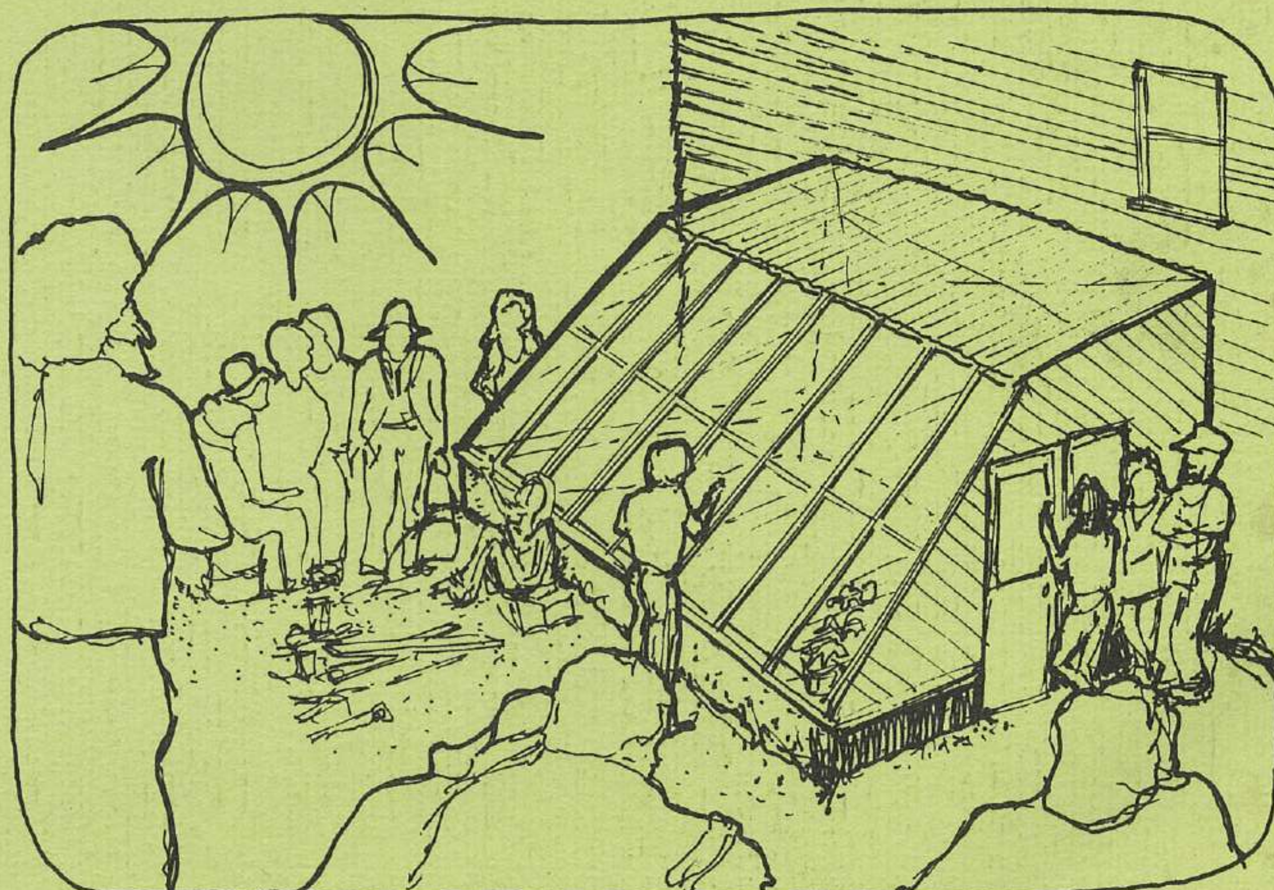
a solar greenhouse guide for the northwest



$5.00

ECOTOPE GROUP
seattle, washington

a solar greenhouse guide for the northwest

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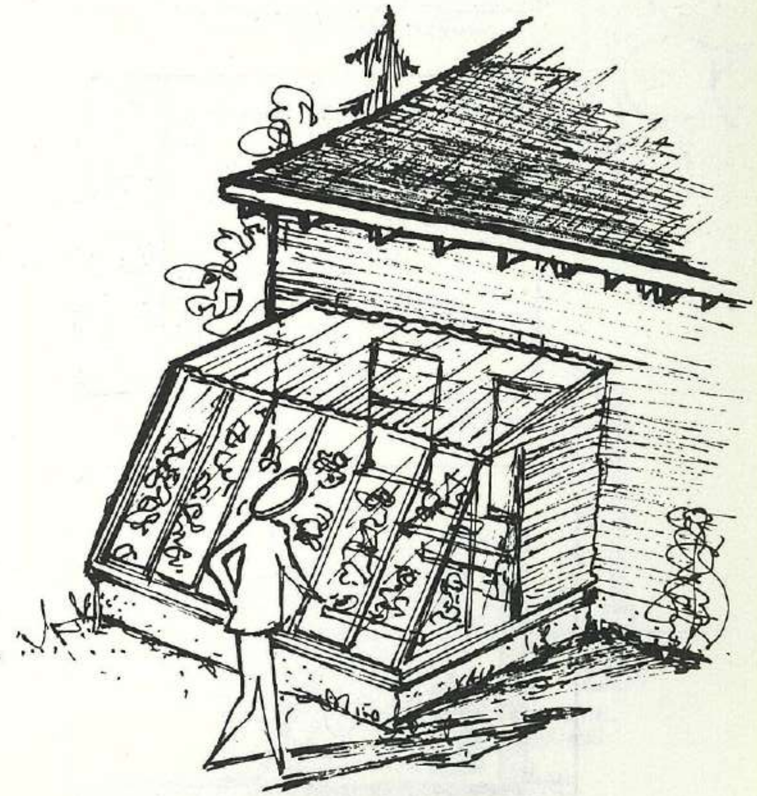
The insolation data in the Appendix is taken, with Steve Baker's kind permission, from INSOLATION ON SOUTH-FACING TILTED SURFACES: PACIFIC NORTHWEST LOCATIONS

TABLE OF CONTENTS

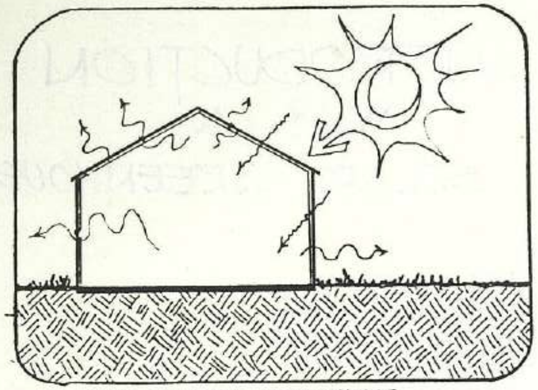
I. INTRODUCTION WHY A SOLAR GREENHOUSE?



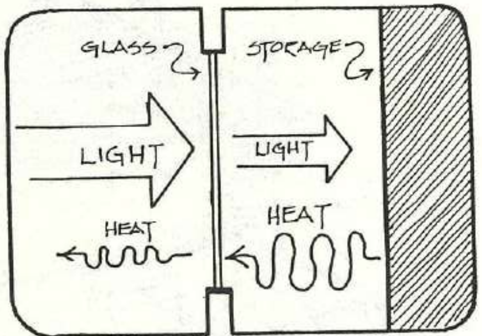
We have in the Northwest an abundance of the most inexpensive hydro-produced electricity in the country. Yet we are faced with the controversial development of thermal power generation to meet our growing energy demands. Predictions of this growing demand are based on the increasing use of electricity for residential heating. Home heating now represents 18% of Seattle's total energy demand (which includes total commercial, industrial and transportation energy usage). Household insulation projects can help lower the growth of our future domestic energy needs. If this is coupled with the use of simple solar heating systems, the future of our domestic energy consumption can be brought below current use levels -- negating the need for increased thermal generating capacity.

The Pacific Northwest exhibits a fortunate balance of weather conditions necessary for the successful operation of solar heating systems. The Seattle area, although cloudy during much of December and January, maintains a relatively mild climate due to the "blanket" effect of the clouds . In this climate, household heating can be inexpensively maintained with passive solar heating backed up with conventional systems using wood, oil, gas or electricity. East of the Cascades, with even greater amounts of sunshine, it is colder in the winter, largely due to the clear evening skies. The abundance of sunshine, if collected and properly used, will supply a substantial percent of heating for an insulated home, even under the conditions of the colder climate.

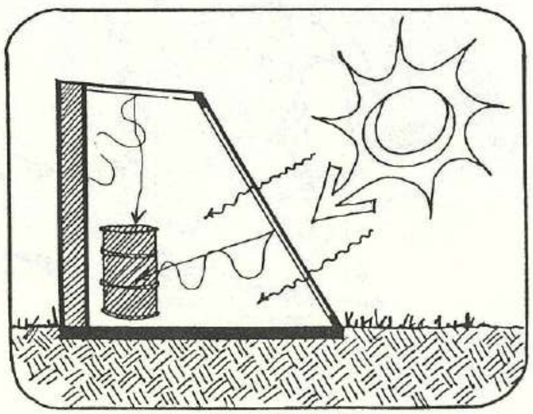
Combining these diverse climatic conditions with the variety of needs and desires of the Northwest's inhabitants, ECOTOPE GROUP is helping to develop a solar collector that is flexible enough in design to be able to fulfill the diversity of personal and climatological needs. This collector -- THE ATTACHED SOLAR GREENHOUSE -- can be designed to be an effective source of heat, and will meet the broad financial, philosophic and aesthetic needs of its users. If properly installed, it will shine your shoes, wash your dishes, babysit your children and walk the dog. (Batteries not included)



CONVENTIONAL GREENHOUSE



GREENHOUSE HEAT TRAP EFFECT



SOLAR GREENHOUSE

A solar greenhouse works simply and elegantly as a solar heat collector by accepting the incoming sunlight which is absorbed and converted to heat within the greenhouse. The glass walls constantly reradiate part of the heat back into the structure as it tries to escape (the greenhouse effect) and inhibit drafts and breezes from dispersing the collected heat (convective loss).

The idea of collecting heat through the "greenhouse effect" has been in use since Greek and Roman times, but was brought to fruition in the Netherlands during the Sixteenth Century. What we now consider a typical greenhouse is an energy-intensive structure which was developed through the use of cheap and abundant fossil fuels as heating sources. Its shape was also influenced by the convenience in covering large areas of land when built in rows. The original greenhouses designed by the Dutch were in the form of what we contemporarily consider solar greenhouses to be. Their glazed surfaces faced south, with all other surfaces being opaque. These "glasshouses" were attached to large buildings or massive brick and masonry walls, and often used night shutters to resist heat loss.

There are three basic distinctions which differentiate a *freestanding* solar greenhouse from a conventional greenhouse:

1. SITING AND ORIENTATION
The glazed face of the greenhouse must face south without any obstructions shading the low-angle winter sun. This will allow the structure to collect the maximum amount of available sunlight.

2. PROPER INSULATION AND AIR-TIGHT CONSTRUCTION
All surfaces not receiving direct winter sunlight (northern walls and roof) should be solid and highly insulated. The greenhouse can then "scoop" the sunlight from the southern sky without allowing any of the heat produced to escape through the northern walls.*

---

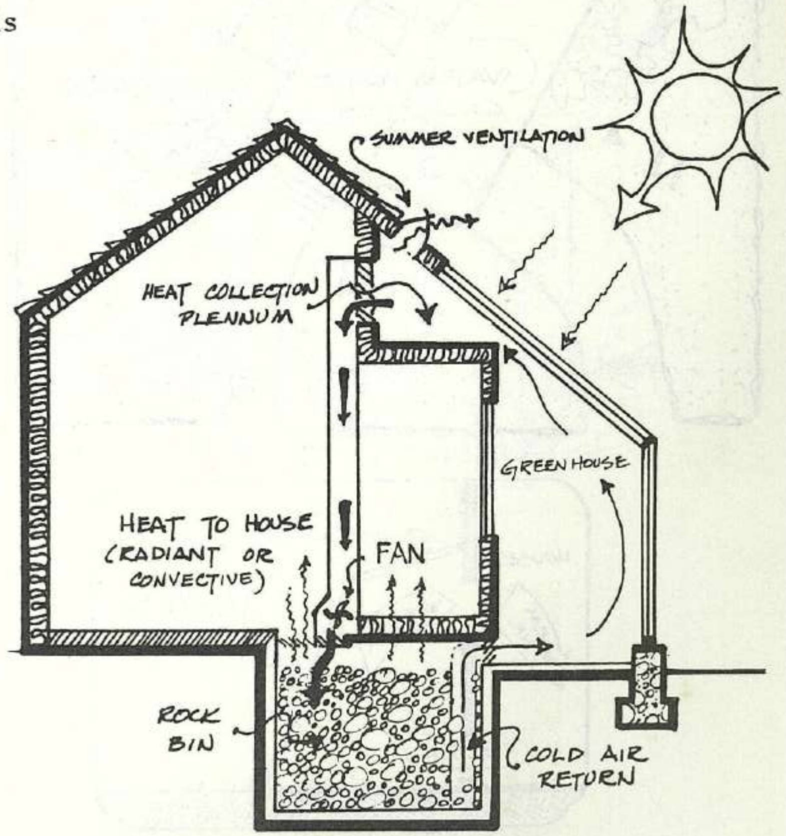
*In a conventional greenhouse, the amount of heat lost through the highly conductive northern glazed surfaces is many times greater than the amount of heat gained from incoming diffuse northern light.

The construction must also be air-tight and weatherstripped to prevent heat loss through drafts.

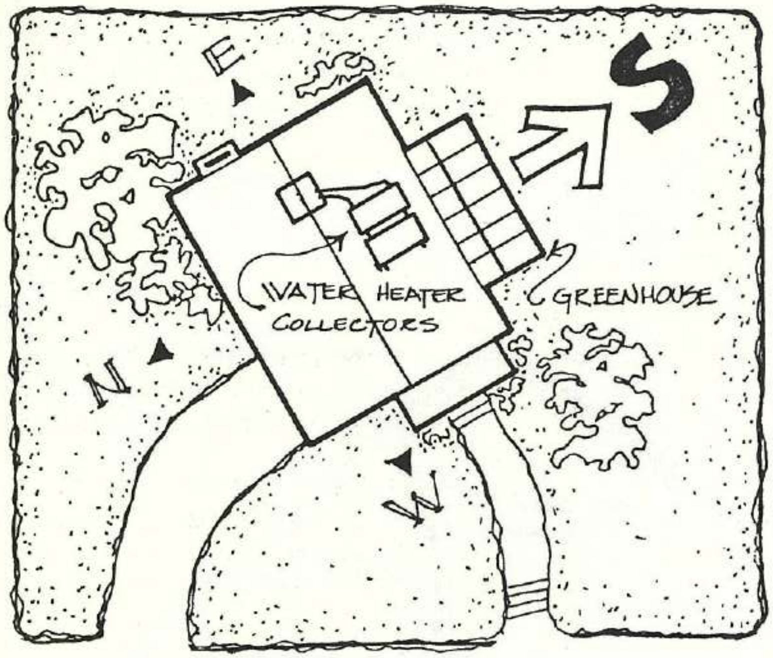
3. STORAGE

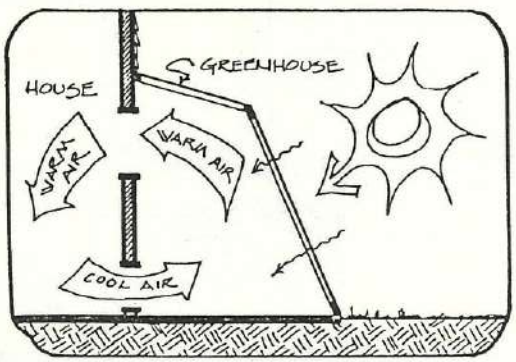
All greenhouses are solar heated during sunny periods, and in fact produce an excess of heat which is harmful to plants. A solar greenhouse takes advantage of this excess by warming massive objects within its structure during the day. This heated mass (containers of water, stone, masonry walls) radiates heat throughout the night, keeping the greenhouse at a comfortable temperature. This large amount of mass storing heat is called THERMAL STORAGE.

A freestanding solar greenhouse takes advantage of simple "passive" solar technologies to collect and store heat for the end benefit of the plants within the structure. But due to the insufficient light levels, short winter days inhibit the production of many food plants. Because of this, the easiest and most productive food plants to grow in a solar greenhouse during winter are basic salad vegetables. These are not only responsive to low-light winter conditions, but also grow well in a cooler greenhouse. On sunny winter days, a solar greenhouse produces an excess of heat during the day and may be warmer than necessary at night for efficient salad production.



These two clues lead us to the possibility of a different use for the excess heat from the greenhouse collector. Attached to the southern side of a home, this excess heat can be vented into the home during the daylight hours. By using little or no thermal storage in the collector (which would selfishly store the heat and harbor it from use in the house), a cooler evening environment will be maintained. As even a "super" insulated house loses heat slowly through the walls (in this case, into the greenhouse), a comfortable growing temperature is achieved. The house will be acting in the same manner as the thermal storage does in a freestanding greenhouse. From a conservation standpoint, the greenhouse can be thought of as an enormous insulated window, slowing down the home's heat loss.





CONVECTED AIR FLOW

An *attached* solar greenhouse must have these qualities:

1. INITIAL HOME CONSERVATION MEASURES
A solar greenhouse will not function effectively on a leaky, poorly insulated house. The greenhouse should be thought of as part of a conservation process for the home. This includes:

- full insulation
- weatherstripping }for poorly fitting windows and doors
- caulking
- insulated windows or stormwindows or
- possibly insulating shutters or curtains

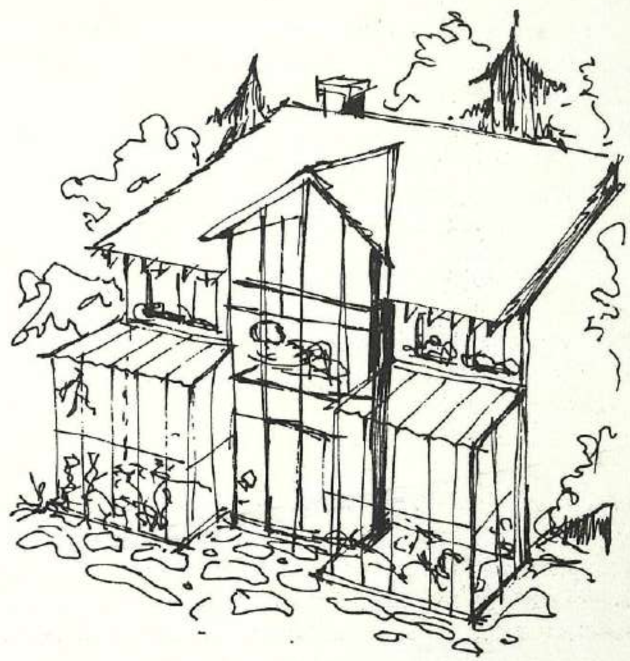
2. SITING AND ORIENTATION
The glazed face of the greenhouse must face south with no obstructions shading it from the low-angle winter sun. This will allow the structure to collect the maximum amount of winter sunlight.

3. PROPER INSULATION AND AIR-TIGHT CONSTRUCTION OF GREENHOUSE
All or part of the end walls should be well-insulated to resist heat loss. The construction must also be caulked and weatherstripped to prevent heat loss through drafts.

4. HOUSE CONNECTION
The greenhouse needs to be attached so that it covers an opening into the house. During the day, the collector will share its excess heat with the house as warm air rises in through the opening. At night, the collector should be sealed off so the house may retain the collected heat as long as possible. This is most simply accomplished with a "lean-to"-type greenhouse added on over an existing door or window.

An attached solar greenhouse takes advantage of simple passive solar technologies to collect heat for the end benefit of the house and its inhabitants, without a loss in efficient growing conditions. The greenhouse performs the service of being alternately a collector and a conserver of home heat.

The solar collector greenhouse may be designed to fit in with any architectural style or personal taste. It may be used as an atrium, covered patio, breakfast nook, or as a living room. But the use of a collector as a *greenhouse* will be of value on many levels. A $200 direct savings on vegetables may be had in a year out of a solar greenhouse if intensively managed. One may also produce a myriad of vegetable starts and annuals for garden use. A great contribution of the solar greenhouse is the potential for local food production. This in a working relationship with our regional farmlands can mean a reduction in our national energy and food demands.



We are caught in a web where our dwindling fossil fuels are raising our costs of living. The word *conservation* to many means giving up some pleasurable aspects of their lives. By designing, constructing and living with an attached solar greenhouse, you will be enjoying a transitional tool which will enable you to lead a richer lifestyle while maintaining a lower energy profile.

We need to implement energy systems which provide the same quality energy as needed for their intended use. *Capturing the sun in a greenhouse at 100°F in order to heat a home at 68° is energetically efficient and appropriate.* The quality of heat collected from the sun in a passive greenhouse is well matched to an end-use of home heating.

ECOTOPE's solar greenhouse workshops are designed specifically for the Pacific Northwest. As a participant you will get theory, design knowledge and informational access, gaining a very real understanding of solar heating so that you may design and build your own system. Through the actual construction of a greenhouse, you will have the confidence and skills necessary to begin building your own.

An evening seminar, along with this guide and several reference books,will cover the ground rules of theory and design. In the two construction days of the workshop, a complete system is built by the workshop participants. Constant review and discussion allow for a thorough understanding of the project, while special considerations are made for person-to-person contact to meet individual skill needs.

This guide follows the workshop process and supplies more in-depth information for your specific needs. With the experience from the workshop and these guidelines, you will have the resources to build your own -- or even lead a workshop with friends.

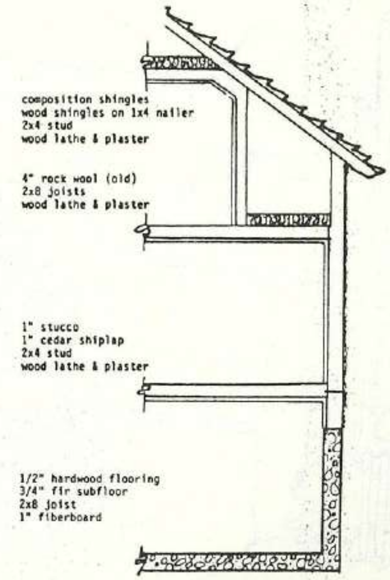
II. WILL IT WORK IN THE NORTHWEST?
REGIONAL FEASIBILITY

People in the Northwest are concerned about the *feasibility* of solar heating in their area. Another concern is for the initial expense of a solar system and the potential savings returned over conventional heating costs. This section of the guide will detail the costs and payback analysis of a basic design and will show the effects that a solar remodel can have on an average house in Seattle. The benefits are shown by placing the same house in four other representational areas in the Northwest. By comparing this information to your house and location, a quick idea of the performance of a solar remodel on your home can be made.

SOUTH ELEVATION:

Our sample house is a small-to-average three-bedroom family home with a full basement, main floor and converted attic. The heated floor area is 1320 ft^2 and it has an annual fuel consumption of 770 gallons of oil ($358/year @ 46½¢/gallon), maintaining a 65°F daytime and a 55° nighttime temperature. The only insulation currently in place is 4" of rockwool in the ceiling joists.

