwest $\overline{R}_B$	East and West $\overline{R}_T$	East and West $\overline{R}_B$	North $\overline{R}_T$
JAN	1.06	1.37	.71	.71	.32
FEB	.90	1.05	.69	.66	.31
MAR	.74	.75	.66	.61	.30
APR	.60	.50	.64	.56	.31
MAY	.50	.34	.62	.53	.32
JUN	.46	.27	.61	.52	.34
JUL	.48	.30	.61	.52	.33
AUG	.55	.42	.63	.55	.31
SEPT	.68	.64	.65	.59	.30
OCT	.84	.92	.68	.64	.30
NOV	1.01	1.26	.70	.69	.32
DEC	1.08	1.48	.71	.72	.34

TILTED SOUTH-FACING SURFACES

TILT	20°		35°		50°		65°		90°	
MONTH	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$	$\overline{R}_T$	$\overline{R}_B$
JAN	1.29	1.56	1.43	1.85	1.49	2.02	1.48	2.05	1.29	1.80
FEB	1.20	1.38	1.28	1.55	1.29	1.62	1.24	1.58	1.02	1.28
MAR	1.10	1.20	1.12	1.25	1.08	1.22	.99	1.11	.74	.76
APR	1.02	1.05	.98	1.01	.90	.90	.78	.73	.52	.35
MAY	.97	.96	.89	.86	.78	.70	.65	.51	.39	.16
JUN	.94	.91	.85	.79	.74	.62	.59	.43	.35	.09
JULY	.95	.93	.87	.81	.75	.65	.61	.46	.36	.11
AUG	1.00	1.00	.94	.93	.84	.80	.71	.62	.45	.25
SEPT	1.07	1.13	1.06	1.14	1.00	1.07	.89	.93	.63	.56
OCT	1.17	1.30	1.22	1.42	1.22	1.45	1.15	1.38	.92	1.05
NOV	1.26	1.50	1.38	1.75	1.43	1.89	1.40	1.90	1.20	1.63
DEC	1.29	1.62	1.44	1.96	1.52	2.17	1.51	2.22	1.33	1.99

MEAN DAILY TOTAL SOLAR RADIATION FOR TILTED AND VERTICAL SURFACES

($\bar{I}_{TTS}$)

Step 1—Find the mean daily total horizontal solar radiation, $\bar{I}_{TH}$, for the month and location of interest from the solar radiation maps.

Step 2—Look at Figure 7 on page 88 to determine what region of the state your location is in.

Step 3—Look in Tilt Factor tables, pages 89 to 91, for the appropriate tilt factor, $\bar{R}_T$. Simply multiply the tilt factor ($\bar{R}_T$) by the total horizontal radiation ($\bar{I}_{TH}$) to get the answer:

$$\bar{I}_{TTS} = \bar{I}_{TH} \times \bar{R}_T$$

To find monthly average value, multiply $\bar{I}_{TTS}$ by the number of days in the month of interest.

Example One

Mr. Jones of Little Rock is thinking about installing flat-plate collectors on his roof for water-heating purposes. His roof faces due south with a tilt of 35° from the horizontal. Find the amount of total solar radiation falling on his flat-plate collectors for a day in January.

Step 1—Look at the mean daily total horizontal solar radiation map for January on page 81. For Little Rock,

$$\bar{I}_{TH} = 740 \text{ BTU/ft}^2 \bullet \text{day}$$

Step 2—Looking at Figure 7 on page 88, we see that Little Rock is in Region 2.

Step 3—From Tilt Factor Table on page 90, for the month of January and a tilt of 35°, $\bar{R}_T$ is found to be 1.43. Therefore, $\bar{I}_{TTS} = 740 \times 1.43 = 1060$ BTU/ft² • day.

Answer:

Mr. Jones can expect an average of 1060 BTU/ft² • day incident on his flat-plate collectors during the month of January. For the entire month, he would expect:

1060×31 days $= 32{,}860$ BTU/ft²

The transparent covers (glazings) on the collector will further decrease the value of solar radiation and must be taken into account to determine the solar energy actually received by the collector (See Example 3).

MEAN DAILY BEAM SOLAR RADIATION FOR TILTED AND VERTICAL SURFACES

($\bar{I}_{BTS}$)

Step 1—Find the mean daily total horizontal solar radiation, $\bar{I}_{TH}$, for the month and location of interest from the solar radiation maps on pages 81 - 86.