The first concern when determining the feasibility of a solar remodel is the extent to which the house is insulated and what improvements can be made. *A solar heating system will not perform efficiently in a drafty, poorly insulated house.*



CROSS SECTION

To determine the cost benefits of a solar remodel on the sample house, an extensive heat loss analysis was performed on its present condition. Then, conservation measures were detailed:

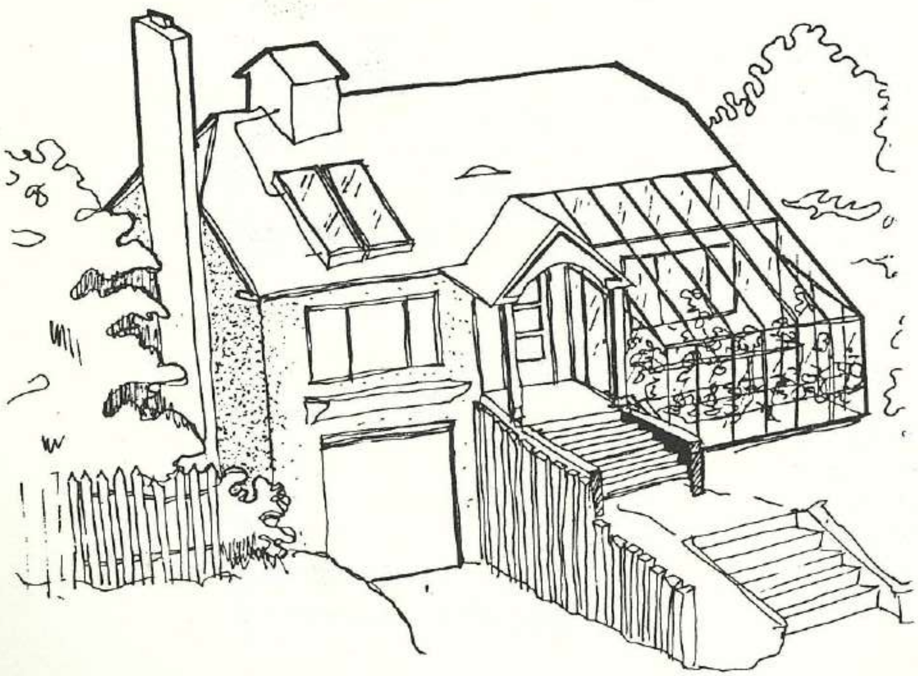
- complete insulation
- weatherstripping and caulking
- placement of storm windows

A second analysis was performed and a comparison made in the cost-benefit of reduced heat loss through conservation. A small solar greenhouse was designed and a solar survey showed the amount of available sunlight. The solar gain was subtracted (after multiplication by an efficiency factor) from the conserving heat loss figure to arrive at the final heating needs for the season after a full solar remodel.

The conservation modifications made in the house brought its insulating levels up to:

- •R-15 to R-20 for the walls
- •R-30 to R-40 for the ceilings
- •R-19 for the floor
- •Double-glazed windows (storm windows)
- •one-third to one-half reduction in infiltration losses through weatherstripping and caulking

The greenhouse collector which was designed has 234 ft^2 of collecting surface. It uses a simple fan and rockbin storage system for increased collection efficiency and to expand the time for use of available heat. The costs for the system, assuming that the owners would do some of the less technical work, were:



ESTIMATED COSTS:

SOLAR		
greenhouse	*@ $7.00/sq.ft. glazing*	$1638
controls & fan		100
storage bin		200
rock		50
ducts		50
installation		500
		2538
CONSERVATION		
insulation		
roof	*@ 30¢ sq.ft.*	220
attic walls	*@ 25¢ sq.ft.*	172
exterior walls	*@ 50¢ sq.ft.*	388
floors	*@ 35¢/sq.ft.*	257
storm windows		140
weatherstrip & caulk		50
vestibule entry		300
		1527
Contingencies		400
Design		400
TOTAL		$4865

PAYBACK ESTIMATES:

	low	high
Total System	12.2	16.5 years
Conservation Only	7.5	9.1
Solar Only	20.5	32.7

A full heat loss analysis was performed. Wall and roof surfaces were measured and their insulating values determined. Windows and and doorways were similarly measured and infiltration losses estimated.

The U VALUE shown in the *HEAT LOSS CHART* is the number of BTU's each square foot of surface will lose in an hour for each °F that the house is maintained above the outside temperature. This is multiplied by the area of each surface, added together to determine the house's total U value per hour, and multiplied by 24 hours to obtain the U value/day.

This was performed for the house "as is" (*U* in the chart) and for the conserving house (*U II* in the chart). These figures were then "plugged-in" to the *MONTHLY HEAT DEMAND* chart.

The figures in the *MONTHLY HEAT DEMAND* chart are based on the following:

DEGREE DAYS: Maintaining your house 1°F above the ambient (outside) temperature for one day = *1 degree day*. Keeping your home at 65° in February when it is 40° outside for one day = 25 *degree days* (65 minus 40). Degree days are based upon 65°F internal temperatures and are compiled for monthly average temperatures to show the heat demand placed upon a house for any given month.

GROSS HEAT LOSS: The degree days are the degrees above ambient temperature which will give the heat demand for the month when multiplied by the total $\underline{U}$ value of the house -- in this case in millions of BTU's.

INTERNAL HEAT GAIN: People and appliances contribute heat.

SOLAR GAIN (THROUGH) WINDOWS): There may already be solar heating in your home. This figure in the chart shows gain through unobstructed southern windows.

NET HEAT LOSS I: Subtracting internal gain and solar gain gives the *net heat loss* for the uninsulated house. The total represents the heating season of nine months at a cost of $385 ($4.60/mmBTU's).

HEAT LOSS CHART

Surface	Area (ft²)	U	Loss Factor	U II	Loss Factor II
Roof	735	.09	79.8	.033	24.26
Wall					
Attic	689	.22	151.6	.075	62.01
Ext.	776	.21	161.7	.048	37.25
Floor	735	.33	72.8	.039	31.61
Window	140	1.13	158.2	.7	98.00
Door	60	.33	19.8	.33	5.94
Infil-tration	10,584	1.50	285.7	1.00	190.50
Total			929.3		449.27 (BTU/°F-hr)

MONTHLY HEAT DEMAND

SEATTLE

	degree days	*gross heat loss*	*internal heat gain*	*solar gain through windows*	*net heat loss*	*gross heat loss II*	*net heat loss II*	*with solar greenhouse net gain*	*net loss with solar greenhouse*
Jan	784	17.4	1.5	.5	15.4	8.8	6.5	1.47	5.0
Feb	602	13.4	1.5	.7	11.3	6.5	4.4	3.01	1.4
Mar	605	13.5	1.5	1.1	10.9	6.5	3.9	3.74	.2
Apr	438	9.8	1.5	1.0	7.3	4.7	2.2	4.16	-
May	269	5.0	1.5	.8	2.7	7.9	.6	4.95	-
Jun	133	3.0	1.5	.7	.8	1.4	-	-	-
Jly	62	1.4	1.5	.8	-	.7	-	-	-
Aug	58	1.3	1.5	1.1	-	.6	-	-	-
Sep	148	3.3	1.5	1.2	.6	1.6	-	-	-
Oct	335	7.5	1.5	1.0	5.0	3.6	1.1	3.3	-
Nov	579	12.9	1.5	.7	10.7	6.2	4.0	2.0	2.0
Dec	713	15.9	1.5	.5	13.9	7.7	5.7	1.26	4.4
Total					77.7		28.4		13.0

Figures shown in mmBTU

GROSS HEAT LOSS II: This is calculated as for the uninsulated house, but figured for the new insulating qualities of the conservation house.

NET HEAT LOSS II: Heat loss is figured again, subtracting internal and solar gains, for the new conserving house. By performing the conservation measures, the heating season for the house was cut down from nine months to six months. *No heat is added: only its loss is restricted.* The cost for heat is now $130/year, a savings of $228/year.

BTU/ft^2/hr-°F:
The amount of heat, measured in BTU's, lost through one square foot of a surface area (of given thermal conductivity) for every one degree Fahrenheit difference between inside and outside temperatures in one hour.

SOLAR GAIN WITH COLLECTOR: This is the amount of heat in BTU's contributed to the house by the new solar greenhouse.

NET HEAT LOSS WITH COLLECTOR: The heat demand of the conserving house after the solar greenhouse is added. The heating season is reduced another two months.

The total heating bill for the house is now $60/year, a savings of $298/year.

The figures show that by insulating our sample house, the cost of heating (78.6 mmBTU's) is reduced by two-thirds! Of the one-third left (28 mmBTU), over half (15 mmBTU) of the heat is supplied by the greenhouse collector, and the remainder (13 mmBTU) can be supplied by $60 worth of oil or one cord of wood (17 mmBTU burned at 75% efficiency in a good wood stove).

It is important to notice that, although the greenhouse is supplying one-half of the home's heat, doubling the size of the greenhouse will not fulfill the entire heating needs of the house. The solar gain in December and January is too low for practical 100% solar heating under Washington's cloud cover. Increasing the size of the collector will greatly enhance its heating capability for the rest of the heating season and will increase the daily heating comfort level. We can economically justify 75% solar heating of a home, but there will be a point of diminishing returns. Remember that 95% solar heated homes are designed with full conservation and good orientation at the outset; in this case we are dealing with homes not built to full conservation standards.

The pay-back periods on the $4900 initial investment for the remodel were estimated on a 15-year housing improvement loan at 9% interest. Inflation was based at 6% per year and the escalation of fuel costs was estimated to be 15% per year. The pay-back period shown for this remodel (12.2 years) is less than the life of the 15-year loan.

The effectiveness of solar heating in a solar/conservation remodel is shown by the comparison between pay-back estimates of a "conservation only"remodel and a "solar only" model. The conservation will pay for itself in 7.5 years, while simply adding a greenhouse without providing for conservation will mean a 20 year pay-back of investment costs over heat savings.

The combination of conservation with solar in the remodel, with a 12.2-year pay-back, will save 83% of the energy now used to heat this house. Such remodels of existing houses on a nationwide scale could mean a substantial amount of energy saved!

The chart in the right column shows the potential heat savings for a similar house as a solar remodel done in four other locations:

- •Coastal (Astoria)
- •Inland Oregon (Corvallis)
- •SE Washington desert (Prosser)
- •NE Washington (Spokane)

There are so many micro-climates in the Northwest that some imagination may be necessary to make comparisons with your location, but these are a good cross-section of regional variations. Local climatological data may be had from your local weather station, college meteorological department or division of Forestry if you wish to determine more exact figures for your specific locale.

Potential Heat Savings for Solar Remodel at Pacific Northwest Locations

Based on BTU's needed per year at $4.60/mmBTU	*uninsulated*	*conserver house*	*with greenhouse collecter*	*total savings*
Seattle	$358	$130	$60	$298
Astoria	435	145	57	378
Corvallis	391	146	76	315
Prosser	445	172	75	370
Spokane	574	231	123	451

Monthly Heat Demand Charts are in the appendix.

III. WILL IT WORK FOR ME?
SPECIFIC FEASIBILITY

A well-insulated home will save you money with or without solar heating -- and will take a large load off of the nation's total energy demand. "Tightening" up your house is an essential starting point for a solar remodel. It may take from two to four hours to assess your home and to see possible conservation measures and savings available, but it will give you the strong base necessary for future solar design considerations.

The heat loss in your home occurs through air infiltration and through heat transmitted out floors, ceilings, walls, windows and doors. To find out how much you're losing, you need to measure the surface area of your home and its different parts and figure its volume. These measurements need only include the portions of your home that you heat (don't include an unheated basement you aren't planning to remodel). You can then determine the U VALUE of the different parts of your home and find the TOTAL MONTHLY HEAT LOSS for your house.

The U value of a material is its heat loss in BTU's PER HOUR PER SQUARE FOOT IN DEGREES FAHRENHEIT (BTU/hr/ft^2-°F). By multiplying the U value of each different part of your house, you can determine the house's total heat loss in BTU's/hr-°F. <<<

A HEAT LOSS ANALYSIS
With a friend, a tape measure and some graph paper, measure and layout each exterior wall of your house. Include in the drawings door and window measurements. Also measure and layout the area of the ceiling of your top floor. In converted attics, the sloping walls should be considered ceilings.

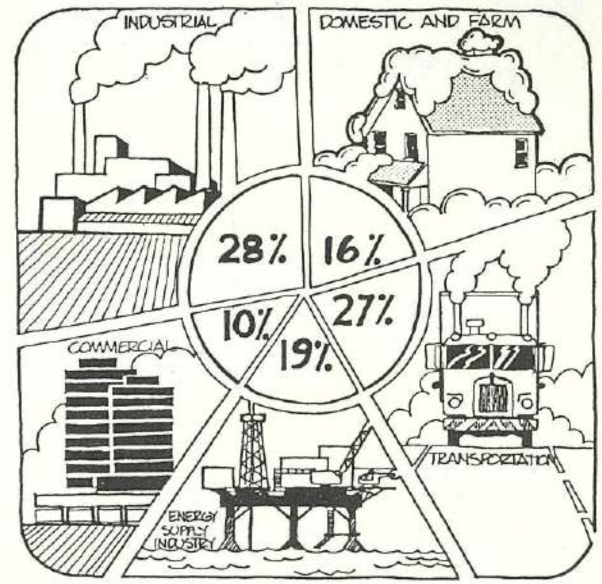
INFILTRATION
Determine the volume of your house by multiplying its ground floor area by the total height of the living areas. Decide from the *Air Exchange Chart* how many times an hour you lose this volume of warm air and therefore have to reheat it.

Example:

$1000\ ft^2 \cdot 8' = 8000\ ft^3 \cdot 2$ changes/hr $= 16{,}000\ ft^3$/hr

floor area/ ceiling

ENERGY USE :



The following are typical features of buildings having infiltration rates of approximately 1, 2, or 3 air changes per hour:

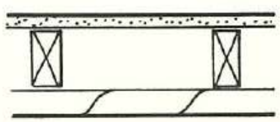
Building Component	One Air Change Per Hour	Two Air Changes Per Hour	Three Air Changes Per Hour
Building with cellar OR	Tight, no cracks, caulked sills, sealed cellar windows, no grade entrance leaks	Some foundation cracks, no weatherstripping on cellar windows, grade entrance not tight	Stone foundation, considerable leakage area, poor seal around grade entrance
Building with crawl space or on posts	Plywood floor, no trap door leaks, no leaks around water, sewer and electrical openings	Tongue and groove board floor, reasonable fit on trap doors, around pipes, etc.	Board floor, loose fit around pipes, etc.
Windows	Storm windows with good fit	No storm windows, good fit on regular windows	No storm windows, loose fit on regular windows
Doors	Good fit on storm doors	Loose storm doors, poor fit on inside door	No storm doors, loose fit on inside door
Walls	Caulked windows and doors, building paper used under siding	Caulking in poor repair, building needs paint	No indication of building paper, evident cracks around door and window frame

HEAT LOSS CHART

	U	AREA	UA
INFILTRATION			
WALLS			
FLOORS			
DOORS			
WINDOWS			
CEILING/ ROOF			

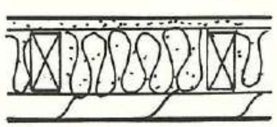
WALLS:

U= .25



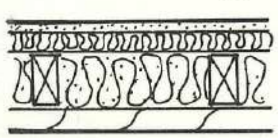
PLASTER
AIR SPACE
SIDING

U= .08



PLASTER
R-11 INSULATION
SIDING

U= .055



PLASTER
R5.5 · STYROFOAM
R11 - INSULATION
SIDING

By multiplying this by the heat capacity of air (.018 BTU/ft^3 -°F), you will find the total infiltration heat loss for your house in BTU/hr-°F (equivalent to the UA values in the *Heat Loss Chart*).

Example:

$16{,}000\ ft^3/hr \cdot .018\ BTU/ft^3/hr = 288\ BTU/hr\text{-}°F$

Enter this figure in the UA column of your *Heat Loss Chart*

WALLS

Determine the total area of your walls *minus* the windows and doors. Draw a cross section of your walls showing the materials that they are made of. Examples of materials with their U values are shown here. If you need a more exact figure, refer to the appendix for the U and R values of different materials. Multiply the wall area by its appropriate U value.

Example:

$1200\ ft^2 \cdot .25\ BTU/hr/ft^2\text{-}°F = 300\ BTU/hr\text{-}°F$

Enter this figure in the UA column of your chart.

FLOORS

Although the floor area is multiplied by the U value of the materials like the walls, some adjustments must be made:

1. Uninsulated floor over a crawlspace or basement loses heat at a lower rate than a wall and has an adjustment factor of .4.

Example:

$1000\ ft^2 \cdot .4\ BTU/ft^2/hr\text{-}°F \cdot .4$ adjustment factor = 160 BTU/hr-°F
floor area

2. An insulated floor over a basement or crawlspace also loses heat at a lower rate than a wall and has an adjustment factor of .75 .

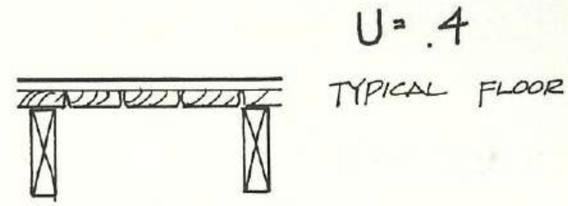
Example:

$1000\ ft^2 \cdot .046\ BTU/ft^2/hr\text{-}°F \cdot .75$ adjustment = 34.5 BTU/hr-°F

3. For a slab floor such as your basement, the simplest calculation to make is to multiply the number of perimeter feet of your house by .81 BTU/hr-°F/linear feet to see how much heat is lost

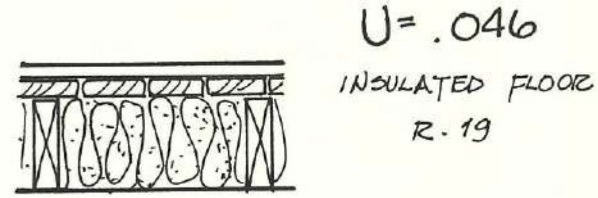
out of the floor through the ground.
  Example:

220 ft • .81 BTU/hr-°F/ft = 178 BTU/hr -°F
perimeter

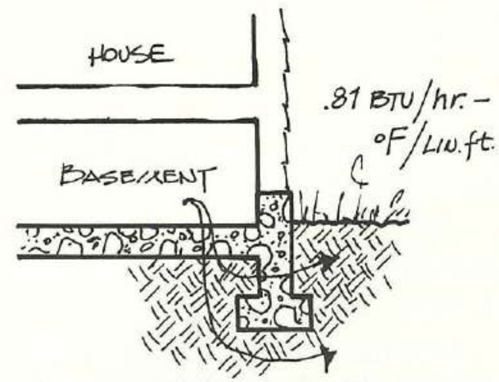


4. If you insulate your foundation to the depth of the footing with 2" of structural styrofoam, multiply the number of perimeter feet of your house by .23 BTU/hr-°F/linear feet.
  Example:

220 ft • .23 BTU/hr-°F/linear feet = 50.6 BTU/hr-°F
linear



Determine which floor heating situation is applicable to you and enter the figure from your computations into the <u>UA</u> column of the *Heat Loss Chart.*



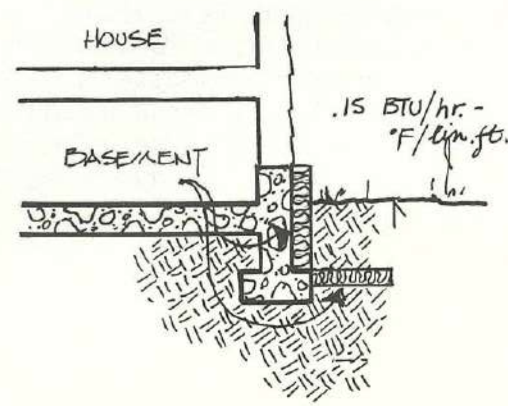
DOORS
A typical solid core exterior door will have a U value of .2.
  Example:

3 doors @ 6'8"x2'6" = 50 ft^2 •.2 = 10 BTU/hr-°F

Enter these numbers into the chart.

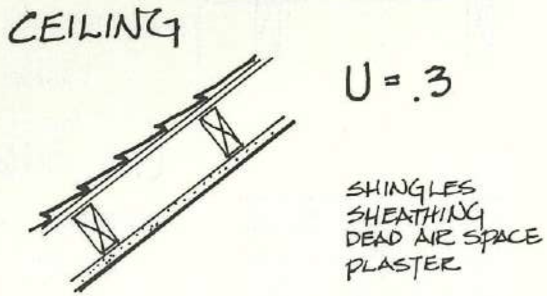
WINDOWS
The U value of your windows will vary according to the number of dead air spaces that are formed by storm windows or double glazing. Multiply the number of square feet of windows in your home by their appropriate U value and enter the figure in the chart. (The "U Value Chart" is on page 16.)
  Example:

140 ft^2 • 1.13 BTU/hr/ft^2-°F = 158 BTU/hr-°F



CEILINGS
The heat loss of the ceilings is performed in the same manner as the walls, but is adjusted with a multiplication factor of 1.2 as they lose heat at a faster rate than walls. Enter your total.
  Example:

1000 ft^2 •.3 BTU/ft^2/hr-°F • 1.2 adjustment = 360 BTU/hr-°F



U Value Chart for Windows

window type	U value
single glazed	1.13
double glazed	.55
single with storm windows	.7
triple glazing or interior insulating shutters with double glass or storm windows	.38

R-VALUE: *A material's "resistance" value is the inverse of its U value. R-11 insulation has a U value of 1/11. To determine the U value of a composite section, add up the total of the R values and determine the inverse value. The U value may not be added together to determine a total.*

TOTAL HEAT LOSS

Sample *Heat Loss Chart*

	U	*Area*	*UA*
Infiltration	.018 · 2 changes/hr	8000 ft^3	288
Walls	.25	1200 ft^2	300
Floor	.4	1000 ft^2	160
Doors	.2	50 ft^2	10
Windows	1.13	140 ft^2	158
Ceiling	.3	1000 ft^2	360
		Total:	1276 BTU/hr-°F
			x 24 hours
			=30,624 BTU/day-°F

This final figure when multiplied by the degree days in the *Monthly Heat Demand Chart* will give you the heat loss for your home on a monthly basis, or for the entire heating season if you are maintaining 65°F. The appropriate degree days for regions other than Seattle may be found in the appendix.

HEAT GAIN

Internal heat gain and solar heat gain in the house must be subtracted from the gross heat loss to give an accurate total figure.

People and appliances contribute some home heating. A standard figure to use for appliances is one million BTU/month and for people, 300,000 per person per month. A two-person household can be expected to contribute 1.6 mmBTU/month. Subtract this from each monthly gross heat loss.

Your south-facing windows *if unobstructed* will contribute to your home heat as well. The exact determination of the amount will be more thoroughly discussed in the SOLAR INSOLATION section. Solar gain charts for different regions are found in the appendix. For sake of completing our chart here, we will go through it in a simple manner now.

The charts for each region tell the number of BTU's that will strike each square foot of your vertical windows each day. Multiply this figure by the number of days in that month and the number of square feet of unobstructed windows to determine the BTU's/month available to your house. This amount is then multiplied by an 80% transmission factor (due to losses caused by glass and wood). The chart shown here describes this process for a house with 30 square feet of unobstructed south windows in Seattle. These figures are also subtracted from the gross heat loss of your home to arrive at the net heat loss.

This calculated number represents the number of BTU's necessary to maintain a house in Seattle at 65°F for the entire heating season. This number can be adjusted to match the number of BTU's that you annually purchase. Performing this adjustment will detail misinterpretations in the analysis to help you become aware of special problems while tightening up your house. It will also give you a dollar value to apply to your analysis so that potential savings may be seen.

Assemble your heating bills for the past few years and try to find the average yearly amount of oil, gas, wood or electricity used to heat your home and the current cost of these fuels. To find the BTU's per unit of fuel purchased, use the conversions shown on this page.

A comparison may now be made between the calculated figures and what really hapened in your house. A more detailed analysis may be performed with the help of books listed in the bibliography.

Heat Gain for 30ft^2 South-Facing Vertical Surface in Seattle

	BTU/ft^2/day		*days/month*		*total mmBTU*
J	483	x	31	x 30ft^2=	.5
F	810		28		.7
M	1015		31		1.1
A	971		30		1.0
M	950		31		.8
J	877		30		.7
J	979		31		.8
A	1036		31		1.1
S	1118		30		1.2
O	979		31		1.0
N	683		30		.7
D	433		31		.5

ELECTRICITY: 3412 BTU's per kilowatt
100% efficiency, once in the house. With 100% electric heat, assume 75% of your bill is for heating.

NATURAL GAS: 1 therm = 100,000 BTU's
Use a 70% multiplying factor for furnace efficiency.

OIL: 140,000 BTU's per gallon
Multiply # of gallons used by BTU's/gallon and by a 75% furnace efficiency factor (if your's is well adjusted!).

WOOD: 1 cord of alder has 17mmBTU's
A very efficient wood stove will get 75% efficiency, but a fireplace with a leaky or unclosed damper may take more heat than it gives.

Net Heat Loss Calculation for

Sample House in Seattle

	degree days	*gross heat loss*	*internal gain**	*solar gain*	*net heat loss*
J	784	24.0	1.6	.5	21.9
F	602	18.4	1.6	.7	16.1
M	605	18.5	1.6	1.1	15.8
A	438	13.4	1.6	1.0	10.8
M	269	8.2	1.6	.8	5.8
J	133	4.1	1.6	.7	1.8
J	62	1.9	1.6	.8	--
A	58	1.8	1.6	1.1	--
S	148	4.5	1.6	1.2	1.7
O	335	10.3	1.6	1.0	7.7
N	579	17.7	1.6	.7	15.4
D	713	21.8	1.6	.5	19.7
		Figures in mmBTU			115.0 mmBTU

**people & appliances*

* Be careful! Degree days are worked out on a monthly basis due to each month's different highs and lows. For exact degree-day changes, consult references found in the bibliography.

If the calculated heat loss differs substantially from your yearly consumption, adjust the calculated losses by considering these points:

1. If you are maintaining a different household temperature than 65°F, adjust the degree days accordingly. *Be careful!**
   Example:

   70° - 65° = 5°•31 days in January = 155 degree days to add to January's degree day column

2. You may need to adjust the infiltration losses if your house is draftier or tighter than you had originally estimated.

3. The wall, ceiling and floor sections may need more exact U value determinations.

4. Your heat gains for the house may be off.

5. Perhaps there is a math error!

When the calculations are adequately adjusted, perform the analysis again, but this time make your house a SUPER CONSERVER house using the figures from the chart below. Compare the two final figures and see what savings are available, both in energy and money. Be sure to note the shorter heating season of the conserving house. Such a house is more comfortable to live in due to less drafts, warmer walls, floors and windows.

Now that you've seen what you can save in your house, let's see what can be gained from the sun.

Heat Loss for SUPER CONSERVER House

Infiltration:	.5 to .75 air changes/hour	
Walls:	U - .055	*This assumes a decrease in thermal transmission brought about by increasing insulation, double glazing, caulk and weatherstripping.*
Ceiling:	U - .033 - .025	
Floor:	U - .055	
Windows:	U - .38 - .70	

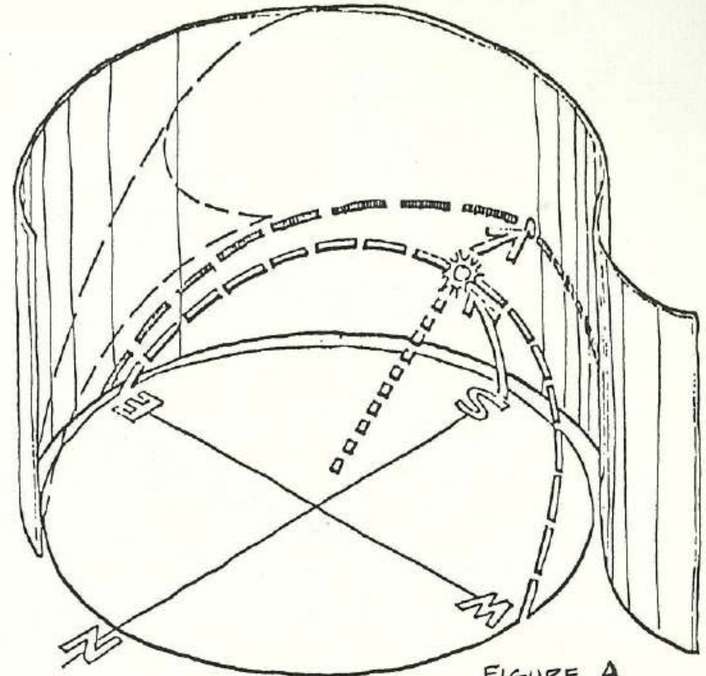


FIGURE A

The prime consideration in the siting of a solar greenhouse is the availability of sufficient sunlight. The greatest amount of this energy comes from the direction of the southern sky. Prior to making other design decisions, a site survey will show you whether there is enough sun to proceed.

THE SITE SURVEY

Walk around your site and become familiar with the obvious obstructions to the sun. At this time, it is valuable to make notes on a pad of the types of obstructions and their ownership (e.g., neighbor's house due south or deciduous trees on the site's property which might block the sun when in full leaf).

Remember that in the winter the sun is much lower in the sky than in the summer and that you are trying to maximize your warmth evenly throughout the year. When you think you have found the best of several locations for available sun, ask yourself, *"What would it be like here?"*

After you have considered all the things which might get in your way -- and you still think this is the right place, it is time to plot the skyline on the *Sun Path Chart* (see page 22A).

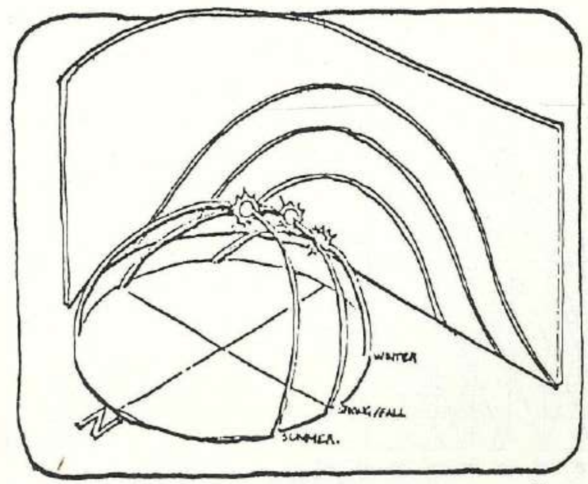


FIGURE B

SUN PATH CHART

The *Sun Path Chart* is used in circumstances where the sun's location during different times of the day and year must be known. We will be using it to show what the potential blockages to light from buildings and terrain would be at the proposed solar location. The chart is made by projecting the sun's apparent motion onto a sheet of paper. Figures A and B show how this is done. The chart included with this GUIDE is for 48°North latitude. Seattle and Spokane are very close to this. Other latitudes for the Pacific Northwest are available in *The Solar Guide and Calculator* (see bibliography).

Along the bottom of the chart run two sets of numbers. The upper set is the TRUE BEARING and the lower set is the SOLAR AZIMUTH. True bearing is the measurement of an object's position in degrees of arc relative to true north. The solar azimuth is a similar

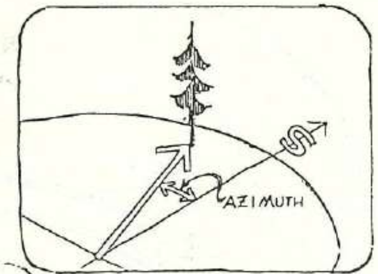


FIGURE G

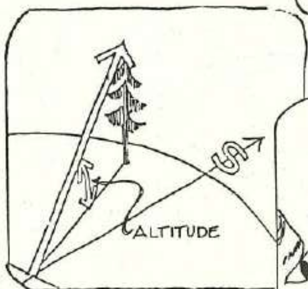


FIGURE D

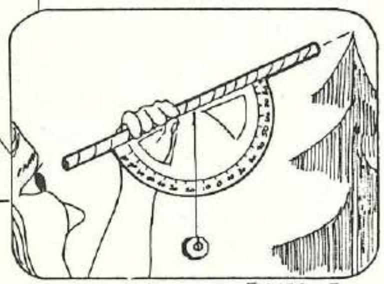


FIGURE E

SUN PATH CHART

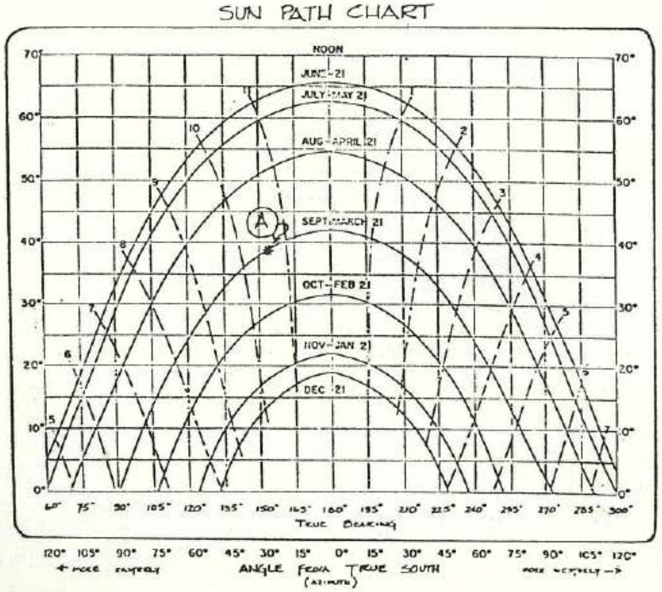


FIGURE F

measurement, only it is made from true south. We will be plotting objects using the true bearing.

The solar altitude runs up the left side of the *Sun Path Chart*. It is the angle of an object above the horizon (see Figure D) and is measured with a transit or a simple protractor-plumbob (Figure E).

The objects of concern to us are the sun and obstructions that block its light. We will plot these obstructions on the chart for the location of the proposed collector.

The arcs on the *Sun Path Chart* are marked with the dates on which the sun would trace this exact arc, with the highest arc on June 21 (summer solstice) and the lowest arc on December 21 (winter solstice). Solar time is shown by the numbered and dotted lines. (The standard time at some locations within a time zone and the solar time can differ by as much as 1¼ hours.)

As an example, the star at point A on the *Sun Path Chart* shows the location of the sun at these two times:
10:30 a.m., September 21 and
10:30 a.m., March 21 (solar time)
when the sun is approximately at:
38° altitude and
154° true bearing, equivalent to
28° solar azimuth. (see Figure F)

To plot the "skyline" on your *Sun Path Chart*, face south and pick the highest obstruction. With your protractor-plumbob or a transit, find the altitude angle(refer back to Figure E). Put a pencil mark at this altitude on the chart at the approximate bearing. To get the true bearing, take your compass and:

1. Point the "direction of travel" arrow toward the object. (Figure H)

2. Turn the dial until the North designation is aligned with the magnetic North on the needle. (Figure I)

3. Read and note the magnetic bearing from the dial directly over **the "direction of travel" arrow.**

Magnetic north and true north are not the same in most locations. Since the magnetic field varies and moves slowly over the earth's surface, it is necessary to know the difference for your locale between magnetic and true north (called the DECLINATION). The magnetic needle's North end either points further east than true north (east declination) or further west (west declination). Seattle is 22° east as of 1978.

Once you know your local declination, the following will convert the magnetic bearing from Step 3 above into a true bearing:

True bearing = magnetic bearing + east declination
or
True bearing = magnetic bearing - west declination

Once you get the true bearing, you can go back to the approximate location that you marked on the *Sun Path Chart* for that high location and mark it exactly. Do this procedure again for other obvious obstructions and then fill in every 15° of solar azimuth to complete the skyline. You will get a chart something like that shown in Figure J. Now you will have to determine whether this is too much shading.

Not all the areas on the *Sun Path Chart* are as valuable for solar heat as others. This is partly due to the greater amounts of atmosphere that low-angled sunlight must pass through and partly due to the particular climate of your area. An example of this later effect would be consistent morning fog which would make an effective shadow covering the early morning (easterly) area of the chart. A detailed analysis could be done hour-by-hour using *The Solar Guide and Calculator* and information about your local weather patterns. A more simplified approach follows here.

The area in Figure J outline by the heavy line contains virtually all of the energy in a clear sky. So, if your skyline does *not* come up into this area, you need not be concerned with shadowing of your greenhouse. If it does come into this area, then try to get an idea of the *percentage of the area obstructed.* The lower section (Area A) contains 40% of the energy and the upper section

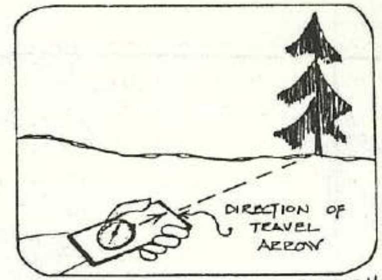


FIGURE H

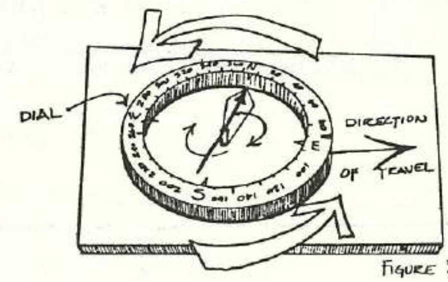


FIGURE I

SUN PATH CHART

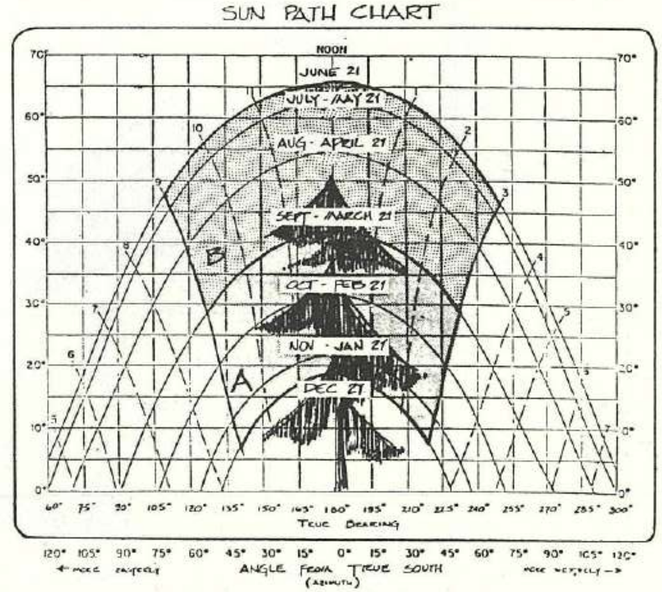
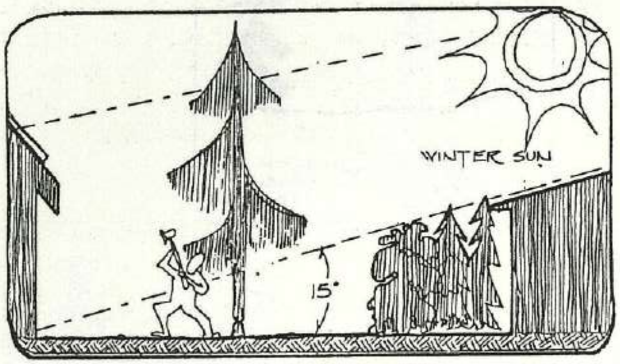


FIGURE J



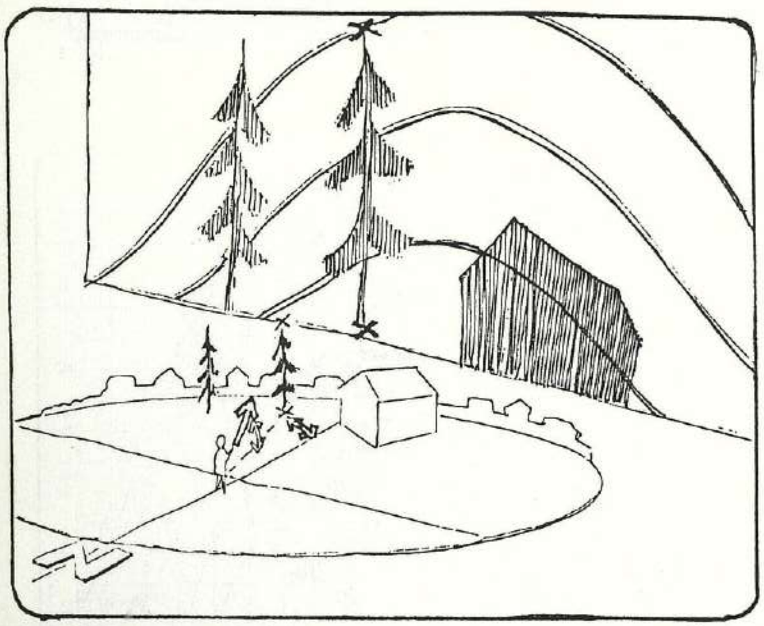


FIGURE G

(Area B) contains 60% of the energy. So shadows must be multiplied by this weighing factor. A sample calculation would be:

A tree which is obstructing 30% of Area A and continues up to obstruct 10% of Area B reduces the solar greenhouse output by:

$$\underset{A}{(.3 \cdot .4)} + \underset{B}{(.1 \cdot .6)} = .18 \text{ or } 18\%$$

If the tree in question is a deciduous and not an evergreen tree, it gets a little more complicated since in winter (Area A) the tree will have lost its solar-blocking leaves and will then block only about 25% of the light. This can be incorporated into the above equation by multiplying the shaded area during the season when the tree is without leaves by .25 .

If after doing the calculations, you find that the greenhouse output will be reduced by 40% or more and there is no way to move either the greenhouse location or the obstruction, you may find that the economics do not look well. At this point, the best thing would be to put that hard-earned money into some more home insulation, weatherstripping, or other types of conservation techniques which are not dependent upon the solar energy at your site.

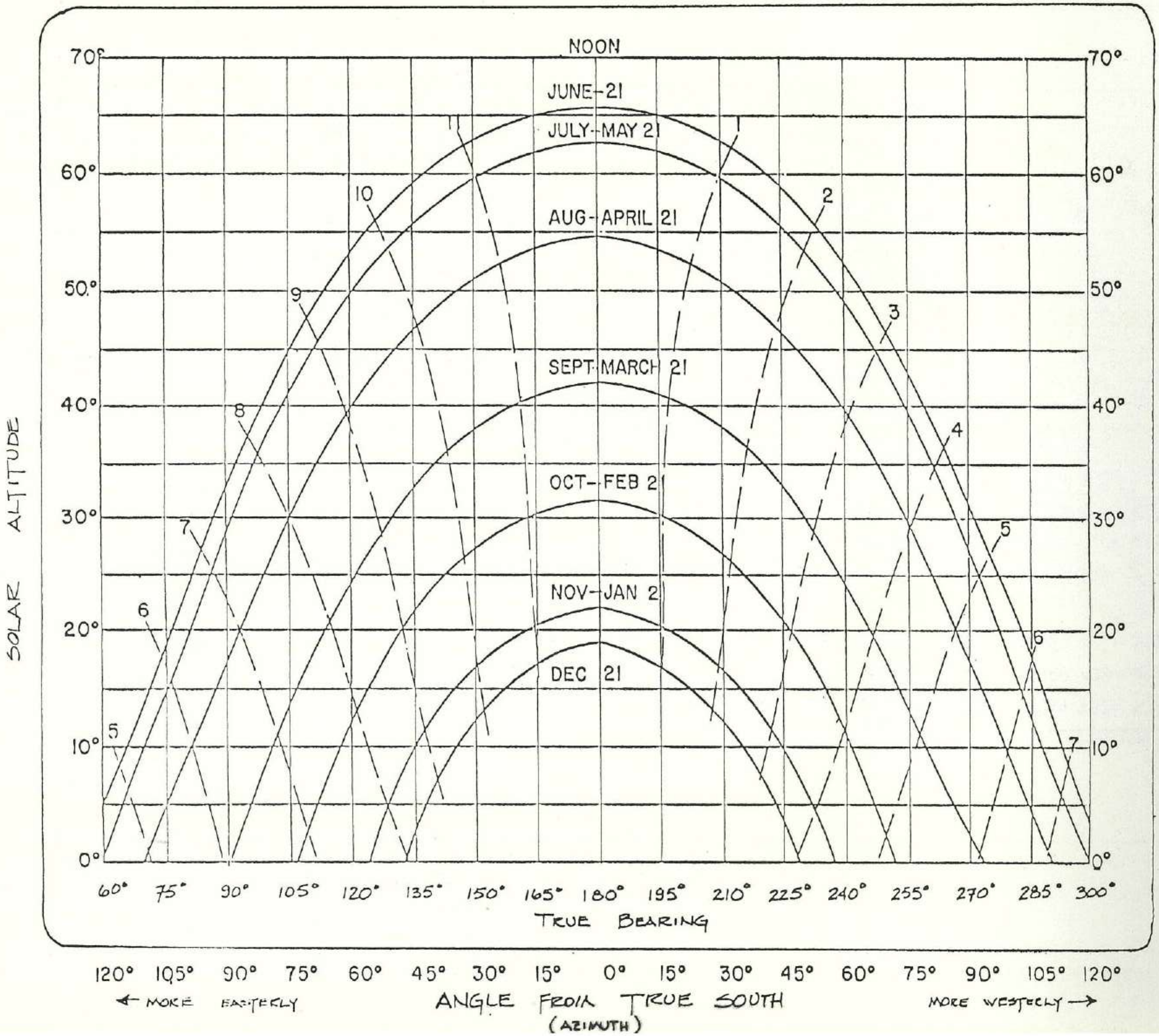
SOLAR INSOLATION

After the determination of your percent sun chart, you can now find the amount of heat that can be expected from your design for a greenhouse collector. This information will allow you to size your greenhouse to obtain the maximum amount of solar heating that is economically justified (considering the initial investment in the greenhouse) for your household's needs.

The solar insolation data in the appendix gives the average amount of sunlight available in different regions of the Northwest. The values are given in BTU/ft^2/day that shine onto the south facing surfaces. The values are also determined for surfaces lying horizontally and at 15° intervals to vertical.

SUN PATH CHART

CUT ALONG DOTTED LINE



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To determine the amount of solar gain available to a greenhouse collector, we must first find the areas and angles of its south facing surfaces. The greenhouse described in the construction section of this GUIDE has a south face that has 119 ft^2 at a 75° angle, and a roof which is 127 ft^2 at a 15° angle.

Looking at the Seattle insolation chart under the columns for 15° and 75°, multiply each of the corresponding surface areas by the insolation values opposite each month.

Add the surfaces together and multiply by the days of that month to obtain the monthly values in BTU's available to the greenhouse. Now, multiply by the percent sun chart for your site. (In the example, we are using 90%.)