Step 2—Find the mean daily extraterrestrial solar radiation on a horizontal surface, $\bar{I}_{EXT}$, from Table 2:

Step 3—Calculate $\bar{K}_T$ by the following equation:

$$\bar{K}_T = \frac{\bar{I}_{TH}}{\bar{I}_{EXT}}$$

Step 4—Calculate the diffuse ($\bar{I}_{DIF}$) to total ($\bar{I}_{TH}$) split by the following equation:

$$\frac{\bar{I}_{DIF}}{\bar{I}_{TH}} = 1 - 1.096 \times \bar{K}_T$$

Step 5—Calculate the mean daily beam radiation on a horizontal surface, $\bar{I}_B$, by the following equation:

$$\bar{I}_B = \left(1 - \frac{\bar{I}_{DIF}}{\bar{I}_{TH}}\right) \times \bar{I}_{TH}$$

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TABLE 2
MONTHLY AVERAGED DAILY EXTRATERRESTRIAL SOLAR RADIATION
$\bar{I}_{EXT}$ (BTU/ft² • day)

MONTH	REGION 1	REGION 2	REGION 3
JAN	1540	1607	1674
FEB	2016	2039	2100
MAR	2551	2598	2643
APR	3121	3146	3168
MAY	3488	3492	3495
JUN	3637	3630	3621
JUL	3564	3561	3557
AUG	3270	3284	3297
SEPT	2768	2805	2841
OCT	2180	2235	2290
NOV	1658	1723	1788
DEC	1407	1475	1544

Step 6—Look in Tilt Factor Tables, pages 89, 90 and 91, for appropriate beam tilt factor, $\bar{R}_B$. The mean daily beam component of radiation on the tilted surface, $\bar{I}_{BTS}$, is calculated as follows:

$$\bar{I}_{BTS} = \bar{I}_B \times \bar{R}_B$$

Example Two

Suppose Mr. Jones would now like to know the average amount of beam solar radiation that will be incident on his flat-plate collectors for a day in January.

Solution

Step 1—The mean daily total horizontal solar radiation contour map for January is on page 81. Looking at the map for Little Rock,

$$\bar{I}_{TH} = 740 \text{ BTU/ft}^2 \bullet \text{day}$$

Step 2—Looking at Figure 7, we find that Little Rock is in Region 2.

Step 3—From Table 2 and the month of January, $\bar{I}_{EXT}$ is found to be 1,607 Btu/ft² • day

Step 4—$\bar{K}_T$ is calculated as follows:

$$\bar{K}_T = \frac{740}{1,607} = 0.460$$

Step 5—The split is calculated as follows:

$$\frac{\bar{I}_{DIF}}{\bar{I}_{TH}} = 1 - 1.096 \times 0.460 = 0.495$$

Step 6—The mean daily beam component is calculated as follows:

$$\bar{I}_B = (1 - 0.495) \times 740 = 375 \text{ BTU/ft}^2 \bullet \text{day}$$

Step 7—Mr. Jones' roof was south-facing with a tilt of 35°. From Region 2 Tilt Factor Table on page 90, $\bar{R}_B$ is found to be 1.90. Therefore,

$$\bar{I}_{BTS} = 375 \times 1.90 = 710 \text{ BTU/ft}^2$$

Answer:

Mr. Jones can expect an average of 710 BTU/ft² • day of beam radiation on his flat-plate collectors during the month of January. As in Example 1, this amount is subject to a reduction due to glazings used on the collector (See Example 3).

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SOLAR RADIATION TRANSMITTED THROUGH GLAZINGS

A glazing is any transparent material, such as glass, fiberglass, or plastic, which allows light to pass through. In many solar and architectural applications, more than one layer of glazing is used to reduce heat losses.

Figure 8 depicts the solar energy flow through a double glazed surface. This surface can be considered a window, a solar collector cover, a greenhouse, a sliding glass door, or any other transparent surface.

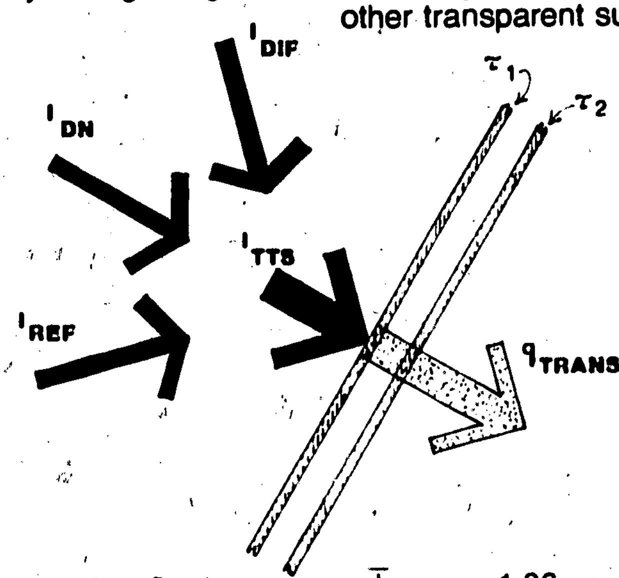

FIG. 8. TRANSFER OF ENERGY THROUGH GLAZED SURFACES

The transmissivity of the glazing, τ, is a measure of how much radiation (or light) is transferred through each layer of glazing. The energy transmitted, q_{trans}, for the sketch in Figure 8 can be approximated by the following equation:

$$q_{trans} = \bar{I}_{TTS}\,(\tau_1) \times (\tau_2)$$

Example 3

Mr. Smith of Fayetteville, Arkansas, has a vertical, south-facing, double-paned, tempered glass window in his den. He would like to know the amount of solar radiation that is transmitted through the window into his den for an average day in the month of February.

Solution

Step 1—Following the method presented in Example 1, from the February solar radiation map on page 81, the total horizontal radiation $\bar{I}_{TH}$, is about 996 BTU/ft² • day in February.

Step 2—From Figure 7 on page 88, Fayetteville is in Region 1.

Step 3—From Region 1 Tilt Factor Table on page 89 for vertical south-facing surfaces in February, $\bar{R}_T$ is found to be 1.06. Therefore,

$$\bar{I}_{TTS} = \bar{R}_T \times \bar{I}_{TH}$$

$$\bar{I}_{TTS} = 1.06 \times 995 = 1{,}055 \text{ BTU/ft}^2 \bullet \text{day}$$

Step 4—From Table 3 on page 94, τ for each window pane is 0.85. Therefore

$$q_{trans} = 1{,}055 \times (0.85) \times (0.85) = 760 \text{BTU/ft}^2$$

Answer:

Mr. Smith can expect an average of 760 BTU/ft² • day of solar energy to be transmitted through the window that could be absorbed in his den space for an average day in the month of February. If the window area is 10 ft² then 760 × 10 = 7,600 BTU would be transmitted through the window each day. The average radiation for the entire month of February would be 7.600 × 28 (days) = 212,800 BTU.

TABLE 3 TRANSMISSIVITY OF GLAZINGS

LOW-IRON GLASS	.91	ACRYLICS	.92
TEMPERED GLASS	.85	POLYETHELYNE	.82
WINDOW GLASS	.90	CLEAR VINYL	.91
FIBERGLASS REINFORCED POLYESTER	.84	TEDLAR (PVF FILM)	.93
POLYCARBONATES	.90		

BEAM AND TOTAL SOLAR RADIATION TABLES

The previous two sections discussed methods on how to carry out beam and total solar radiation calculations using the tilt factors on pages 89 through 91. This section contains a complete set of tabulated beam and total solar radiation values for a city in each of the three regions of the state. The cities chosen were Fayetteville for Region 1, Little Rock for Region 2, and Texarkana for Region 3. The results are presented in the tables 4 through 9 that follow on pages 96 through 101.

Also presented for each city is a graph showing the effects of tilt for south-facing surfaces (See Figures 9, 11, and 13). A rule of thumb for maximizing the amount of solar radiation collected on a year-round basis is to tilt surfaces the latitude ± 15 degrees. Since the average latitude for the state can be considered as 35 degrees, tilts of 20, 35 and 50 degrees were shown. For comparative purposes, the radiation on horizontal and vertical south-facing surfaces were also shown. The area under the curve indicates the annual amount of solar radiation.

Another graph for each city shows the effects of orientation for vertical surfaces (Figures 10, 12, and 14). Radiation values are given for vertical surfaces facing east, west, southeast, southwest, north and south.

The amount of total horizontal solar radiation falling on other locations within the state can be found from the contour maps. The results in each region will vary, depending on the monthly average, but will be close to the values shown in Tables 4 through 9 and in Figures 9 through 14.

TABLE 4 SOLAR RADIATION ON SOUTH-FACING TILTED SURFACES FAYETTEVILLE (REGION 1)

TILT	HORIZONTAL		20°		35°		50°		65°		VERTICAL	
MONTH	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
JAN	720	370	940	595	1055	720	1110	795	1110	820	975	730
FEB	995	540	1205	755	1290	860	1315	905	1270	885	1055	730
MAR	1275	700	1420	855	1450	905	1410	895	1305	820	995	580
APR	1625	925	1675	990	1620	960	1495	865	1305	715	880	370
MAY	1900	1135	1855	1100	1725	995	1530	835	1275	620	790	215
JUN	2105	1335	1995	1235	1820	1085	1575	870	1280	610	755	155
JUL	2115	1375	2025	1295	1860	1150	1620	940	1325	675	780	200
AUG	1875	1180	1885	1200	1795	1125	1620	980	1375	775	875	340
SEPT	1395	770	1500	885	1495	905	1420	860	1280	755	925	475
OCT	1120	630	1320	840	1400	930	1400	960	1335	925	1080	725
NOV	780	400	995	625	1100	740	1145	805	1135	820	985	715
DEC	635	315	845	530	955	655	1015	730	1025	760	915	690