There are inefficiencies due to transmission losses in glazing materials and due to conductive losses, heat transfer losses and storage losses. A factor of 50% is used to compensate for these loses and to give a final realistic heat gain for the house. The heat gain for our greenhouse built in Seattle is shown at right.

The subtracting of these monthly heat gains from your house's monthly heat demand derived previously will demonstrate the heat gain and savings developed by the greenhouse collector. Don't forget that any excess heat developed during the heating months will be available to heat your house warmer than 65° (as shown in April, May, September and October). Any excesses developed during the non-heating months may be simply shaded from the greenhouse or vented to the outside so that overheating for your house or greenhouse is not a problem. A larger greenhouse with more collection area will supply more heat for the heating season, with the exception of December and January when the levels of insolation due to cloud cover inhibit extra heat production.

From your figures you can now see that a greenhouse on a good site contributes a substantial amount of heat to a well-insulated home. But to a leaky, poorly insulated home, it's a drop in the heat demand bucket. But for that matter, so are the fossil fuels now used to heat the same poorly insulated house. It seems appropriate to invest the fossil fuels in insulation and glazing materials to save greater amounts of them for future use!

Heat Gain for a Seattle Site with 90% Sun Chart

	15°	• 127ft	+ 75°	• 119ft^2	# of days/month	mmBTU	x % Sun Chart (.9) and efficiency losses (.5) =
J	358	45466	501	59619	x31=	3.26	1.5 mm BTU
F	682	86614	866	103054	x28=	5.3	2.4
M	1117	141859	1144	136136	x31=	8.6	3.9
A	1494	189738	1175	139825	x30=	9.9	4.5
M	1861	236347	1218	144942	x31=	11.8	5.3
	-	-	-	-		-	-
O	877	111379	1063	126497	x31=	7.4	3.3
N	494	62738	714	84966	x30=	4.4	2.0
D	304	38602	446	53074	x31=	2.8	1.3

IV. DESIGNING YOUR GREENHOUSE

The design possibilities for solar collectors enclosing living space are as broad as all of architectural design. Although we can't attempt to cover a diversity of designs, we can offer a quality design which can be adapted to your size, style or cost needs.

Since an attached greenhouse doesn't involve any major structural modifications to your home, it offers immediate solar implementation. In addition, the design and construction processes described here offer an introduction to techniques and a reinforcement of the idea that one need not possess professional "mystique" to construct a building.

As an example of the design process for a solar greenhouse, we are presenting here questions and parameters that are involved when we design our standard 10x16' attached greenhouse in preparation for a workshop. The development of a construction-ready design follows these guidelines:

1. The site of the greenhouse is on a well-insulated home with a good percentage of unobstructed south sunshine.

2. The greenhouse should cover one or more windows or doors for an effective heat transfer to the house.

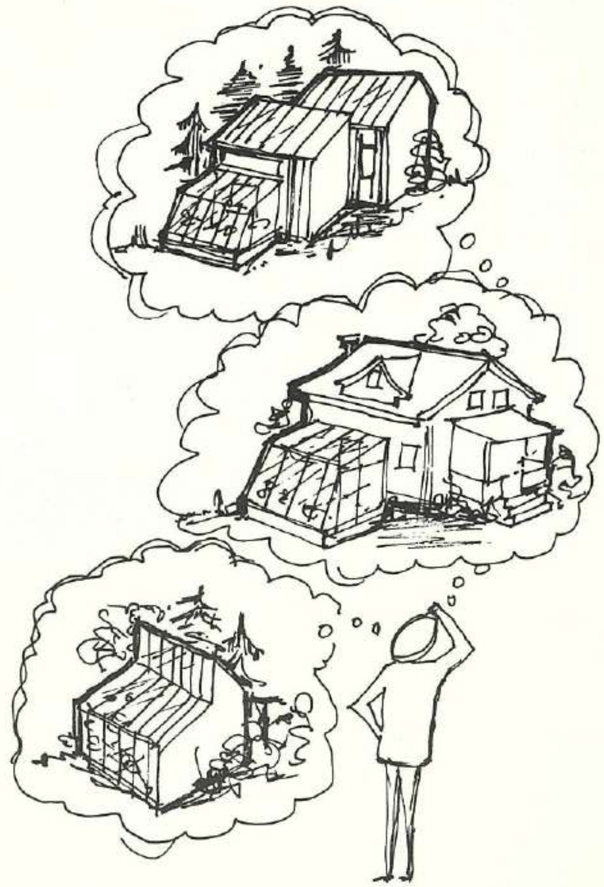
3. The greenhouse should present as large a south-facing clear surface as the site and cost will allow.

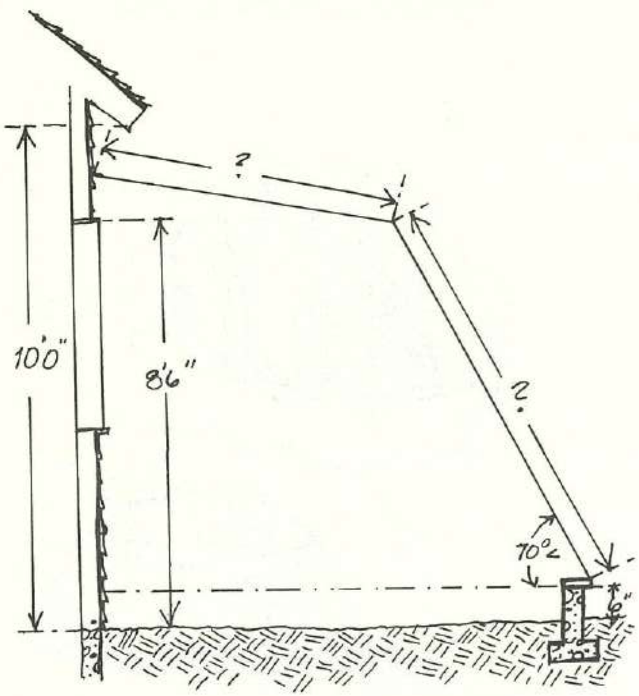
4. The site should not present any major construction obstacles for connecting with the house or for placement of the foundation.

5. The location should be fully accessible and appropriate for the use of the greenhouse and should not block any commonly used thoroughfares.

Answering these next questions can help define the design:

1. Are you designing with standard-sized materials in mind (to avoid waste) and with the structural limitations of these materials?





2. Which construction details will define the size and shape?

3. Will your design incorporate well thought-out building techniques?

4. Will the design meet zoning and structural code requirements (if necessary) in your area?

SKETCHING THE DESIGN
When the best site has been determined, the initial design step is sketching the site from the side, front and above, incorporating the dimensions and locations of all windows, doors, roofline, grade and any obvious obstructions to the structure. With an architect's rule, draw up the sketches to scale and develop a feeling for the interrelationship of all the parts.

Working with the dimensional materials in mind, begin "applying" your greenhouse to the site by drawing it to scale. This sketching process helps you to begin some creative designing, as well as pointing out the limitations of the site -- problems not immediately apparent will now leap out at you! It's good at this point to work with these sketches for a couple of weeks -- the decisions made at this point will be around for a long time.

THE ECOTOPE WORKSHOP GREENHOUSE DESIGN
The shape of the ECOTOPE workshop greenhouse is a common one because of its ease of application in a number of situations. Alterations are accomplished with slight variations in angles or the lengths of materials, still staying within standard material sizes.

The ECOTOPE workshop greenhouse is designed with the following parameters:

1. The roofline drops to 10' above grade.

2. The window frame rises to $8\frac{1}{2}$'.

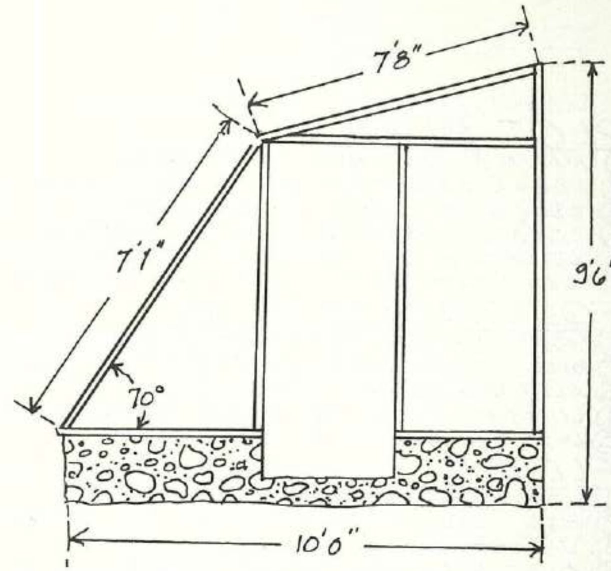
3. The greenhouse is 10' wide.

4. Code requires a 6" stem wall at the foundation.

5. Standard sheets of glass are 7' long and other materials are standard sizes of 8', 10', 12', 14', 16' and 20'

6. As vertical a south face as possible is good for head room.

By incorporating a 70^{o} south face with a height of 9½' at the back, we can work within standard material sizes and make use of the 6" stem wall needed for code. A more vertical face would require longer rafters -- therefore more substantial lumber. The 10' width of the greenhouse is a good size to work with when laying out the interior. It breaks down nicely into two 3'9" beds and a 30" walkway.



SIDE ELEVATION

Now that the greenhouse is properly located and sized, we can begin drafting it, which will determine exact overall dimensions, locating doors, vents and solid walls. From the final drawings, a complete and accurate materials list can be developed to determine the cost of the structure. Developing the working drawings solves many construction design problems while they are still on paper. A proper working drawing will also be necessary for obtaining a building permit.

THE CODE

These guidelines are for Seattle. Check with your local building department for variations.

There are basically five requirements that have to be met to obtain a building permit. Pamphlets are available detailing tha basic requirements and will usually be helpful in determining the integrity of a structure you have designed.

1. ZONING: The building department requires that only 35% of a city lot may be covered with buildings. An addition must be 5' back from property lines at the side yard and 25' back from the front and rear property lines.

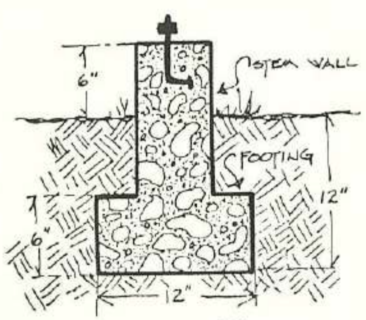
2. MATERIALS: A structure must be built of properly sized structural materials and meet code building practices. Check your design with a carpenter-friend to see that you have done this.

PLOT PLAN:
1. NAME & ADDRESS OF OWNER.
2. LEGAL DESCRIPTION OF PROPERTY.
3. ALL PROP. LINES DIMENSIONED.
4. LOCATION & SIZE OF EXIST. BLDGS.
5. LOCATION & SIZE OF PROP. STRUCT.
6. LOCATION OF STREETS AND ALLEYS.

FOUNDATION PLAN:
1. LOCATION & SIZE OF WALLS & FOOTINGS.
2. SIZE, DIRECTION & SPAN OF FLOOR JSTS.
3. ALL SUPPORTING BEAMS.
4. LOCATION & SIZE OF POSTS & FOOTINGS.
5. USE OF AREAS IF BASEMENT

FLOOR PLAN:
1. LOCATION OF ALL WALLS.
2. SIZE, DIRECTION & SPAN OF CLG. JSTS.
3. USE OF ALL AREAS.
4. SIZE & LOCATION OF WINDOWS & DOORS.

NOTE:
ABOVE MUST BE INDICATED ON PLANS



FOUNDATION FOOTING

3. THE FOUNDATION: The foundation or footings must sit a foot below grade on undisturbed earth with a 12" wide foot and rise 6" above grade. This is done with a footing 6" thick and 12" wide supporting a 6" wide STEM WALL that rises to 6" above grade.

4. WINDOWS: In covering windows, the building department, to insure adequate ventilation, requires that there are openable areas equal to 10% of the floor area of each room. This is a debatable point as we will be using the greenhouse for ventilation, but this is a new area for the building department so some changes will be necessary. If this is a problem for you, try to get a variance. This law is protecting you from a problem you aren't creating.

5. GREENHOUSE AS LIVING SPACE: If your solar collector is for additional living space other than a greenhouse (living room, dining room, kitchen addition), any overhead glass must be tempered plate or wire glass. If it is indeed a greenhouse, double strength glass overhead is fine. The determination of whether an attached greenhouse is a greenhouse or not is up to the individual building inspector. There are no clearly defined guidelines to work with in this situation.

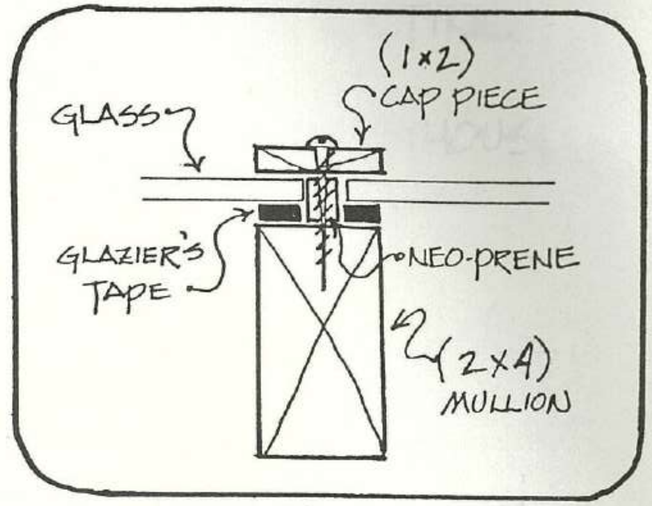
In order to get a building permit, a plan must be submitted detailing the lot, the foundation and the structure. The requirements are shown in the margin.

THE GLAZING SYSTEM

ECOTOPE uses glass for the glazing in its solar greenhouses. Glass is durable, elegant and allows a large percentage of sunlight to pass through it and into the greenhouse. Although glass is more expensive than fiberglass and plastic products, the extra expense only amounts to 10% of the total cost of the structure.

Since standard spacings for lumber in wood frame walls are 16" and 24" and since most building materials work within these standard dimensions, it is a good practice to stick to them in the glazing detail. Glass comes in standard 4'x7' sheets. We have them split into two sheets 23¼"x7'. This will allow the MULLIONS to remain on 24" centers with a space in between the strips of glass.

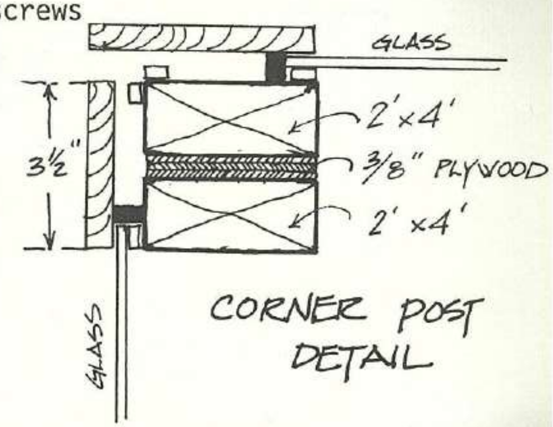
In order to form an airtight, waterproof seal and avoid expensive machinery to detail the lumber, we secure the glass with neoprene sponge rubber and GLAZIER'S TAPE held tight with a wooden CAP STRIP. The neoprene sponge should be locally available in 3/8"x3/8" strips from gasket, rubber products or packing companies. The glazier's tape (1/8"x3/8"), either regular putty tape or the better butyl glazier's tape (Tremco 400_{tm}) is available from glazing, greenhouse or sealant companies.



GLAZING DETAIL

The neoprene sponge rests between the sheets of glass on the mullions, with the strips of glazier's tape between the glass and the mullion. A wooden cap strip is screwed down on top of the mullion, compressing the neoprene and sealing the glass against the tape.

The screws used are FLAT HEAD, SQUARE-DRIVE SHEET METAL SCREWS #10x2". Instead of a slot, they have a square hole in the top. When used with a square driver purchased with them, they are a very positive, non-slip securing system. The square drivers may be used in a screwdriver handle, in a bit and brace, or in a variable speed electric drill. <<<Robertson screws

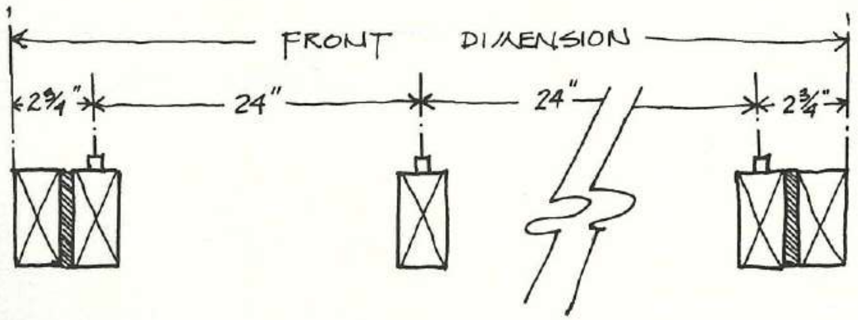


CORNER POST DETAIL

The length of the mullions needs to be sized so that the glass overhangs above and below ½". If the south face slopes, we notch the bottom of the mullion and lay in a 1x2. With the glass lying over this, it creates a mullion 7'1" long. (See working drawings.) See illustration on page 30.
To find the exact length of the greenhouse, the corner posts must be taken into account. We sandwich a piece of 3/8" plywood in between two 2x4s to give a square 3½" corner post. An eight "light" greenhouse will then be 8 • 24" + 2 • 2 3/4" = 16'5½" long.

The greenhouse is now 10'x16'5½", and the foundation can be built to the same dimensions, or we can incorporate the foundation insulation into these dimensions so that the outside surface of the greenhouse will be on the same plane as the outside surface of the insulation. This saves flashing problems and leaves a more professional appearance. The perimeter insulation is made up of 2" structural styrofoam. Subtracting 2" from each end and from the front of the greenhouse, the foundation's outside dimensions become 9'10"x16'1½". The sill for the greenhouse uses a 2x6 cantelevered over the styrofoam.

With these parameters for the design, you can finalize working drawings to scale, work out the "bugs," determine the cost -- and get to work! An example working drawing reduced from ½" scale is included in the appendix.



V. CONSTRUCTING A SOLAR GREENHOUSE

This section of the SOLAR GREENHOUSE WORKSHOP GUIDE follows the construction outline of the workshop format. The next pages detail the building process of a "standard" 10'x16' solar greenhouse. If you've designed your own solar greenhouse for your specific needs, it may differ substantially from this basic design. Use this construction section for processes, problem solving and techniques.

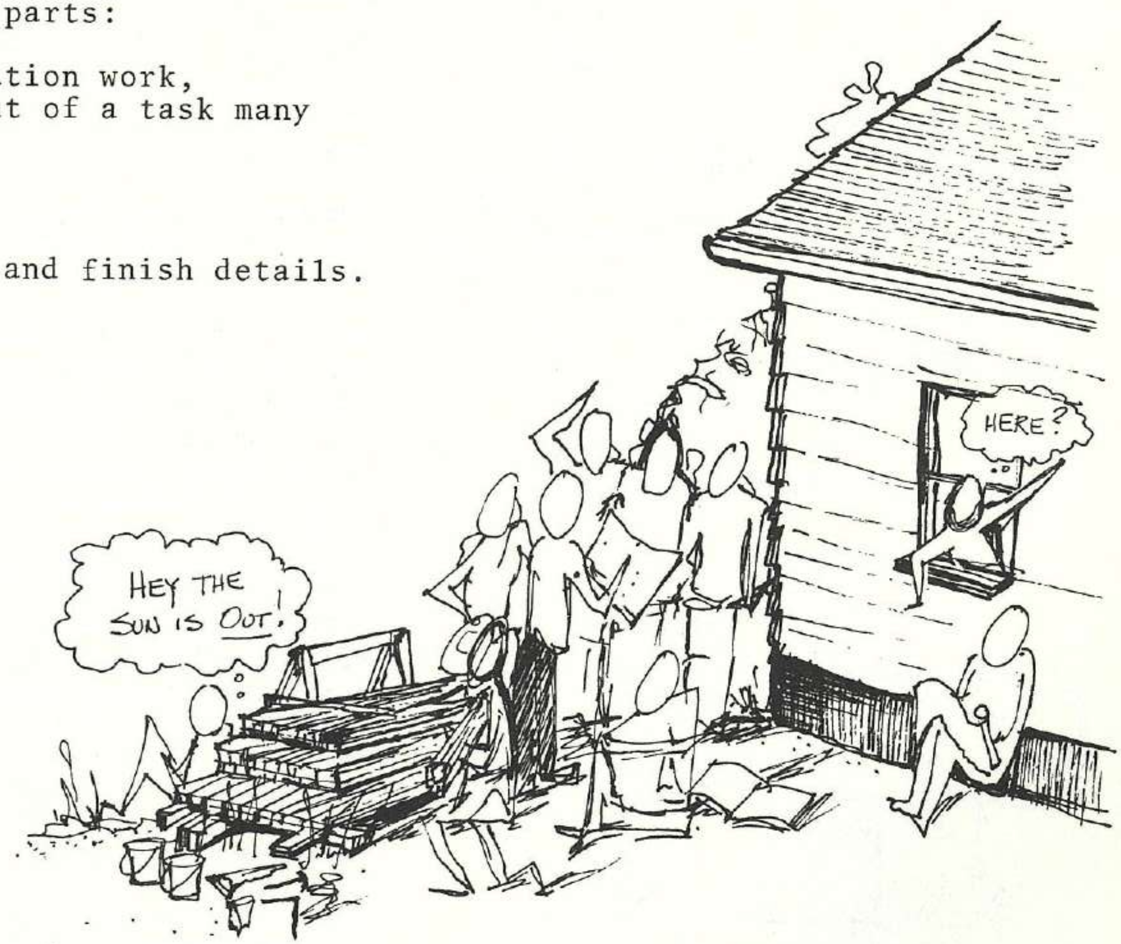
This section is divided into three parts:

{1} A detailed discussion of foundation work, designed to take the mystery out of a task many people shy away from.

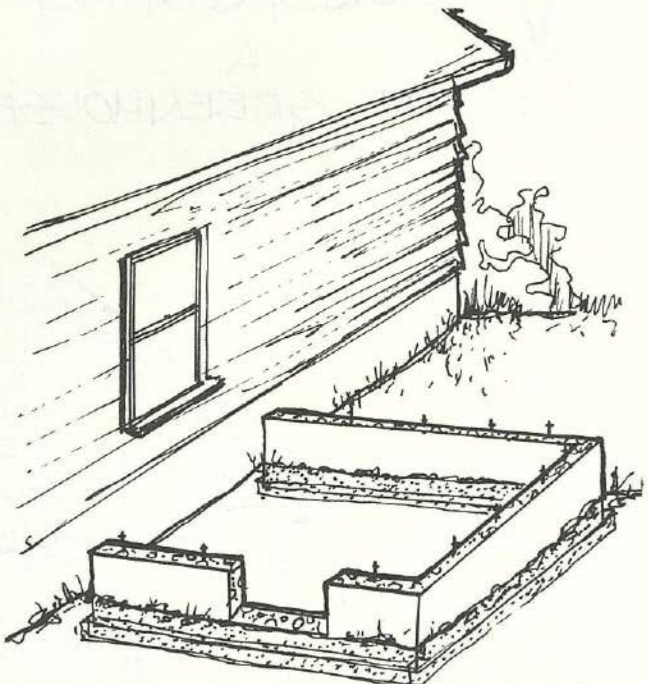
{2} Framing the greenhouse.

{3} Glazing, sheathing, insulating and finish details.