FIG. 9. EFFECT OF TILT ON SOUTH-FACING SURFACES

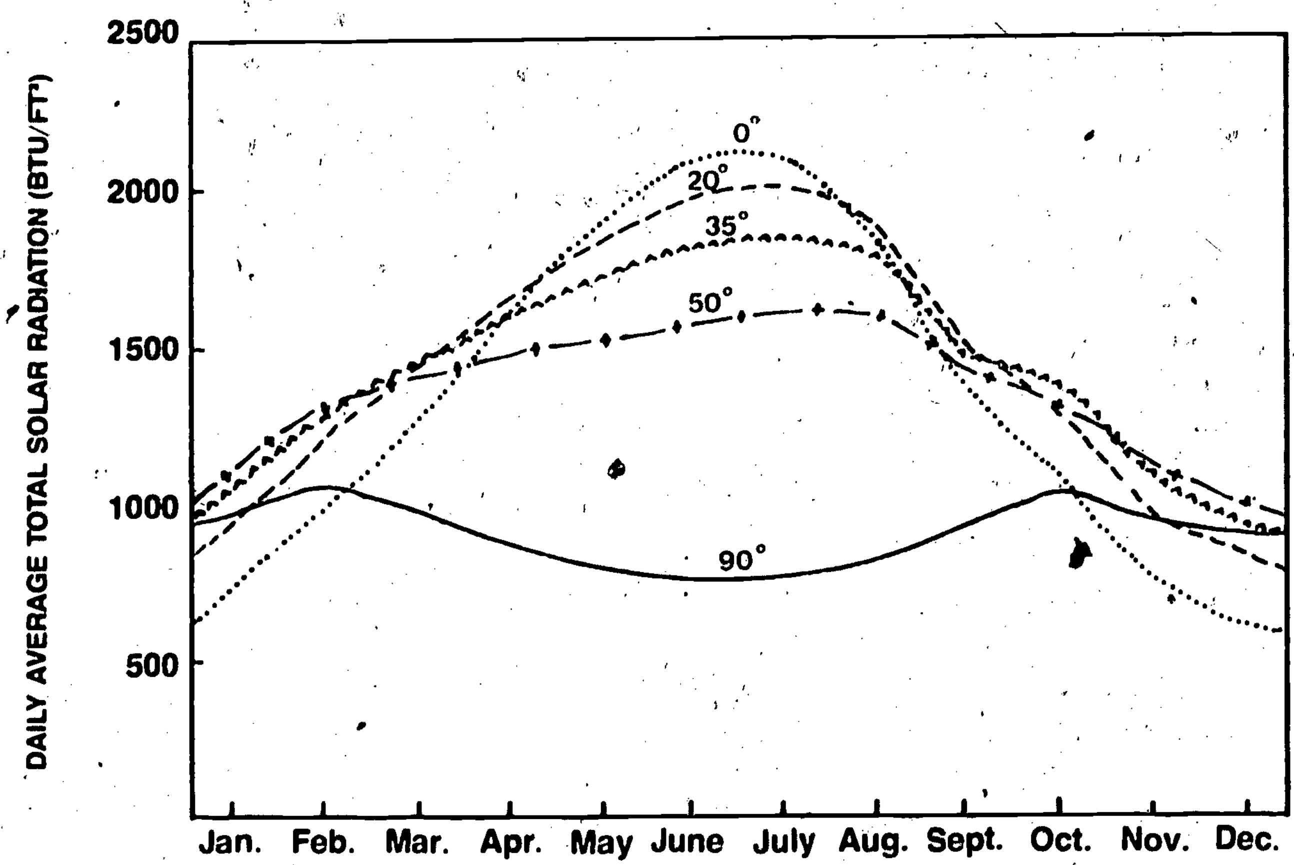

TABLE 5 SOLAR RADIATION ON VERTICAL SURFACES FAYETTEVILLE (REGION 1)

MONTH	SOUTHEAST AND SOUTHWEST		EAST AND WEST		NORTH
	TOTAL	BEAM	TOTAL	BEAM	TOTAL
JAN	795	550	520	275	235
FEB	945	526	700	375	305
MAR	980	565	855	440	395
APR	1015	500	1045	535	505
MAY	1000	425	1190	618	620
JUN	995	400	1300	705	700
JUL	1035	455	1315	735	670
AUG	1075	540	1195	660	555
SEPT	980	525	920	465	430
OCT	980	625	775	415	340
NOV	820	550	560	290	255
DEC	735	510	465	240	215

FIG. 10. EFFECT OF ORIENTATION ON VERTICAL SURFACES

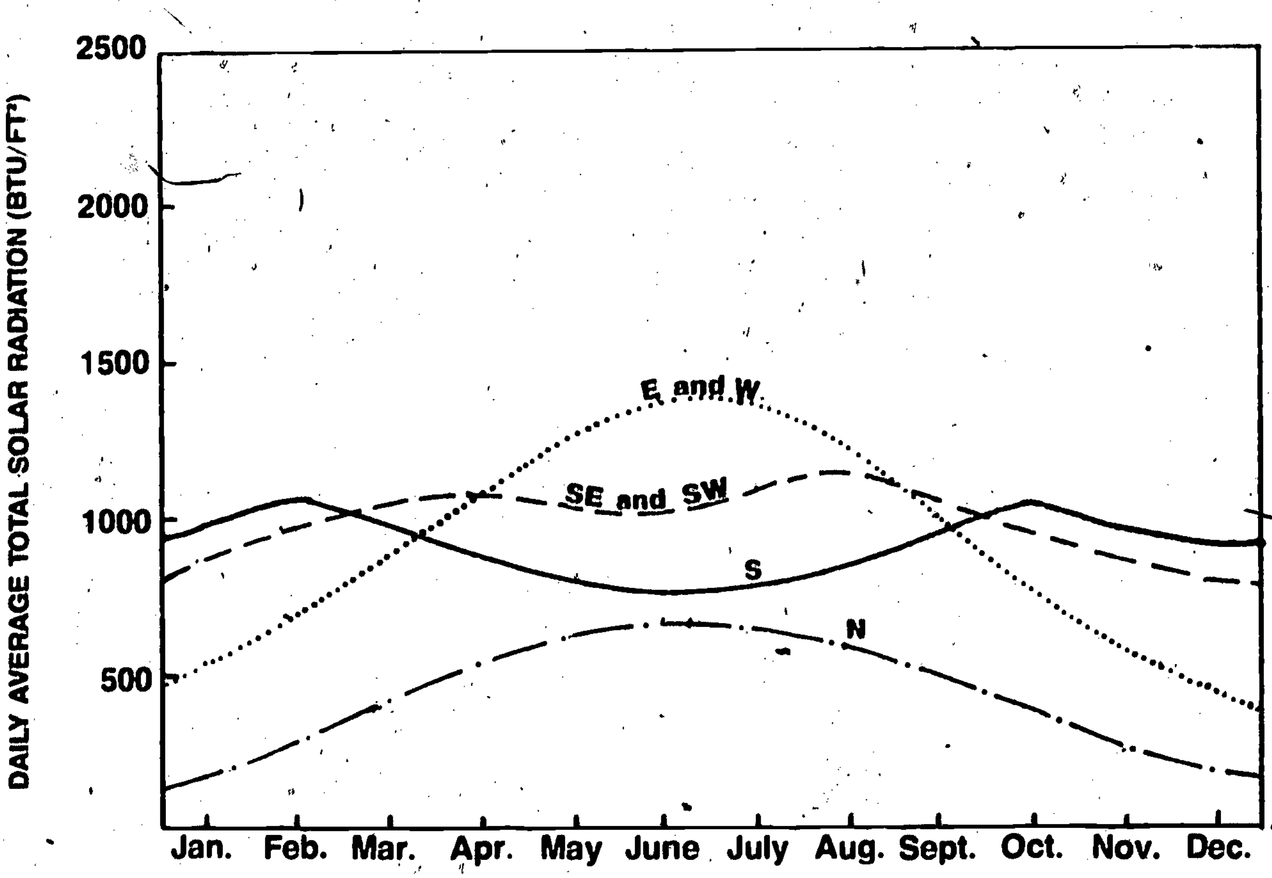

TABLE 6 SOLAR RADIATION ON SOUTH-FACING TILTED SURFACES LITTLE ROCK (REGION 2)

TILT	HORIZONTAL		20°		35°		50°		85°		VERTICAL	
MONTH	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
JAN	745	380	960	600	1085	720	1120	790	1110	805	970	715
FEB	1050	590	1275	825	1375	940	1400	985	1355	965	1125	790
MAR	1300	715	1440	865	1465	910	1420	890	1305	815	990	595
APR	1830	925	1870	980	1815	945	1485	845	1290	695	860	345
MAY	1945	1185	1890	1145	1755	1030	1545	855	1280	830	780	205
JUN	2110	1345	1995	1240	1810	1075	1560	855	1260	595	730	140
JUL	2035	1275	1945	1195	1780	1050	1550	850	1285	605	745	165
AUG	1860	1155	1860	1185	1765	1090	1585	940	1345	735	845	310
SEPT	1420	790	1520	900	1510	910	1430	880	1285	750	920	465
OCT	1185	890	1395	905	1470	1000	1475	1025	1400	980	1125	760
NOV	835	445	1060	875	1185	795	1215	865	1200	870	1035	755
DEC	870	335	880	550	990	675	1050	750	1050	770	930	695