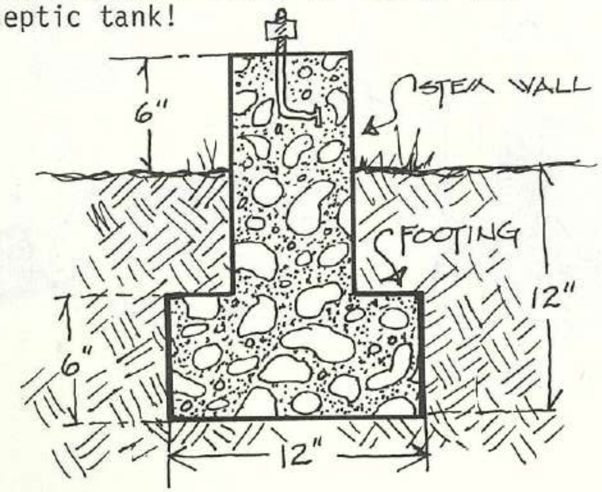
Good luck -- and enjoy yourself!



INTRODUCTION TO FOUNDATIONS



If your house is in a rural area without sewers, don't build on top of the septic tank!



The foundation of a building is the area of construction least familiar to many people, but is also of prime importance to the integrity and longevity of a building. If properly made, it will simplify the rest of the construction process. The foundation that we will be forming will meet the City of Seattle building code. Check with your building department for local variations.

The foundation for an attached greenhouse runs continuously around its perimeter, save for a section where the door goes. To meet local code, the foundation must begin 12" below grade (ground level) to protect it from frost heaving, and rest on undisturbed earth so that it won't settle. To protect the wooden structure in the building from micro-organisms in the soil, the STEM WALL must rise 6" above grade.

The most common shape for the foundation is the inverted "T". The base or FOOTING must be 12" wide and 6" thick. A 6" wide stem wall continues up from this another foot to 6" above grade.

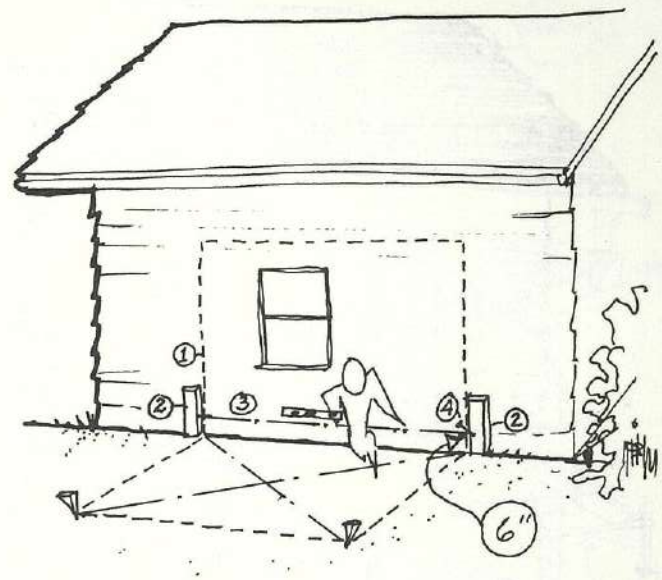
Begin forming the foundation by determining its exact dimensions and its location in conjunction with the house. A level area is excavated adjacent to the house. The perimeter is marked out precisely with WORKING LINES and BATTERBOARDS at the corners. The perimeter is made perfectly square by adjusting its shape until its diagonals are of equal measure.

OVERVIEW:

A trench roughly 18" wide and 12" deep is dug. Forms are built and set in place, with constant reference to the working lines to maintain size, square and level. The forms are then staked down, reinforced and braced. Concrete mixed by hand or delivered from a truck is poured, tamped down into the forms' corners, and SKREEDED (smoothed and leveled off). ANCHOR BOLTS are then set into the concrete at regular intervals for bolting down the SILL PLATES. The foundation is then left to cure for 2 or 3 days. The forms are removed, perimeter insulation set in, and the trenches backfilled. The foundation is then ready for framing.

The foundational process is not all THAT difficult and can be an enjoyable learning experience. Plan to do it in a comfortable length of time so that you CAN enjoy it.

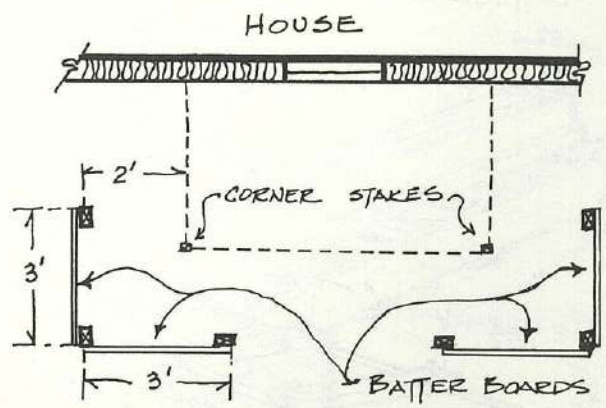
Begin by getting all of your materials together. As they are only in use a brief time, use scraps and what you have lying around. Check to see what lumber just purchased for the greenhouse can be used without cutting it up, as the concrete won't harm it for use later. It doesn't matter if you have a brace that's 8' long. Be creative with your use of materials for the forms.



As you may be using a lot of scraps, it's easy to get stuck in a gumption trap when you run out of what you estimate to be enough, especially late Sunday when you are just about done! Plan it well. Keep in mind that you'll be needing a lot of 3' stakes (1x4s, 2x2s and 2x4s) sharp at one end. You'll also need quite a bit of 1x2 material for form ties. Utility grade 1x2s can be bought inexpensively in bundles.

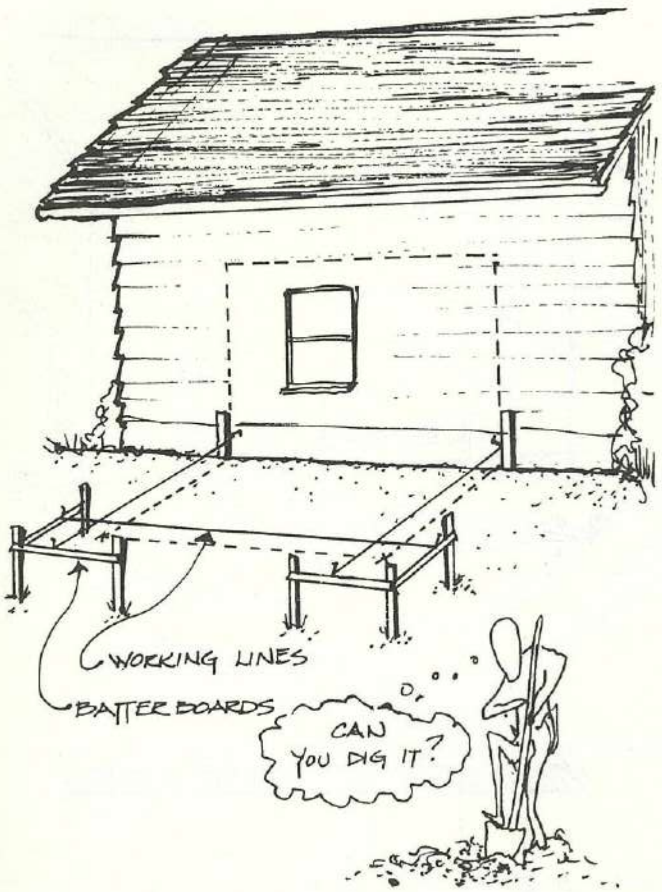
Locate the points on your house where the greenhouse will be attached. If the land slopes away from the house, excavate it and check it for level with a 2x4 and a spirit level. *The key to successful building is keeping square and level throughout.*

[1]Mark the outside dimensions of the foundation onto the house.
[2]Nail a short 2x4 touching the outside of each mark so that 2x4s define the outside of the stem wall where it meets the house.
[3]Mark the 2x4s 6" above grade, making sure that these marks are level with each other. (Run a line between them and set a simple line level up to determine this.)
[4]Put a nail at each of these 2 points on the inner edge of the 2x4.



We'll mark out the perimeter of the foundation from these points. Using a carpenter's square and tape measure, come out 9'10" on each end and mark these points with a small corner stake. Adjust the stake until all four sides are the right length and the diagonals are equal in length.

Outside of these corners, we'll set up the batterboards. You'll need six stakes 36" long. At each corner, pound in three stakes 3' apart, forming a right angle so that they lie 2' outside of the foundation perimeter. They should be in good and sound, sticking up about a foot. Get some heavy nylon string for use in leveling and as the working lines for the batterboards.



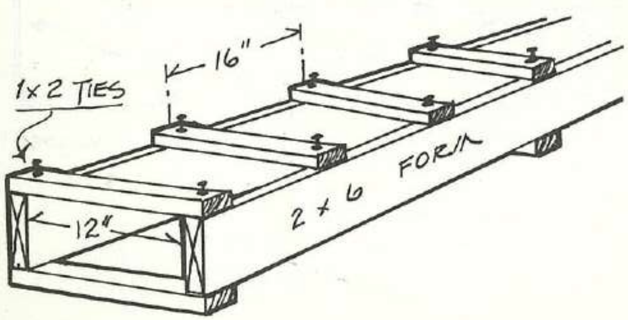
Nail up the batterboards so that their tops are level with the 6" marks on the house by using a line level between the nails at the house and the stakes. The tops of the batterboards and the nails at the house should describe a plane that is perfectly level 6" off the ground.

Tie a line to one of the nails at the house and stretch it over the corner stake to the batterboard. When it's directly over the corner stake, mark the batterboard with a nail and tie it there. Do the same at the other end and for the front of the greenhouse.

Adjust the nails until the diagonals are perfect and the distances correct. When they are, the nails and their lines will be your constant reference points throughout the construction of the foundation. They mark the perimeter of the stem wall, its exact height, and will keep it square and dead level.

>>>These WORKING LINES can be removed while digging, but quickly slipped back on for a check. Check their positions occasionally in case someone trips on and shifts the batterboards.

Dig out a trench 13" deep and 18" wide so that it extends 6" to the outside and 12" inside of the working line. Clean it out so that you have a nice square trench with a level bottom that is exactly 19" below the line (the form lumber eats up an inch of space in the depth of the footing).

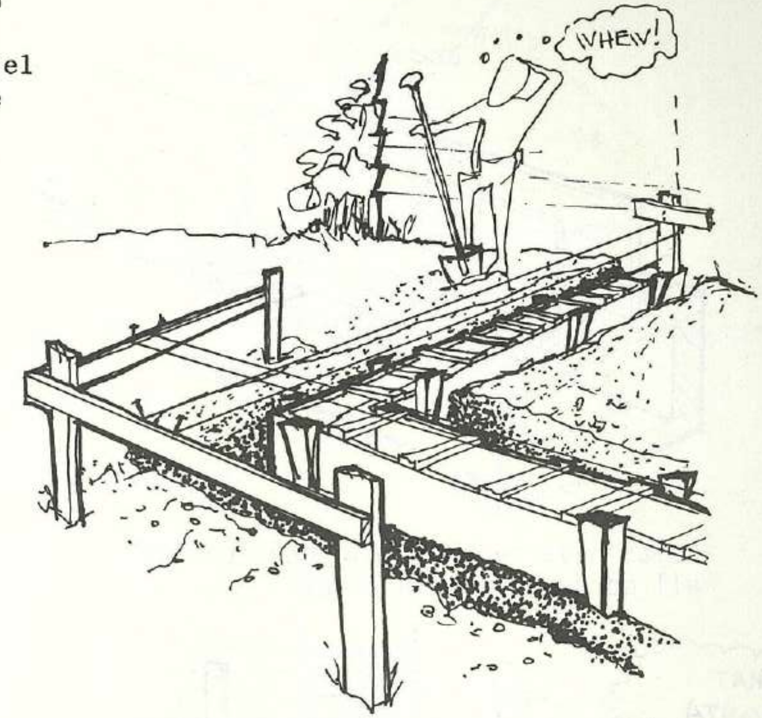


The construction of the foundational forms is divided into 2 parts: [1]The FOOTING form is constructed outside of the trench and lowered in. [2]The STEM WALL form is added on to it while in the trench.

The footing form is built to look like a ladder with 2x6 sides held 12" apart by 1x2 form ties. Use the sill plates and 2x6s from the materials list for this. When cutting the lumber, check the outside dimensions of the footing forms -- they stick out further and so are longer than the stem wall.

Space the form ties 16" apart on the top and 48" apart underneath. Be sure to use doubleheaded 6d or 8d nails so the forms will come apart easily when taking them off.

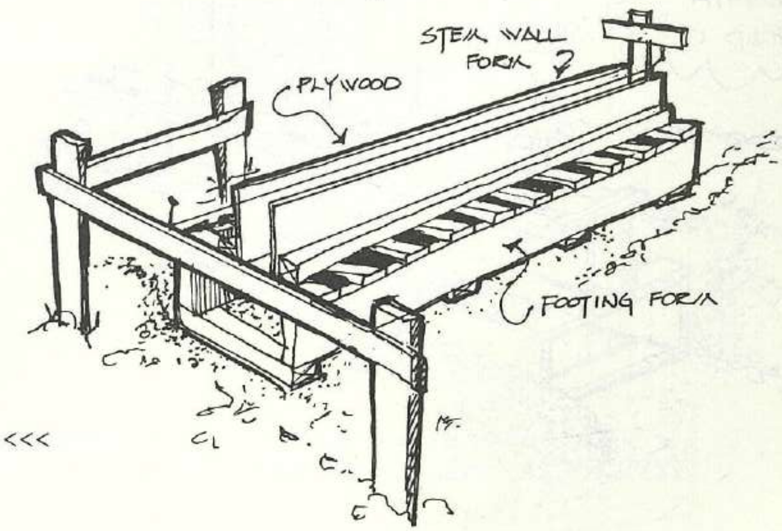
Build the footing forms in three sections that can be lowered into the trench and fitted together(the inside corners can be cut to match at that point). Run a new line from the batterboards parallel to and 3" outside of the original. Sight down this line along the inside edge of the 2x6 to set the forms in the correct position, straight and square. Check to see that they are at the right depth. When you're satisfied with their position, pound stakes next to them every 4' on both sides and at joints -- then double check to see that they don't move. Level the form as you nail the stake to it. Stand back and admire your work -- you're almost done!



You now need to lay out the form for the stem wall. Go around the three footing forms and snap two parallel chalk lines (on the tops of the form ties) 3½" out from the center of the forms. Cut to the appropriate length and nail 2x4s along these lines so that there is a 7" wide channel running along the center of the form where the stem wall is going to begin.

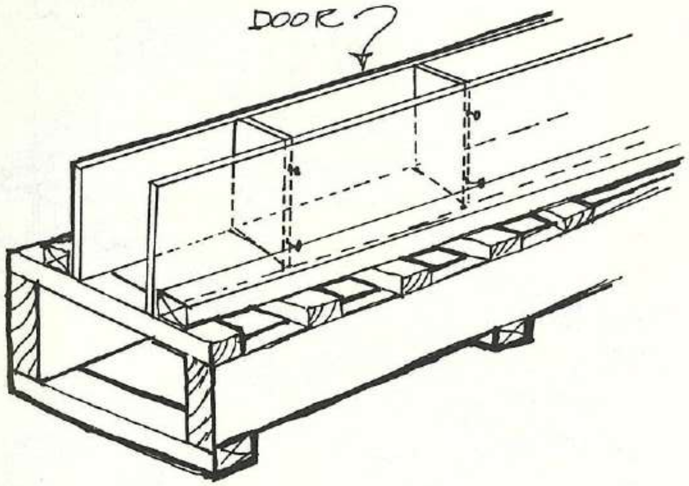
Cut 1' strips of ½" CDX plywood to the appropriate lengths for the side of the stem wall form. Nail these to the inside of the 2x4s so that there is now a 6" channel 1' high.

The stem wall form must be well reinforced and braced against the weight of the concrete. Don't cut up good 2x4s to do this. Use scrap pieces any length for bracing, including the new 8' ones for the greenhouse.

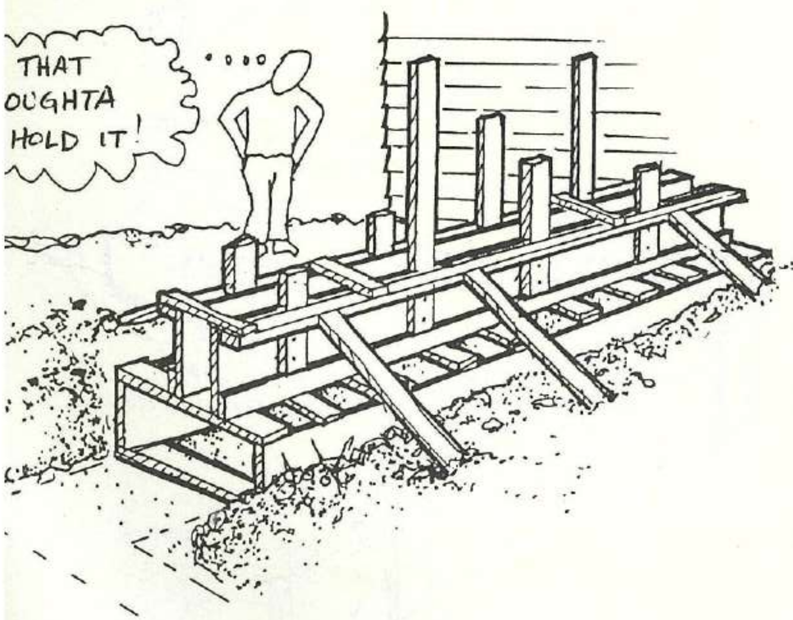


Start off by nailing vertical pieces on the outside of the form every 2-3'. Then nail a 2x4 on edge at the top around the outside perimeter. This is called a WALE and will keep the form from bowing. Now nail some form ties across the top of the form or wire the vertical posts together so that the form won't bow out when it's filled with concrete. Brace the outsides of the form every 3-4' with diagonal braces staked to the ground.

Check your forms for the last time with the working lines to see <<< that they are still square, dimensional and level. The top of the plywood should be at the same level and describe the same



Bolts have to be within one foot of <<<
all corners on both sides.



perimeter as the original working line. If it's square and level all around, you're home free. If your height is off any major amount, snap a chalk line along the inside of the plywood at the correct level and mark it with a few well-spaced finish nails to guide your trowel when skreeding the concrete.

Check the plans for the location and dimensions of the gap to be left in the stem wall for the door. This is simply done by cutting some 6" strips of wood to the right lengths, wedging them into the form so that they describe the proper space, and nail through the form into the strips. The concrete is easily tamped under this form.

MIXING CONCRETE:
Determine the volume within the form for ordering the pre-mixed concrete or for purchasing dry materials. A good basic dry mix is:

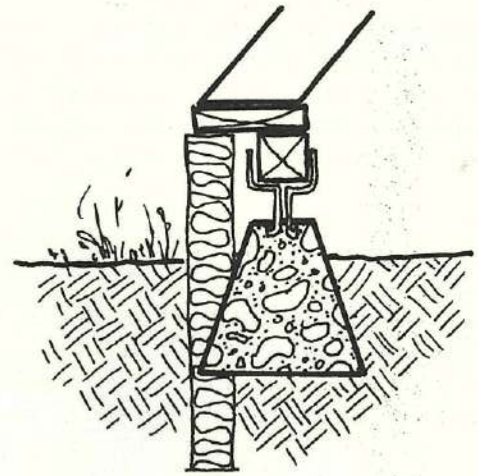
- 1 part cement
- 2 parts sand
- 4 parts $\frac{3}{4}$" gravel
- $7\frac{1}{4}$ gallons water for each 94-lb. bag of portland cement

Pour the concrete into the forms slowly and tamp it down well to fill all the corners and gaps. Skreed it smooth on the top. Place in the $\frac{1}{2}$"x6" anchor bolts at 4' centers, making sure that they don't come up where a greenhouse stud, mullion, or corner post will go. They should be $1\frac{3}{4}$" in from the outside edge and stick out $2\frac{1}{2}$" from the top of the concrete. Put the nuts on to protect the threads from concrete.

Let the concrete cure for 2 days before removing the forms. Apply 2" structural styrofoam (DowSM$_{tm}$) to the exterior of the foundation. Backfill the trench with the earth. Paint or sheath the styrofoam to protect it from sunlight.

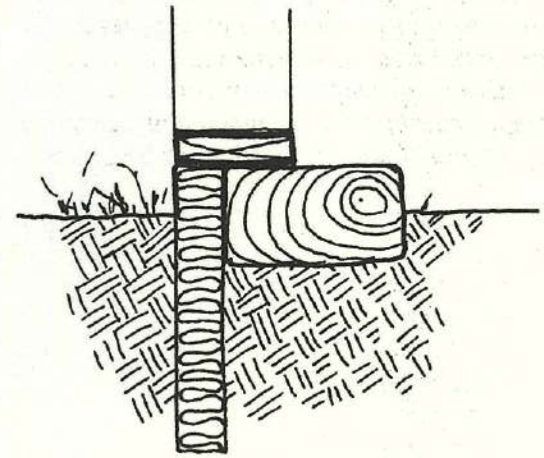
You're done and ready to frame!

ALTERNATIVE FOUNDATIONS:
For non-code situations, several other types of footings are possible. Pre-formed pier blocks with stirrups may be dug in and placed every 4' around the perimeter of the greenhouse and treated 4x4s set into the stirrups. The ensuing gap may be sealed up with structural styrofoam. The sill plate is then nailed directly onto the 4x4.



A successful and substantial foundation is to set railway ties into a shallow, level trench. Insulate their exterior 18-24" down with structural styrofoam. This is an effective foundation for use in *arid* conditions. Again, the sill can be nailed right onto the railway ties. (Ties treated with creosote may harm plants. You will want to wrap them with plastic.)

This overview of constructing a foundation will hopefully meet your needs while designing and constructing a quality greenhouse that will last many years. Although lengthy in description, don't be scared away. Your friends may have experience in form building and may be willing to offer advice or lend a hand. Pouring a foundation is a valuable experience and one which may save you several hundred dollars.



Remember: *The key to successful building is KEEPING SQUARE AND LEVEL*

FRAMING THE GREENHOUSE

THE LUMBER:

The first step in purchasing lumber is to become aware of the grades and qualities of lumber available. The grade lumber you are after is STANDARD or COMMON #2 or BETTER. It falls right in between UTILITY #'s 3 and 4 (which is inferior grade lumber with loose knots, slashes and often bad splits) and FINISH grade lumber (clear and vertical grain kiln-dried wood which is free from knots for use in cabinets and joining work).