FIG. 11. EFFECT OF TILT ON SOUTH-FACING SURFACES

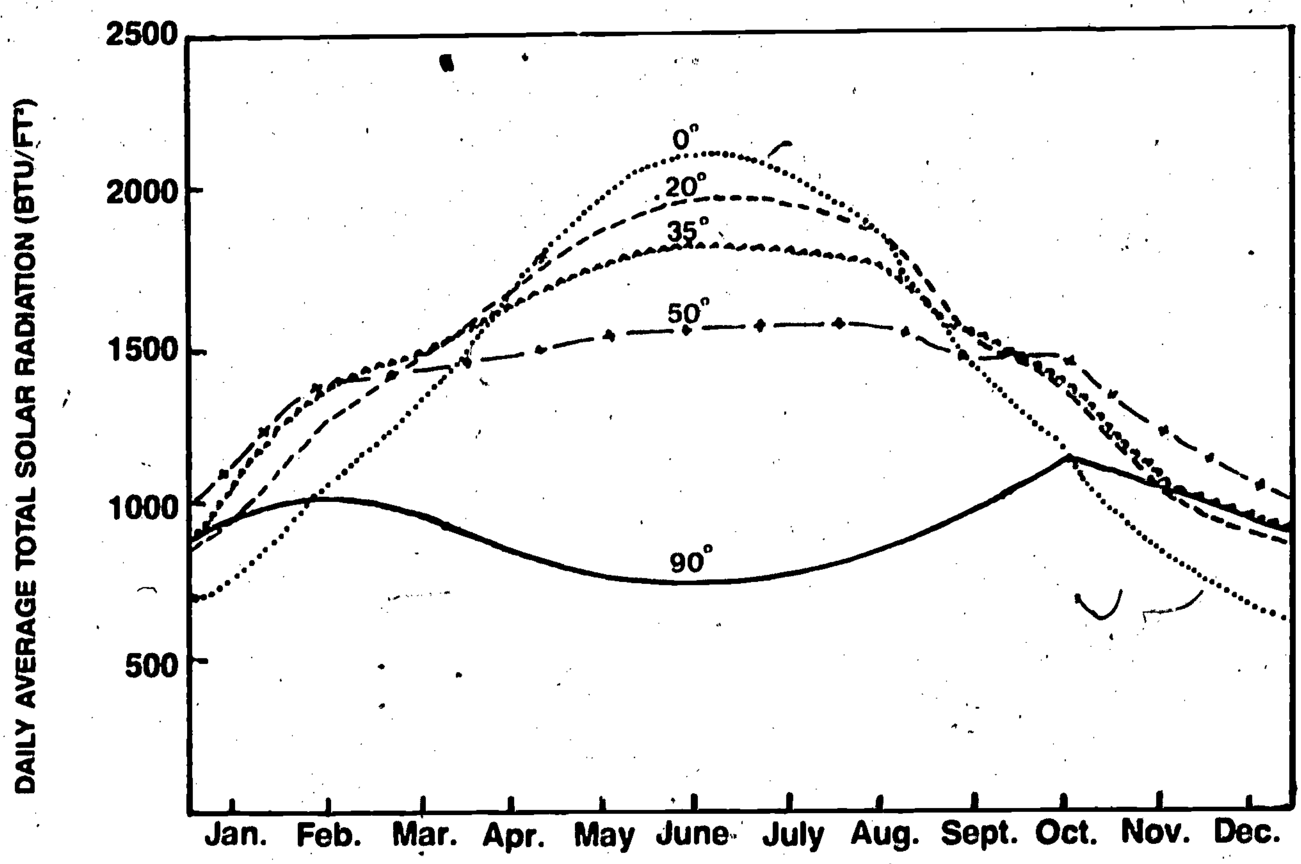

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TABLE 7 SOLAR RADIATION ON VERTICAL SURFACES LITTLE ROCK (REGION 2)

MONTH	Southeast and Southwest		East and West		North
	TOTAL	BEAM	TOTAL	BEAM	TOTAL
JAN	795	540	530	275	245
FEB	980	650	730	400	315
MAR	980	555	865	440	400
APR	1000	485	1045	530	510
MAY	1000	430	1210	640	625
JUN	980	385	1295	700	700
JUL	985	400	1255	675	685
AUG	1050	510	1180	640	555
SEPT	980	520	930	470	435
OCT	1025	660	815	445	350
NOV	860	585	590	315	265
DEC	750	515	480	245	225