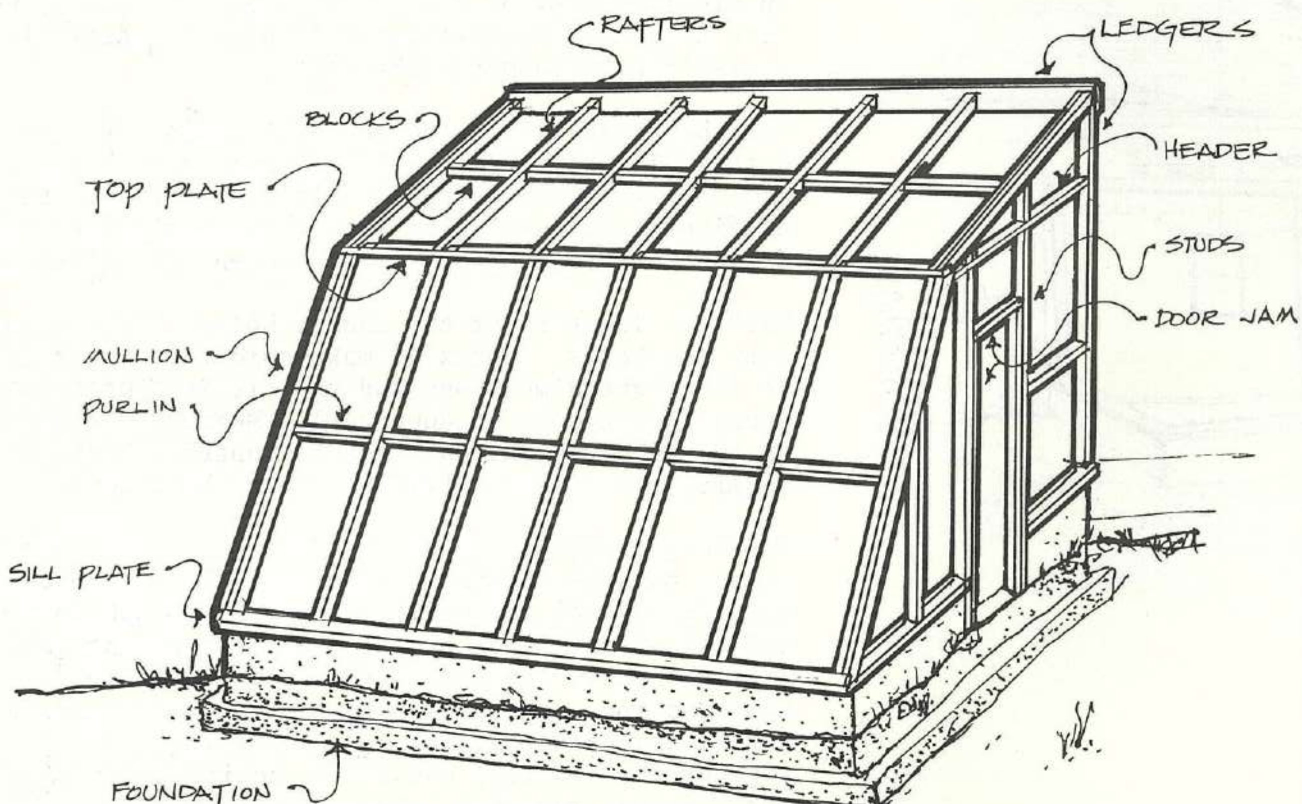
Standard #2& better is sound lumber used in proper construction. It is graded to withstand the stresses described in the building code. This grade has in it randomly 25% #1, and 75% #2 lumber. Both of these are free from slash, large splits, and all knots are tight, never to come out even under force. Standard grade lumber is available kiln-dried (more expensive, but nice to work with) or green (in no way detrimental in the framing process).

While shopping around for prices, try to get a feel for the people at each lumber yard, as well as the quality of lumber they sell as representative of the grades. Although all grades are standardized, we have noticed marked differences in quality at different businesses. This difference seems to go hand-in-hand with the quality of the people and service. Unless you have a very reputable "discount" lumber yard near by, we have found that a local yard, even though more expensive, will offer excellent service (often with free advice when you're stuck), very high quality lumber and will let you pick through the piles for the better pieces.

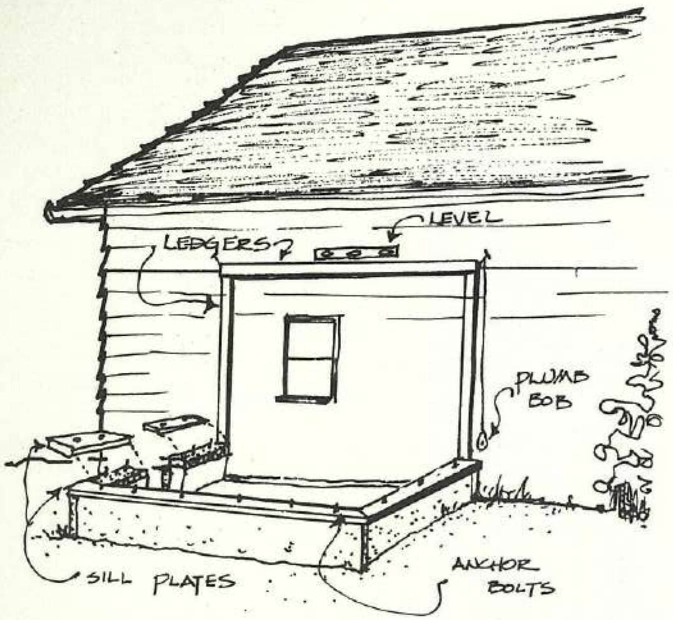
Large wholesalers who sell to professional carpenters have quality materials, but they may not want to deal in small quantities. You can bulk buy with friends to save money.

>>> Be careful when buying your lumber -- there's nothing worse than feeling taken and then having to work with inferior materials through out the construction of your greenhouse.

GREENHOUSE TAXONOMY



The first step in framing the greenhouse is laying out the geometry of the structure. The SILL PLATES and LEDGER PLATES make the connections between the entire greenhouse, its foundation and the house walls. If done square and true, they will give you the reference points for further determining correct dimensions, angles and true surfaces. (This is where your careful foundation work begins paying off!)



The sill plates should be *foundation grade cedar 2x6*, which will ensure longevity of the greenhouse. If this is unobtainable, be sure to get pressure-treated foundation material, or treat it yourself with copper naphthenate.

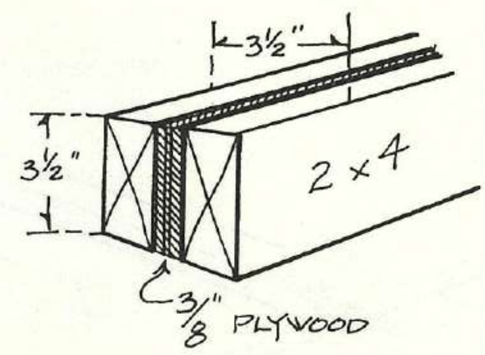
Cut the front sill to be the full length necessary for the glazing detail (16'5½"). This will overhang the stem wall 2" on each end and the front, covering the rigid styrofoam. Lay down a 3½" strip of fiberglass insulation around the entire perimeter of the foundation to form a proper seal between sill plate and foundation.

Mark the location of the anchor bolts, drill them and slip the sill over the bolts. Check to make sure that the sill is overhanging to the right dimensions and that it is SQUARE AND PARALLEL to the house (don't bolt it down yet). Measure the end wall plates right up to the house and cut them to length. Mark, drill, check for square, and when satisfied, bolt these down.

The ledger plates are of standard stock. On the wall of the house, mark the height to the top ledge plate directly above the outside edge of the sill. Drop a plumb bob down from this point and adjust until you are at the right height, directly true and straight above the sill. Mark this location at each end with a nail and run a chalk line down. The nail marks the upper outside corner of the horizontal ledger and the chalk line the outside edge of the vertical ones. The horizontal ledger is a 2x6, and the vertical ones are 2x4s.

>>> (If the upper ledger is placed 1½-2" below the lap in your siding, later in construction flashing can be tucked under the siding as lay covering on the fiberglass roof. A little pre-planning can save hours later!)

Determine where the studs are in the house wall behind your *horizontal* ledger and mark them. Cut the upper ledger to length, staple some fiberglass to the back (if the house wall is very uneven, it can be stuffed in later), start 5 or 6 nails, lift it into place and tack it on. Check it for level, tap it to adjust and when perfect, pound it home.



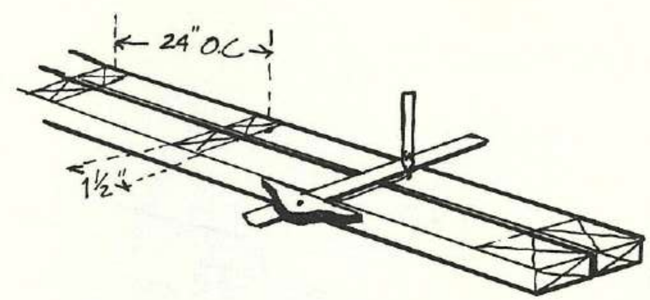
Measure the *vertical* plates and cut to length. Staple some fiberglass insulation to the back of them (unless you have shingles, in which case stuff it in later) and tack them in place when lined up with the chalk line. Check them for level just to be sure, and nail them up.

When you are satisfied that all is square and true, pre-drill and put in five $\frac{5}{16}$x5½" lag screws and washers through the top ledger into the studs, and 3 lag screws and washers into each of the vertical plates. Caulk around the perimeter of the ledgers after the lag screws are in to insure an airtight seal.

Now you're ready to start framing!

FRAMING THE SOUTH WALL:

Cut a 2x4 top plate to match the front sill (16'5½"). Remove the sill from the foundation and lay the top plate and the sill plate flat and side-by-side so that they can be marked together to show the placement of the MULLIONS.



Looking at the plans, there are eleven mullions on the face. The corners are double-studded with a ⅜" strip of plywood sandwiched in between to bring it up to 3½" square.

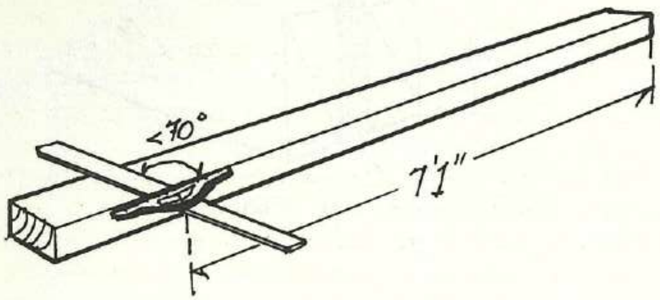
{1} Mark 3½" in from each end with a combination square and scribe a line. This line is the inner edge of the first mullion of the glazing sequence.

{2} Now begin scribing lines all the way to the other end at <u>24"</u> (necessary for accepting the glass). These are also the "inner" edges of the mullions, so scribe another line 1½" back towards the original end and connect with an "X".

The mullions will sit on these marks top and bottom. Double check to see that they are 24 " on center *exactly*.

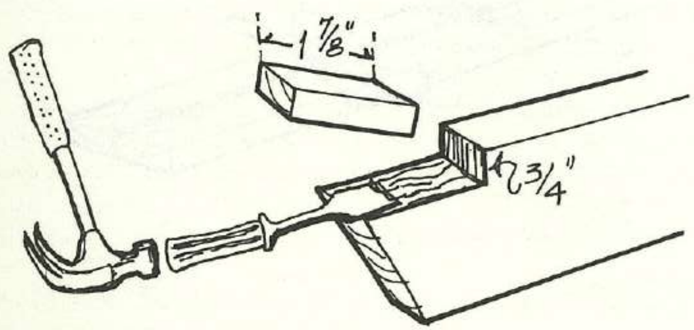
>>> If for some reason the foundation is not the right length to match the dimension sequence for the glazing detail, make up the entire mistake in one of the end sections. You can always trim a piece of glass to fit -- better than trimming them all!

MEASURE TWICE, CUT ONCE!



Pick the 11 straightest 8' 2x4s you have, determine the worst end (these will be cut off) and the clearest edge (for seating the glass). Mark them all at 7'1" from the good end and scribe with a miter gauge set at 70°. DOUBLE CHECK and cut.

The bottom of the mullions must be notched to accept a 1x2 for the glazing detail. Mark $1\frac{7}{8}$" up from the angled end and $\frac{3}{4}$" deep. The notching can be facilitated by laying the mullions side-by-side, marking them at once and making the $\frac{3}{4}$" deep cut on all of them at once. With a wide chisel, chip out the bit of wood and clean out the notch to be parallel and flat with the face of the mullion. Check to see that a 1x2 fits snugly.



Cut four $3\frac{1}{2}$" wide strips of $\frac{3}{8}$" plywood (save two of them for the rafters), sandwich them in between two sets of double 2x4s and trim.

Lay out the entire face of the greenhouse on a level piece of ground (directly in front of the greenhouse if possible), making it fairly square. The 2x6 will stick down a bit -- make sure that it is aligned so that the holes will be oriented in the proper direction for setting it back onto the foundation. Laying in the 1x2 will help make the mullions flush with the leading edge of the sill.

Starting at the corners, nail through the plates into the studs with 16d galvanized nails. DOUBLE CHECK YOUR MEASUREMENTS and nail in the 1x2.

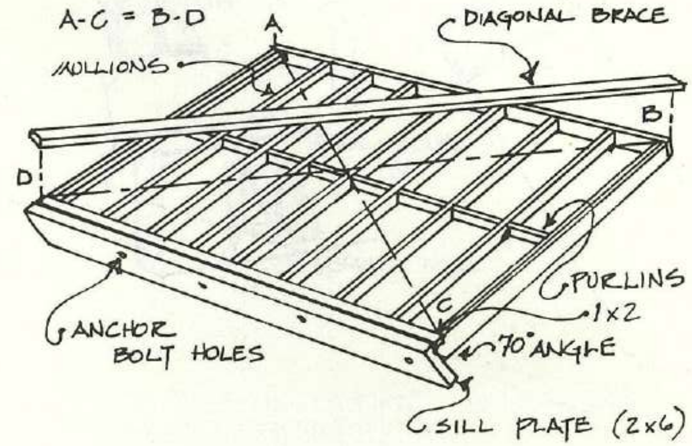
Depending on how dry the 2x4s are, they will be between 1½" and $1^{9}/_{16}$" wide. Measure the space between the mullions. Those $_{16}$ths can add up and badly bow a mullion.

Determine the correct spacing and cut out the PURLINS (called BLOCKING in an unglazed wall). Nail them in place midway up the face in an even line (nail through the mullion in one end and toenail the other). They should be *perfectly* flush with the faces of the mullions, making the mullions rigid, evenly spaced and perfectly straight.

Now, check for absolute square by measuring diagonals. When the diagonals are *exactly* even, tack a long 2x4 diagonally across the face and re-measure the diagonals. When you are perfectly satisfied, nail on the diagonal brace. This brace is going to hold the face square while you lift it onto the foundation and do a lot of adjusting.

Get a crowd together and lift the whole face on to the foundation, slipping it on to the anchor bolts. Lean it back until it is the proper length away from the wall (7'8" from the top of the ledger plate) and prop it up with 2x4s nailed to its sides.

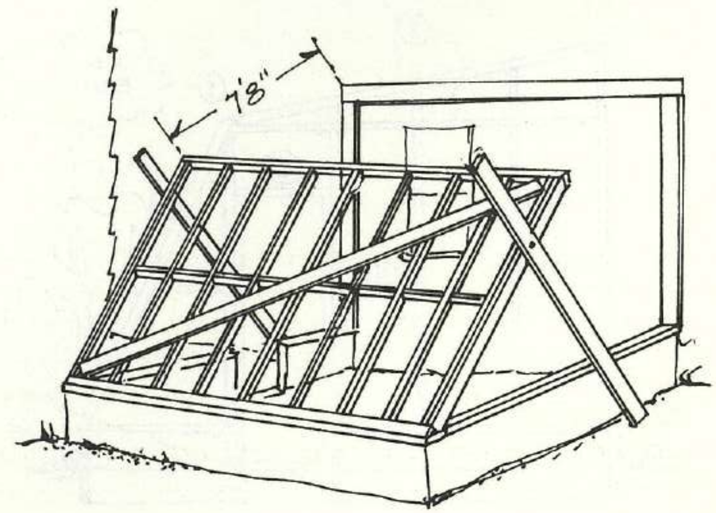
Remeasure, making sure that it is the proper distance from the ledger, parallel, and square with the house.



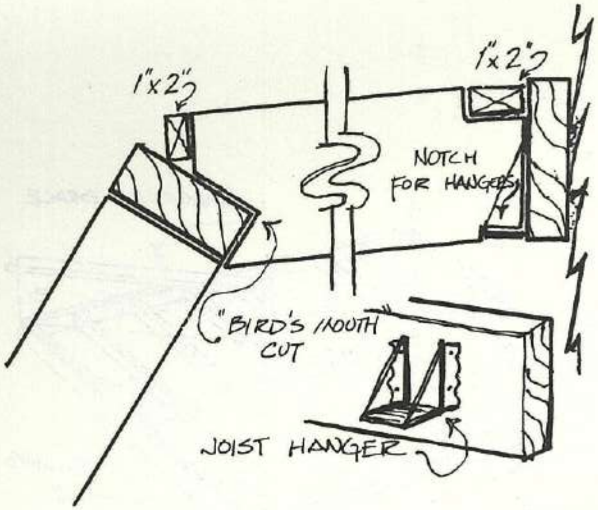
HANGING THE RAFTERS:
Measure the spacing for the joist rafters on the top ledger on 24" centers. The two end hangers will be 4x6 joist hangers, but begin measuring from the inside as on the south face.

These spacings need to be exact so that they will accept the corrugated fiberglass roofing later on. Mark the spacings for the rafters onto the top plate at the same centers.

Hold up an 8'2x6 so that it spans between the ledger and the top plate. Mark it with a BIRD'S MOUTH at one end and with an angle and a notch at the other end. Then cut 3/4" off the pointed end so that a 1x2 can run flush with the top of the rafters the length of the greenhouse. Cut the 2x6 to shape.



<<<Determine while holding the rafter in place the vertical position of the joist hanger within the spacing. When satisfied, nail up the joist hangers.



The bird's-mouth will fit onto the front wall. The notch is for seating into the joist hanger. At the point where the rafter meets the ledger, put in a notch for a 1x2 (as on the south face) to nail the fiberglass to. A little pre-planning now saves lots of time later. If the 2x6 you have cut fits, use it as a model for cutting out the rest of the rafters.

Make double corner rafters with plywood as with the face. Nail all of the rafters up. Put in horizontal BLOCKING, similar to the purlins, at the mid-points.

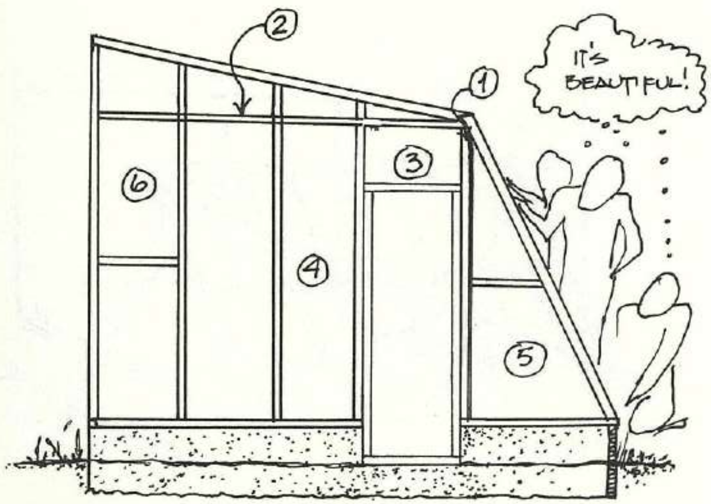
FRAMING END WALLS:
After removing the temporary supports, the end walls may be filled in to meet your specific design. We recommend making a wall that's half insulated and half clear glazing.

Drop a 2x4 from the birds-mouth straight down to the sill[1] and lay a HEADER[2] straight across to the rear wall. Frame in the door using a double-studded frame with a header[3] Next to the door, frame in a "window"[4] with a stud at 24 " center (to accept the glass). Extend the wall back with studs at 24" centers, checking them with a level as you go. Continue these studs up into the triangle with short blocks.

Define the opening for the low vent[5] next to the door by putting in a horizontal spacer (the vent should be about 2'x2').

On the opposite wall, stud in the two windows on 24 " centers. Continue the wall back with studs on 24" centers. Block in the upper triangle and define the opening for the large vent[6] (about 2'x3') with a horizontal spacer.

You're done! Give yourself and those around you a hug and pause to admire your work.



PAINTING/STAINING THE FRAME:
The mullions in your greenhouse will be getting more abuse from the rain and sprinkler cans than do the studs in your house. We recommend treating your lumber for longevity. Copper naphthenate is the best agent to use. Cuprinol wood stains come in a variety of colors and have a tin-based protective agent. Creosote and penta are detrimental to plants!
Depending on your timing and whether you paint or stain, your lumber may be treated previous to framing or after it's erected, then painted with an exterior grade enamel or latex paint. Another solution is to get a cuprinol wood stain to suit your color taste. This will need a day to dry, but using the stain as a protective agent may be done in one coat. Don't forget to paint or stain the 1x2 cap pieces for the glazing detail at this point.

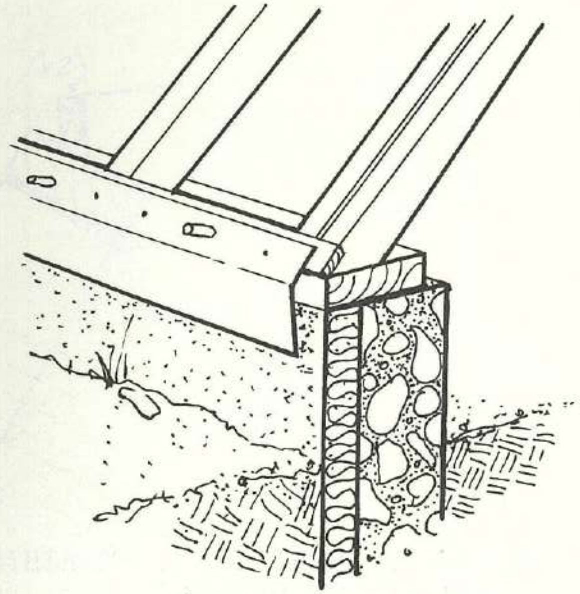
GLAZING, INSULATING, SHEATHING AND FINISH DETAILS

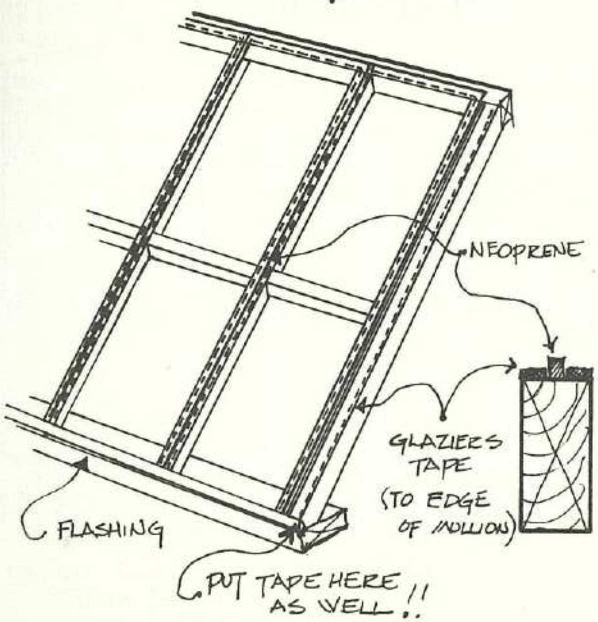
Now that the framing is completed, we will procede with two jobs:

{1} Glazing the greenhouse to make it as airtight and waterproof as possible.

{2} Siding and insulating the end walls to help retain heat.

The sequence in placing a skin over the framework of a greenhouse procedes *in the opposite direction of the flow of water* -- from the bottom to the top, with each surface overlapping like shingles.





OVERVIEW:
The south face of the greenhouse is glazed, with a strip of flashing tucked under the glass and hanging over the perimeter insulation. Tar paper is stapled to the exterior end walls and beveled siding is nailed up and trimmed to shape. The interior walls are insulated with 3½" fiberglass batts and 1" of structural styrofoam, then sheathed with plywood.