FIG. 12. EFFECT OF ORIENTATION ON VERTICAL SURFACES

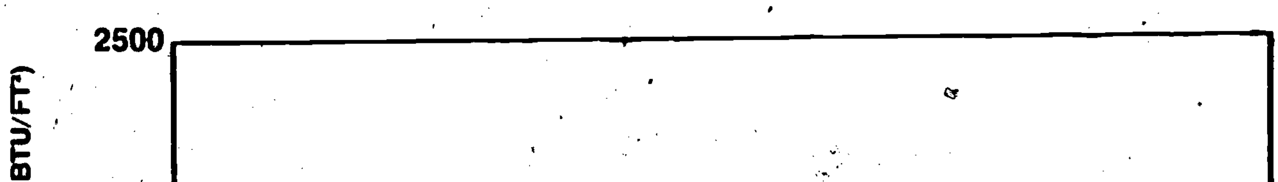

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TABLE 14 SOLAR RADIATION ON SOUTH-FACING TILTED SURFACES TEXARKANA (REGION 3)

TILT	HORIZONTAL		20°		35°		50°		65°		VERTICAL	
MONTH	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM	TOTAL	BEAM
JAN	810	430	1040	670	1155	795	1210	870	1200	880	1045	775
FEB	1040	565	1245	775	1325	875	1345	915	1290	890	1065	720
MAR	1355	760	1495	915	1520	955	1465	930	1345	845	1010	575
APR	1635	925	1670	970	1605	930	1470	830	1270	670	845	325
MAY	1980	1230	1915	1175	1770	1050	1555	865	1280	630	765	190
JUN	2025	1240	1905	1135	1730	980	1490	775	1200	530	705	110
JUL	1975	1200	1880	1120	1720	980	1490	785	1215	550	720	135
AUG	1820	1100	1810	1104	1710	1025	1535	880	1295	680	815	270
SEPT	1470	835	1570	940	1555	950	1465	890	1310	775	930	465
OCT	1205	695	1405	905	1475	980	1470	1010	1309	955	1110	730
NOV	875	470	1100	700	1205	820	1250	885	1230	890	1055	765
DEC	690	340	895	550	995	660	1045	730	1040	750	915	670