Corrugated strips of wood, "WIGGLE-BOARD," are attached to the roof rafters to accept the fiberglass roofing which overhangs the front face and end walls. Flashing is placed over the top of the fiberglass and tucked under the shingles or siding of the house. Doors and vents are constructed, hung and weatherstripped. Finally, all cracks and gaps and caulked and sealed.

THE SOUTH FACE:
Cut a 6" strip of galvanized or aluminum FLASHING to the length of the greenhouse. Nail it onto and covering the 1x2 (with 6d or 8d nails) so that it hangs over the sill and the perimeter insulation. Through this flashing, ½" dowel pins are stuck into the 1x2 to hold up the glass.

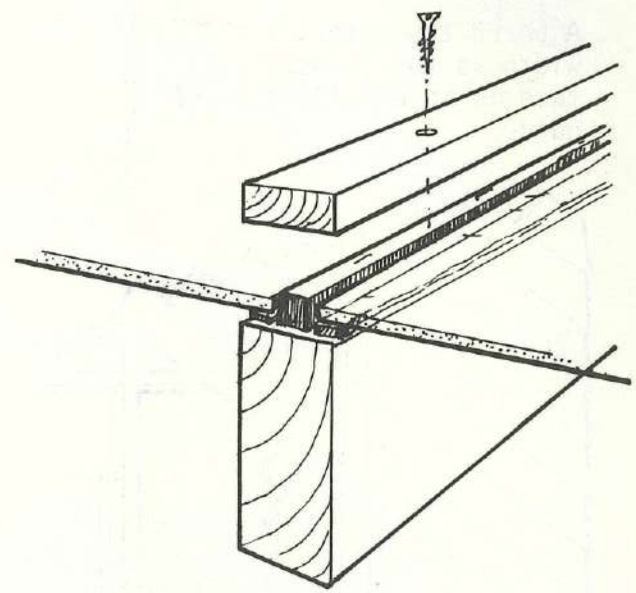
Measure ¾" down from the top of the 1x2 and midway between the mullions. Punch a hole through the flashing with a nail. Drill through the flashing and the 1x2 with a ½" metal bit, keeping perpendicular to the face of the greenhouse. Hammer a 2" long piece of ½" dowel in.

The ⅜" square NEOPRENE STRIP which helps space and seal the glass is stapled down the center faces of the mullions and along the center of the top plate. There should be ½" of mullion exposed on each side of the neoprene strip. Make sure the staples are in line with the length of the neoprene so they won't touch the glass! Carefully take the ⅜"-wide GLAZIER'S TAPE and lay it along the top and the two sides of each glazing section, next to the neoprene and even with the edges of the mullions. You're now ready to set in the 23¼"x7' strips of glass. If all of the spacings are correct and square, there should be no difficulty.

While one person carefully carries the glass (wearing non-slippery leather gloves!) over to the greenhouse, another should be standing ready inside of the greenhouse. Set the glass onto the dowel peg and gently lean it towards the face. The person inside the greenhouse should be holding the glass out, while the person outside positions it perfectly inside of the neoprene strips, guiding it down onto the glaziers' tape. Try not to touch the glass to the glaziers' tape before it's positioned properly. *The tape sticks to the glass better than to the wood and makes a mess!*

The wooden CAP STRIPS are screwed snuggly down over the glass, pressing it against the tape, squishing the neoprene to form an air-tight, waterproof seal. Cut to length and pre-drill all of the caps. The holes should be just large enough for the SQUARE-DRIVE SCREWS to push all the way into with a little force. The holes are spaced 9" apart, *but don't get them any closer than 4" from the ends of the caps as they then tend to curl the cap down and crack off the corners of the glass.*

Make sure that the holes are exactly in the center of the caps <<< and perfectly straight. We want to screw straight down into the neoprene, not diagonally over into the glass!

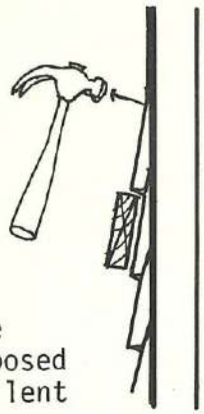


The square drive screws are a very positive screwing system. The drivers may be used in a screwdriver-type handle, in a bit and brace, or in an electric variable-speed drill. Regardless, a special sensitivity is required to know when to keep tightening the screw and when to stop. To gain a feeling of when to stop, watch for the glaziers' tape to just begin to squish out a little bit from between the glass and the mullion (easily visible from the interior of the greenhouse). That is as tight as the caps need to be.

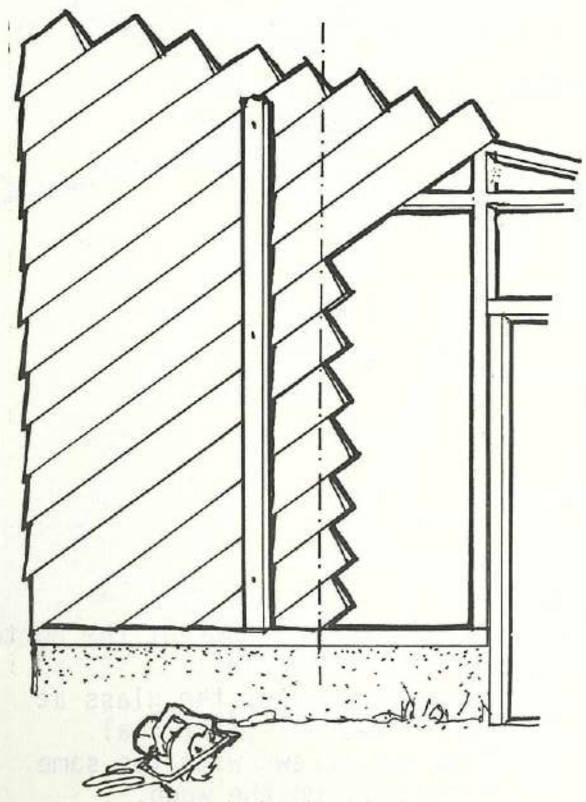
Fasten the cap piece up over the top plate for the full length of the greenhouse first. Then put up the vertical caps. As long as the cap is kept directly over the mullion, there should be no problem. Leave the two end corner caps off until the siding is up. a 1x5 or 1x6 may be used there for caps to seal the glass and to cover the corner post and rough edges of the siding.

Putting up the glass is the quickest, most straight forward part of the building process. Be careful -- but don't be scared away!

NOTE:
- No glazing tape or caps at the bottom edge or on the purlins!
- Silicone the back of the glass at bottom for weather-tight seal.
- Touch up the screws with the same paint you used on the wood.



A board the same width as the exposed face is an excellent guide.



THE END WALLS:
The end walls should be sided before the fiberglass is up on the roof for convenience in placing and trimming to shape. Tar paper (15# roofing felt) is stapled to the exterior of the studs and the siding nailed directly onto that. It is sometimes helpful to snap a chalk line where the studs are behind the roofing felt to aid in nailing. Utility grade cedar siding is very inexpensive if you can find some.

Place the siding either horizontally or diagonally, with the bevels overlapping an inch. A board the same width as the exposed face is a speedy guide for placing the siding so that the overlap doesn't have to be measured each time.

When trimming the edge of the siding once it's up, a guiding board nailed parallel to the cut (spaced to align the saw blade correctly) to run a skill saw against will leave a straight and perfect line.

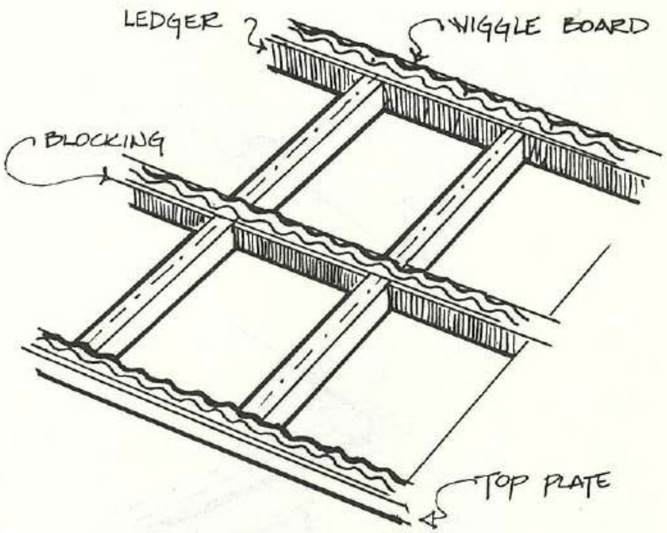
The inside of the end walls are just as simple:
Insulate with 3½" fiberglass batt insulation in between the studs and with 1" structural styrofoam tacked over this onto the surface of the studs. This brings the insulating value of the wall close to R-19. Snap a chalk line where the studs are. Plywood nailed up over this should be painted or stained.

>>> When setting the glass on the end walls, make sure that the siding hasn't hung over the face of the mullion even a small amount. This can displace the cap enough to place the screws directly over the glass!

THE ROOF:
The corrugated fiberglass on the roof should be installed to be just as air-tight and waterproof as the south face glazing. Use silicone caulk around the edges of the roof and on the corrugation overlaps to accomplish this. If you combine this technique with hanging the fiberglass over the end walls one corrugation and overhanging the front face, it will save having to put up flashing.

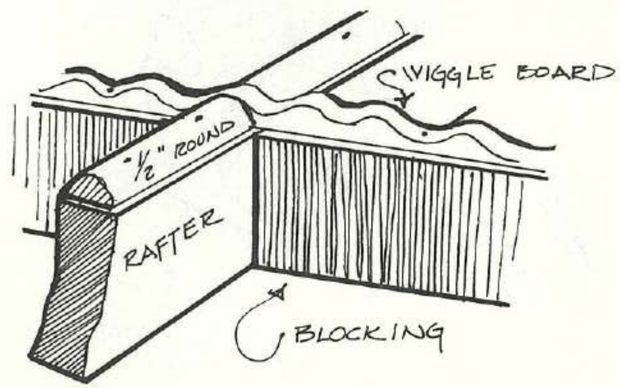
A quick-but-dirty job starts off the roof:

You must go to the top ledger at the house connection and pry up the siding or shakes. You're going to slip flashing under them, so remove any nails that could block this. If your greenhouse is tucked right up under your eaves, you may be able to leave off this flashing.



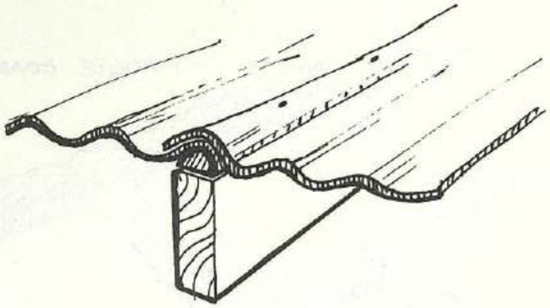
Wiggle-board is now placed the length of the greenhouse along the upper and middle horizontal blocking, and along the top plate at the lower end of the roof. HALF-ROUND MOLDING will run along the tops of the rafters to support the wiggle-board.
The wiggle-board must lie so that the tops of the wiggle-board hills are in line with the rafters.

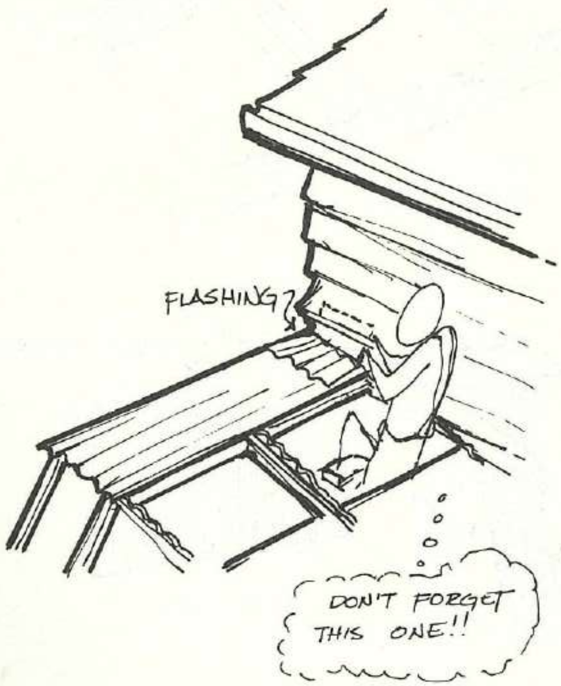
Run a bead of caulk along the back of a strip of wiggleboard and place it on the upper horizontal blocking so it is lined up correctly with hills on top of rafters. Nail it down with finish nails. Run some caulk along the back of two more pieces and lay them down on the middle blocking and the top plate so that they are in line with the first piece. *Don't nail these!*



Put a strip of fiberglass on top of these and square it up with the roof. Adjust the two lower pieces of wiggle-board to sit properly under the fiberglass and mark their position. Take down the roofing and nail up these two pieces of wiggle board (their hilltops should still be in line with the rafters!).

Caulk and nail up the rest of the wiggle board running from these first three pieces. Cut the half-round pieces to fit in between the wiggle-board and to sit on top of the rafters. *Be sure to caulk under the strips on the two outside edges,* then nail it all down.





To finish the roofing, narrow strips (6"x8') may need to be cut, depending on the width of the greenhouse and the siding used, to overhang the end walls.

Now you are ready to lay up the fiberglass. Run a bead of silicone caulk on the tops of the perimeter strips of wiggle-board and half-round where the first piece of fiberglass is going. Drop it straight down onto the silicone without sliding it. Make sure it overhangs the endwalls one corrugation and over the front 2"-6". Nail it down on 6" centers into the half-round with washernails and on the hilltop of every third corrugation. If the wood splits or the fiberglass cracks, *you may have to pre-drill these holes*. Weatherstrip well!
Now, slip the flat side of the end wall flashing underneath the house's siding. Fit it into place onto the section of fiberglass. Silicone the overlap corrugation on the length of fiberglass. Caulk also the top and bottom wiggle-boards and set in the next sheet of fiberglass (it should overlap one corrugation. Nail down (and pre-drill) as before. Continue in this pattern along the entire length of the roof.

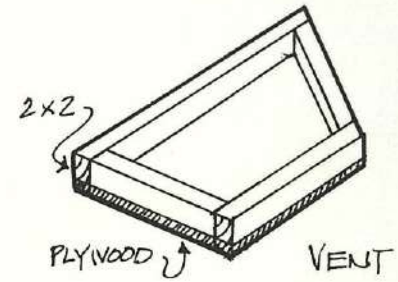
THE DOORS AND VENTS:
The doors and vents presented here are designed to be made as simply and efficiently as possible. The vents are made of 2x2s cut to the dimensions blocked out in the end wall frame, with sections of CDX plywood shaped to fit. Nail and glue the 2x2s to one of the plywood shapes and check it in the opening for ease of fit. Stuff it with styrofoam or fiberglass and glue and nail the front piece of plywood on.

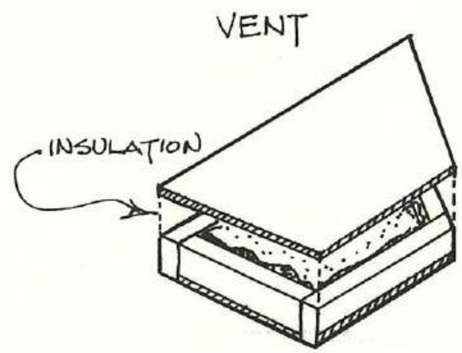
Set the vents in place as they will eventually hang, marking their inside perimeter onto the framework. Nail doorstop molding along this line and hinge the vents so that they open out. A simple hook-and-eye will hold them open or shut.

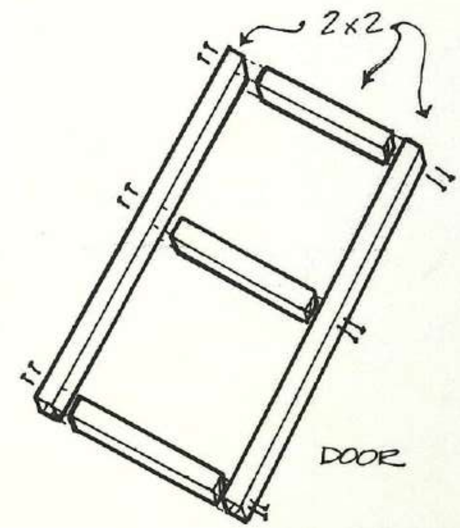
If you are unable to find a nice door lying about, a simple and rigid design is for a door glazed on the upper half and insulated below. Size 2x2s (2x4s make for a sturdier door, but are harder to work with) for a fairly snug fit within the door frame. Glue and nail the corners of the 2x2s and the mid-brace together. A piece of plywood glued and nailed on will keep the door square and rigid. Tack the plywood on and slip the door into the frame, adjusting until a perfect fit is obtained. Nail the plywood tight. Insulate the hollow and apply the plywood face sheet. The glass may be"stopped-in" with molding and glazier's tape.

Nail in the doorstop molding, hang the door, and weatherstrip well. Weatherproof thresholds may be purchased inexpensively and make a very good weather seal at the bottom of the door. Put in some hooks-and-eyes, a handle, and stand back. Look around the greenhouse very carefully. Any cracks, gaps, or poorly joined surfaces should be well-sealed with caulk and, if large enough, stuffed with a little insulation.

YOU DID IT!! Stand back and admire the greenhouse and yourself -- and get ready for a little warmth and homegrown food!







VI. FOOD PRODUCTION

The planting rhythms, organization, crop selection and time spent in a greenhouse will largely determine the amount of food output. The greenhouse can be used for two separate production operations: food production within the greenhouse and early vegetable starts for use out in the garden.

As the greenhouse is a more controlled environment than the garden, a more systematic approach to growing healthy plants can be taken. One can, with a little practice, be assured of the timing involved between initial planting dates and the setting-out dates of vigorous starts. A sudden hail storm or a slug infestation in the garden will not necessarily place one a month behind schedule in the garden.

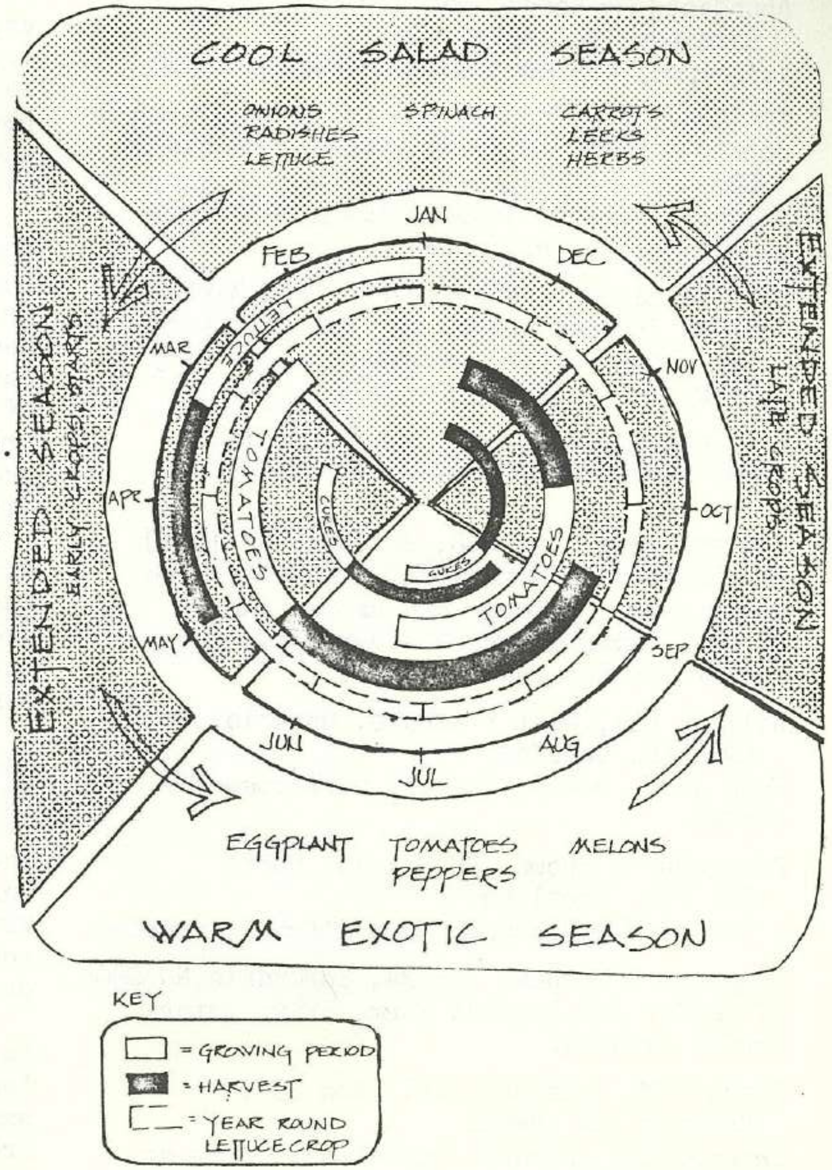
A SEASONAL ROTATION

The solar greenhouse extends seasonal "exotic" vegetable production without artificial light from four and one-half to nine months. In conjunction with this, year-round production of cooler weather crops is available, allowing fresh salads throughout the winter. To achieve this end, a careful organization of the planting rhythms must be maintained, bearing in mind the seasonal light and heat changes which will be interacting at times when one isn't usually growing vegetables.

Although a basic planting timetable is included here, it is of a general nature and will need to be adapted to any specific greenhouse's orientation, size, temperature fluctuations and more usual garden characteristics such as soil conditions and varieties selection.

The seasonal use of plant species is very important for healthy vegetables and for optimal food production. Advantage is taken of the extra heat intensity during spring, summer and fall to grow fruiting plants for periods beyond their normal outside productivity. These fruiting plants include such exotics as tomatoes, peppers, melons, cucumbers and eggplants. Valuable greenhouse space should not be taken up during the "heat season" with cooler weather crops which can be grown in the outside garden.

SOLAR GREENHOUSE
PLANT ROTATION & HARVEST CHART



SEED SOURCES

Abundant Life Seeds, Box 374
Gardiner, WA 98334
Untreated, organic and sometimes locally grown.

Johnny's Selected Seeds, Albion, ME 04910
50¢
Organic, hardy. Grows a lot of his own; knowledgeable, reliable

Seattle Garden Center, Pike Place Market
Carries treated seeds, but Bob Gill knows a lot about winter gardening and is very helpful.

Tillinghast Seeds, La Conner, WA 98257
A few winter coles.

Stokes Seeds, Box 548, Buffalo, NY 14240
Wide selection commercial, much Canadian grown seed. Cheaper and better than Burpee. Many greenhouse varieties for cooler weather and low light.

William Dam, West Flamboro, Ontario,
LOR 2KO, Canada
Some good, cheap, unusual varieties for winter.

Alexander & Brown, PO Box 13, Perth
PH1 5NY, Scotland
A few good varieties for continual cropping.

Thompson & Morgan, Box 24, Somerdale,NJ 08083
US outlet for British firm. Very interesting catalog.

Tsang & Ma International, Box 294,
Belmont, CA 94002
Interesting oriental varieties. Some at Seattle Garden Center

Due to winter's low level light intensity in the Pacific Northwest, the exotics become less healthy and space used for lengthened fruition could be put to more advantageous use. The lower level of solar radiation would be better used for leaf-producing salad vegetables which thrive in a cooler environment and do not need a specific photoperiod for production of food. Towards the end of winter extra space is needed for seedflats to begin another cycle of planting.