FIG. 13. EFFECT OF TILT ON SOUTH-FACING SURFACES

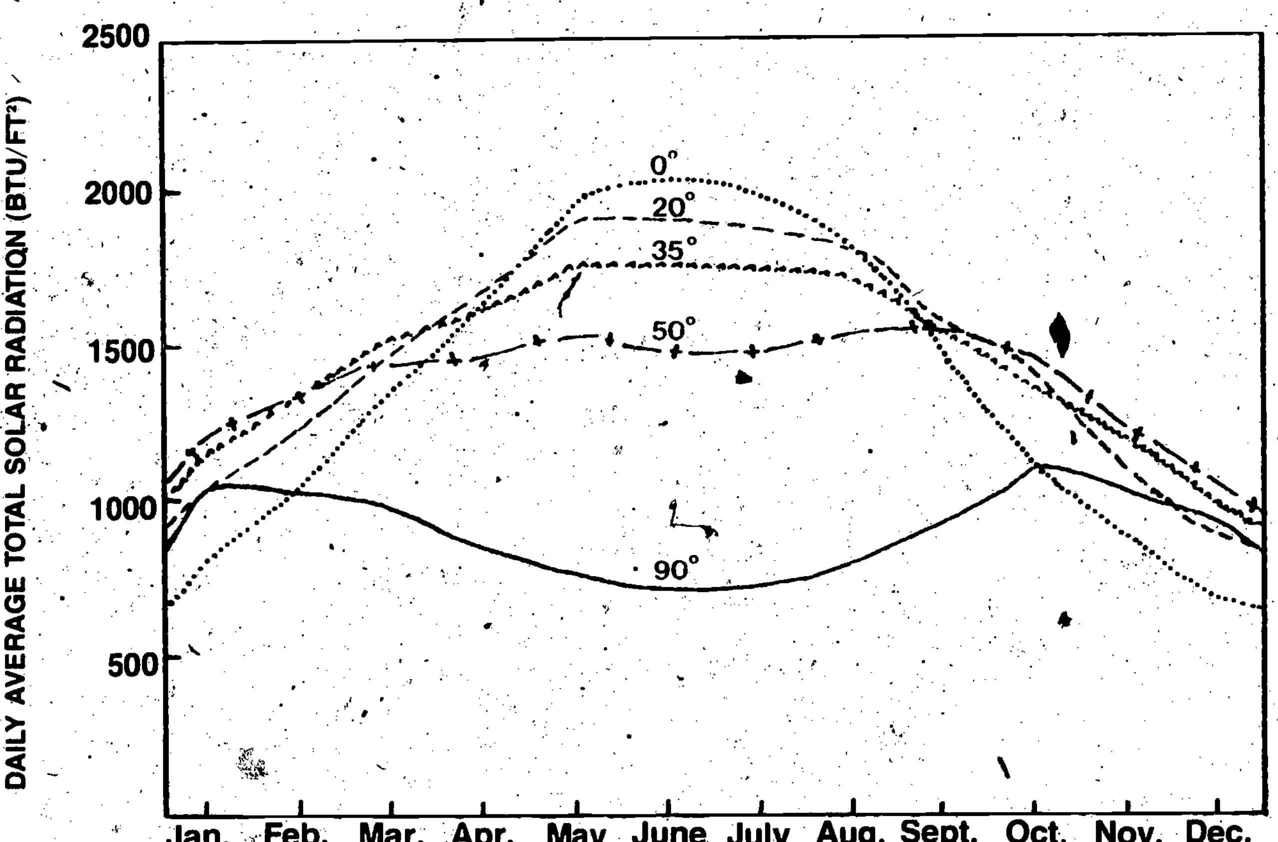
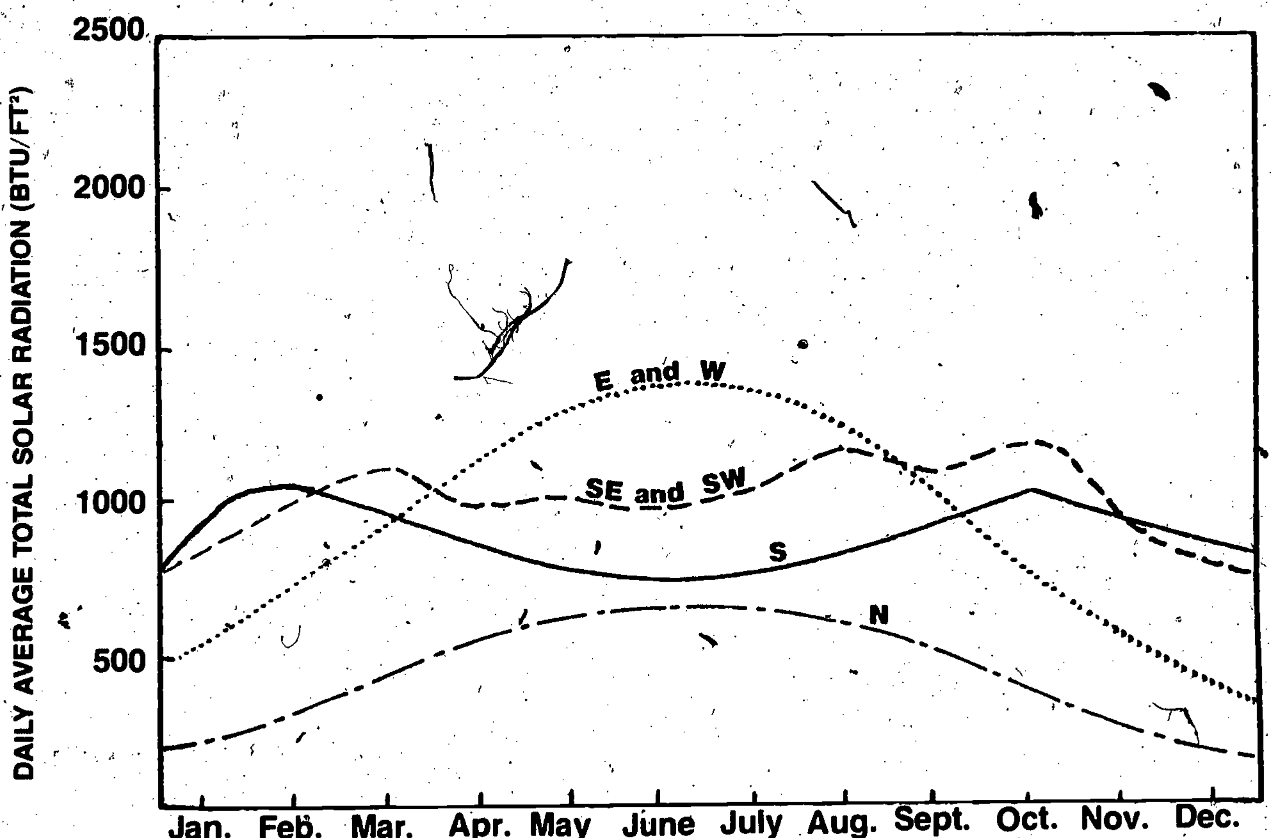


TABLE 9 SOLAR RADIATION ON VERTICAL SURFACES TEXARKANA (REGION 3)

MONTH	Southeast and Southwest TOTAL	Southeast and Southwest BEAM	East and West TOTAL	East and West BEAM	North TOTAL
JAN	860	585	575	305	260
FEB	935	595	715	370	325
MAR	1005	575	895	465	410
APR	985	465	1040	520	510
MAY	995	425	1230	655	625
JUN	935	340	1235	640	690
JUL	945	360	1215	630	660
AUG	1010	470	1145	605	555
SEPT	1000	530	955	490	445
OCT	1020	640	820	445	355
NOV	880	590	615	325	275
DEC	745	500	490	245	235

FIG. 14. EFFECT OF ORIENTATION ON VERTICAL SURFACES



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