PEST CONTROL

Due to the contained environment within a greenhouse, artificial fertilizers and pesticides should not be used. Over-application cannot be tempered easily as in a garden. Plant-specific application is very difficult due to the variety and close proximity of plants. A healthy soil high in organic matter with timely organic fertilizer additions will fulfill the needs of plant growth and inherently have more ability to prevent insect and disease manifestations.

With the enclosed environment, there is protection from outside insect migration. With a high diversity of plant species in the greenhouse, a species specific insect will have difficulty discovering its host plant. If a plant show a disease or insect manifestation, it can simply be removed from the greenhouse.

This sanitation maintenance is in conflict with commercial greenhouse operations. These commercial programs are probably the reason for the myth describing the constant battle against disease and pest problems within a greenhouse. Characteristically, commercial greenhouses are large enclosed monocultural spaces which give infestations great opportunity to spread. If a spore or insect is introduced into the building, the sterile soil conditions provide an ideal medium with no natural predators for control.

In an attached household greenhouse, careful caledar planting and learning to "read" plant symptoms for needed seasonal changes or pest problems should give year-round successful cropping and a broadly varied diet.The previous page shows a sample calendar year for a few basic vegetable planting and harvest rhythms for maximum greenhouse use.

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HEAT LOSS CHARTS OF EXAMPLE SOLAR REMODEL FOR OTHER NORTHWEST LOCATIONS

ASTORIA

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	753	16.8	1.5	.4	14.9	8.1	6.2	1.77	4.43
Feb	622	13.9	1.5	.6	11.8	6.7	4.6	2.68	1.92
Mar	636	14.2	1.5	.8	11.9	6.8	4.5	3.96	.54
Apr	480	10.7	1.5	.7	8.5	5.2	3.0	4.19	-
May	363	8.1	1.5	.7	5.9	3.9	1.7	4.76	-
Jun	231	5.2	1.5	.6	3.1	2.5	.4	4.32	-
Jly	146	3.3	1.5	.7	1.1	1.6	-	-	-
Aug	130	2.9	1.5	.7	2.2	1.4	-	-	-
Sep	210	4.7	1.5	.8	3.9	2.3	-	-	-
Oct	375	8.4	1.5	.8	6.1	4.0	1.7	3.65	-
Nov	561	17.5	1.5	.5	12.0	6.0	4.0	4.0	1.69
Dec	679	15.1	1.5	.4	13.2	7.3	5.4	5.4	3.89
Total					94.6		31.5		12.5

Figures shown in mmBTU

PROSSER

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	1074	23.9	1.5	.7	21.7	11.6	9.4	3.02	6.38
Feb	806	18	1.5	.9	15.6	8.7	6.3	4.3	2
Mar	651	14.5	1.5	1.0	12.0	7.0	4.5	5.46	-
Apr	388	8.6	1.5	.9	6.2	4.2	1.8	6.08	-
May	198	4.4	1.5	.8	2.1	2.1	-	-	-
Jun	57	1.2	1.5	.7	-	.6	-	-	-
Jly	0	-	1.5	.8	-	-	-	-	-
Aug	6	.1	1.5	1.0	-	.06	-	-	-
Sep	115	2.5	1.5	1.2	-	1.2	-	-	-
Oct	380	8.4	1.5	1.1	5.8	4.1	1.5	5.36	-
Nov	754	16.8	1.5	.8	14.5	8.1	5.8	3.31	2.49
Dec	941	21	1.5	.6	18.9	10.1	8.0	2.7	5.3
Total					96.8		37.3		16.2

Figures are in mmBTU

CORVALLIS

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	822	18.3	1.5	.5	16.3	8.9	6.9	2.04	4.86
Feb	647	14.4	1.5	.4	12.5	7.0	5.1	2.12	2.98
Mar	611	13.6	1.5	.6	11.5	6.6	4.5	3.2	1.3
Apr	417	9.3	1.5	.6	7.2	4.5	2.4	3.51	-
May	273	6.1	1.5	.6	4.0	2.9	.8	4.53	-
Jun	144	3.2	1.5	.6	3.1	1.5	-	-	-
Jly	37	.8	1.5	.7	-	.4	-	-	-
Aug	31	.7	1.5	.7	-	.3	-	-	-
Sep	111	2.5	1.5	.8	.2	1.2	-	-	-
Oct	338	8.6	1.5	.7	6.4	3.6	1.4	3.54	-
Nov	594	13.2	1.5	.4	11.3	6.4	4.5	1.89	2.61
Dec	729	16.3	1.5	.3	14.5	7.9	6.1	1.24	4.86
Total					85.0		31.7		16.6

Figures shown in mmBTU

SPOKANE

	degree days	gross heat loss	internal heat gain	solar gain through windows	net heat loss	gross heat loss II	net heat loss II	with solar greenhouse net gain	net loss with solar greenhouse
Jan	1231	27.4	1.5	.7	25.2	13.3	11.1	2.89	8.21
Feb	980	21.9	1.5	.8	19.6	10.6	8.3	3.71	4.59
Mar	834	18.6	1.5	.8	16.3	9.0	6.7	5.07	1.63
Apr	531	11.8	1.5	.8	9.5	5.7	3.4	5.17	-
May	288	6.4	1.5	.8	4.1	3.1	.8	5.6	-
Jun	135	3	1.5	.7	.8	1.4	-	-	-
Jly	9	.2	1.5	.8	-	.1	-	-	-
Aug	25	.5	1.5	.9	-	.2	-	-	-
Sep	168	3.7	1.5	1.0	1.2	1.8	-	-	-
Oct	493	11	1.5	.9	8.6	5.3	2.9	4.42	-
Nov	879	19.6	1.5	.7	17.4	9.5	7.3	2.81	4.49
Dec	1082	24.1	1.5	.5	22.1	11.7	9.7	1.94	7.76
Total					124.5		50.2		26.7

Figures shown in mmBTU

2—Resistance Values of Structural and Finish Materials, Insulations, Air Spaces, and Surface Films*

This information is reprinted from *Insulation Manual: Homes/Apartments*, September 1971
prepared by: NAHB Research Foundation
627 Southlawn Lane
Rockville, MD 20850

Wood bevel siding, 1/2 x 8, lapped	R-0.81
Wood siding shingles, 16", 7½" exposure	R-0.87
Asbestos-cement shingles	R-0.03
Stucco, per inch	R-0.20
Building paper	R-0.06
1/2" nail-base insul. board sheathing	R-1.14
1/2" insul. board sheathing, regular density	R-1.32
25/32" insul. board sheathing, regular density	R-2.04
1/4" plywood	R-0.31
3/8" plywood	R-0.47
1/2" plywood	R-0.62
5/8" plywood	R-0.78
1/4" hardboard	R-0.18
Softwood, per inch	R-1.25
Softwood board, 3/4" thick	R-0.94
Concrete blocks, three oval cores	
Cinder aggregate, 4" thick	R-1.11
Cinder aggregate, 12" thick	R-1.89
Cinder aggregate, 8" thick	R-1.72
Sand and gravel aggregate, 8" thick	R-1.11
Lightweight aggregate (expanded clay, shale, slag, pumice, etc.), 8" thick	R-2.00
Concrete blocks, two rectangular cores	
Sand and gravel aggregate, 8" thick	R-1.04
Lightweight aggregate, 8" thick	R-2.18
Common brick, per inch	R-0.20
Face brick, per inch	R-0.11
Sand-and-gravel concrete, per inch	R-0.08
Sand-and-gravel concrete, 8 inches thick	R-0.64
1/2" gypsumboard	R-0.45
5/8" gypsumboard	R-0.56
1/2" lightweight-aggregate gypsum plaster	R-0.32
25/32" hardwood finish flooring	R-0.68
Asphalt, linoleum, vinyl, or rubber floor tile	R-0.05
Carpet and fibrous pad	R-2.08
Carpet and foam rubber pad	R-1.23
Asphalt roof shingles	R-0.44
Wood roof shingles	R-0.94
3/8" built-up roof	R-0.33

Glass	
Single glass (winter)	U = 1.13
Single glass (summer)	U = 1.06
Insulating glass (double)	
1/4" air space (winter)	U = 0.65
1/4" air space (summer)	U = 0.61
1/2" air space (winter)	U = 0.58
1/2" air space (summer)	U = 0.56
Storm windows	
1" to 4" air space (winter)	U = 0.56
1" to 4" air space (summer)	U = 0.54

Insulation	
2" – 2½" thick	R-7.00
3" – 4" thick	R-11.00
5" – 7" thick	R-19.00

Air Spaces (3/4")	
Heat flow UP	
Non-reflective	R-0.87
Reflective, one surface	R-2.23
Heat flow DOWN	
Non-reflective	R-1.02
Reflective, one surface	R-3.55
Heat flow HORIZONTAL	
Non-reflective (also same for 4" thickness)	R-1.01
Reflective, one surface	R-3.48

Note: The addition of a second reflective surface facing the first reflective surface increases thermal resistance values of an air space only 4 to 7 per cent.

Surface Air Films	
INSIDE (still air)	
Heat flow UP (through horizontal surface)	
Non-reflective	R-0.61
Reflective	R-1.32
Heat flow DOWN (through horizontal surface)	
Non-reflective	R-0.92
Reflective	R-4.55
Heat flow HORIZONTAL (through vertical surface)	
Non-reflective	R-0.68
OUTSIDE	
Heat flow any direction, surface any position	
15 mph wind (winter)	R-0.17
7.5 mph wind (summer)	R-0.25

Example calculations
(to determine the U value of an exterior wall)

Wall Construction	Uninsulated Wall Resistance	Insulated Wall Resistance
Outside surface (film), 15 mph wind	0.17	0.17
Wood bevel siding, lapped	0.81	0.81
½" ins. bd. sheathing, reg. density	1.32	1.32
3½" air space	1.01	
R-11 insulation		11.00
½" gypsumboard	0.45	0.45
Inside surface (film)	0.68	0.68
Totals	4.44	14.43

For uninsulated wall, $U = \frac{1}{R} = \frac{1}{4.44} = U = 0.22$

Therefore, heat loss for the above uninsulated wall section at a +10° F. outside design temperature is equal to 0.22 x 60 (or 70-10) equals 13.2 Btuh per sq. ft. of wall section.

For insulated wall, $U = \frac{1}{R} = \frac{1}{14.43} = U = 0.07$

Therefore, heat loss for the above insulated wall section at a + 10° F. outside design temperature is equal to 0.07 x 60 (or 70-10) equals 4.2 Btuh per sq. ft. of wall section.

* Additional resistance values can be obtained from ASHRAE Handbook of Fundamentals published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Tools Needed for Leading a Solar Greenhouse Workshop

2 shovels, 1 spade, 1 square
3 hammers, framing and 16 ounce
2 handsaws, 1 rip, 1 back
1 circular saw, with extra blades
2 electric drills with bits
2 levels
3 tape measures (2@16 ft., 1@50 ft.)
2 combination squares
1 carpenters steel squares
1 staple gun with staples
1 wheelbarrow (for foundational work)
1 rasp or surform type plane
1 plane, block or jack
1 tin snips
2 caulk guns
1 chalk line
2 50 ft. extension cords
1 mechanics general tool set with sockets, pliers
2 crow bars, 1 wrecking, 1 wonder bar
1 sledge hammer
1 set of nail sets
4 10 inch parallel clamps
4 8 inch "C" clamps
1 set of chisels
2 saw horses
2 carpenters tool aprons
4 R-2 drivers for square drive screws
3 ladders, 1-step, 1-8 foot, 1-16 foot rung ladder
1 miter box with back saw
1 glass cutter with oil for cutting
2 pair safety glasses or goggles
2 pair sound deadening head-phones
2 respirators with extra filters
2 pair gloves
1 bevel marking guage
1 jig-saw or key-hole saw
carpenters pencils
miscellaneous clean up equipment
string
painting equipment; brushes, rollers, trays with inserts, thinner

BASIC TOOL LIST FOR WORKSHOP PARTICIPANTS

Simple necessities:

pencils, notebooks and cameras
weather-proof clothing
safety-equipment; goggles, head-sets, gloves, masks.
tapemeasure
combination square
hammer
saw

More comprehensive:

carpenters square
extension cord
drill and bits
skill saw
level
chalk line
screw-drivers
staple gun and staples
ladders (step and 8-foot)
caulk-gun
carpenters apron
chisels
plane (block or jack)
painting equipment; brushes, rollers, trays & inserts, thinner.

Materials List
Ecotope Solar Greenhouse

Foundation:

36 cubic feet or 1 1/2 yards concrete

Lumber:

5 - 6' 1x2
12 - 8' 1x2 (12 in a bundle)
4 - 10' 1x2
20' 2x2 — must be standard grade! that is #2+ or better
2 - 12' 1x4
1 - 16' 1x4
3 - 14' 2x4
20 - 16' 2x4
1 - 20' 2x4
1 - 20' 2x6
6 - 16' 2x6
2 - 10' 2x6 foundation grade cedar
1 - 18' 2x6 foundation grade cedar
13 - 4' wiggle board
9 - 8' half round for corrugated fiberglass
3 - 3/8" CDX plywood 4'x8'
130 sq. ft. 7/8"x8" utility grade bevel cedar siding
36' 1/2" cove or quarter round moulding
40' 1 3/8" x 1/2" door stop moulding

Other Materials:

125 sq. ft. tar paper
70 sq. ft. 3 1/2" fiberglass insulation
5 sheets 1" 2' x 8' blue structural styrofoam
5 sheets 2" 2' x 8' blue structural styrofoam
1-1/2" x 36" dowel
7-2x6 joist hangers
2-4x6 joist hangers
1-3' door threshold (aluminum extrusion and vinyl)
18'-6" galvanized or aluminum flashing
200 aluminum fiberglass nails with washers
128 square feet greenhouse quality fibergalss 8 - 2' x 8' strips
8-28" pieces end wall flashing (if necessary)
3 tubes caulk
4 tubes silicone caulk
12-5 1/2" x 7/8" lag screws and washers
11 sheets double strength glass 23 1/4" x 84"
200'-1/8" x 3/8" butyl tape
130'-3/8" x 3/8" neoprene sponge
175-#10 x 2" flathead squaredrive screws, and 2 drivers
1 set 3 1/2" - 4" butt hinges for door
2 sets 2 1/2" - 3" butt hinges for vents
3 pulls or handles for door and vents
3 sets hooks and eyes
34' of weatherstrip "spring metal"
10 lbs. #16 galvanized nails
5 lbs. # 8 galvanized nails
2 lbs. # 8 finish nails
1 lb. small finish nails
2 lbs. siding nails
2 gallons copper naphthenate based stain or paint with copper naphthenate preservative
lumber for planting boxes
glazing material for door if desired

Foundation Forms: (if greenhouse materials are not used)

4 sheets 4' x 8' 1/2" CDX plywood
50' of 1x2's
6-36" sharpened stakes (batter boards)
72' of 2x4's
30 short 2x4's (approx. 1' and up)
60-1'-3' stakes
30 longer braces
3lbs. duplex nails 8d
finish nails
line (string)

The following insolation data for Pacific Northwest locations is reprinted by permission from:

Insolation on South Facing Tilted Surfaces: Pacific Northwest Locations by M. Steven Baker and John S. Reynolds, Center for Envirnonmental Research, School of Architecture and Allied Arts, University of Oregon, Eugene, copyrighted 1975.

VANCOUVER, B.C.
49°16'

12-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
January		Direct	103	198	279	341	380	393	379
		Diffuse	151	132	113	98	86	78	76
	KT = 0.30	Reflected	0	7	13	18	22	25	25
		TOTAL	254	336	405	457	488	496	480
February		Direct	262	413	535	620	664	662	615
		Diffuse	243	211	182	157	138	125	121
	KT = 0.38	Reflected	0	13	25	36	44	49	51
		TOTAL	505	637	742	813	845	836	787
March		Direct	506	662	773	831	833	778	670
		Diffuse	379	330	284	245	215	196	190
	KT = 0.43	Reflected	0	23	44	63	77	85	88
		TOTAL	885	1015	1101	1139	1124	1059	948
April		Direct	810	916	963	947	868	732	548
		Diffuse	536	466	402	346	304	277	268
	KT = 0.47	Reflected	0	35	67	95	117	130	135
		TOTAL	1346	1417	1432	1388	1288	1138	951
May		Direct	1234	1276	1249	1148	977	750	484
		Diffuse	635	553	476	411	360	328	318
	KT = 0.54	Reflected	0	48	93	132	162	181	187
		TOTAL	1869	1878	1819	1690	1499	1259	989
June		Direct	1188	1182	1120	996	817	595	350
		Diffuse	703	612	527	455	399	364	352
	KT = 0.50	Reflected	0	49	95	134	164	183	189
		TOTAL	1891	1844	1742	1584	1379	1141	891
July		Direct	1351	1368	1315	1188	991	740	456
		Diffuse	651	567	489	421	369	337	326
	KT = 0.55	Reflected	0	52	100	142	173	193	200
		TOTAL	2002	1987	1904	1750	1534	1270	982

Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
August		Direct	1142	1244	1271	1216	1084	882	627
		Diffuse	558	486	418	361	316	288	279
	KT = 0.55	Reflected	0	44	85	120	147	164	170
		TOTAL	1700	1774	1774	1697	1547	1335	1076
September		Direct	706	874	982	1023	995	899	742
		Diffuse	433	377	325	280	246	224	217
	KT = 0.49	Reflected	0	29	57	81	99	110	114
		TOTAL	1139	1280	1364	1384	1339	1233	1072
October		Direct	360	530	665	754	792	776	707
		Diffuse	282	245	211	182	160	146	141
	KT = 0.42	Reflected	0	17	32	45	56	62	64
		TOTAL	642	792	908	982	1007	984	912
November		Direct	136	248	343	415	458	471	451
		Diffuse	170	148	127	110	96	88	85
	KT = 0.33	Reflected	0	8	15	22	27	30	31
		TOTAL	306	404	486	546	581	588	566
December		Direct	66	137	199	247	278	291	283
		Diffuse	125	109	94	81	71	65	63
	KT = 0.27	Reflected	0	5	10	14	17	19	19
		TOTAL	192	252	303	342	366	374	365

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
VANCOUVER, B.C.

DEC-JAN	223	294	354	399	427	435	423
NOV-MARCH	428	527	606	657	678	668	626
OCT-APRIL	589	692	767	808	813	781	714
ALL YEAR	1064	1138	1167	1150	1084	977	835

SEATTLE-TACOMA, WASHINGTON
47° 27'

19-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
January		Direct	112	204	282	341	377	387	370
		Diffuse	169	147	127	109	96	87	84
	KT = 0.30	Reflected	0	7	14	20	24	27	28
		TOTAL	280	358	422	470	497	501	483
February		Direct	288	440	562	646	685	678	625
		Diffuse	261	227	196	169	148	135	130
	KT = 0.38	Reflected	0	14	27	39	48	53	55
		TOTAL	549	682	785	853	881	866	810
March		Direct	579	746	861	918	912	844	719
		Diffuse	398	346	298	257	226	206	199
	KT = 0.46	Reflected	0	25	49	69	85	94	98
		TOTAL	977	1117	1208	1244	1222	1144	1015
April		Direct	875	980	1021	996	905	754	555
		Diffuse	548	477	411	355	311	284	274
	KT = 0.49	Reflected	0	37	71	101	123	137	142
		TOTAL	1423	1494	1504	1451	1339	1175	971
May		Direct	1220	1254	1218	1110	935	706	442
		Diffuse	642	559	482	415	364	332	321
	KT = 0.53	Reflected	0	48	93	132	161	180	186
		TOTAL	1862	1861	1793	1657	1460	1218	950
June		Direct	1241	1229	1156	1019	826	590	334
		Diffuse	698	608	523	451	396	361	349
	KT = 0.52	Reflected	0	50	97	137	168	187	194
		TOTAL	1939	1887	1777	1608	1390	1139	877
July		Direct	1448	1458	1392	1247	1029	755	449
		Diffuse	643	560	482	415	364	332	321
	KT = 0.58	Reflected	0	54	105	148	181	202	209
		TOTAL	2091	2072	1979	1810	1574	1289	979

Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
August		Direct	1135	1227	1243	1180	1041	837	582
		Diffuse	569	495	426	368	322	294	284
	KT = 0.55	Reflected	0	44	85	120	148	165	170
		TOTAL	1703	1766	1755	1668	1511	1295	1036
September		Direct	785	958	1066	1102	1062	950	774
		Diffuse	443	386	332	286	251	229	221
	KT = 0.52	Reflected	0	32	61	87	106	119	123
		TOTAL	1228	1375	1460	1475	1420	1298	1118
October		Direct	414	596	737	828	862	838	757
		Diffuse	301	262	226	195	171	156	151
	KT = 0.44	Reflected	0	19	36	51	62	69	72
		TOTAL	715	877	999	1073	1095	1063	979
November		Direct	183	320	435	520	569	580	552
		Diffuse	189	164	142	122	107	98	94
	KT = 0.36	Reflected	0	10	19	26	32	36	37
		TOTAL	372	494	595	668	709	714	683
December		Direct	88	173	246	302	337	350	338
		Diffuse	144	125	108	93	82	74	72
	KT = 0.29	Reflected	0	6	12	16	20	22	23
		TOTAL	232	304	365	411	439	446	433

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
SEATTLE-TACOMA, WASHINGTON

DEC-JAN	256	331	394	440	468	474	458
NOV-MARCH	482	590	674	727	747	732	683
OCT-APRIL	649	760	839	880	882	843	767
ALL YEAR	1118	1193	1222	1201	1129	1013	861

SPOKANE, WASHINGTON
47° 37'

19-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

Month		Horiz.	15°	30°	45°	60°	75°	Vert.
January	Direct	240	440	610	738	817	839	804
	Diffuse	173	151	130	112	98	89	87
KT = 0.44	Reflected	0	11	21	29	36	40	41
	TOTAL	413	601	760	880	950	968	932
February	Direct	465	712	910	1047	1112	1101	1015
	Diffuse	265	230	198	171	150	137	132
KT = 0.51	Reflected	0	19	37	52	63	71	73
	TOTAL	730	961	1145	1269	1325	1308	1220
March	Direct	786	1014	1172	1250	1243	1152	982
	Diffuse	386	336	290	250	219	200	193
KT = 0.55	Reflected	0	30	59	83	102	113	117
	TOTAL	1172	1380	1520	1583	1564	1465	1292
April	Direct	1125	1261	1315	1283	1167	973	717
	Diffuse	523	456	393	338	297	271	262
KT = 0.56	Reflected	0	43	82	117	143	159	165
	TOTAL	1648	1759	1790	1738	1606	1403	1144
May	Direct	1451	1493	1451	1323	1116	844	530
	Diffuse	613	534	460	396	348	317	307
KT = 0.59	Reflected	0	53	103	146	179	199	206
	TOTAL	2065	2080	2014	1866	1642	1360	1043
June	Direct	1565	1550	1459	1288	1045	748	424
	Diffuse	658	573	494	425	373	340	329
KT = 0.59	Reflected	0	58	111	157	193	215	222
	TOTAL	2223	2181	2064	1870	1610	1303	976
July	Direct	1863	1877	1794	1607	1328	976	582
	Diffuse	567	493	425	366	321	293	283
KT = 0.67	Reflected	0	63	121	172	210	235	243
	TOTAL	2430	2434	2340	2145	1860	1504	1109

Reflectivity from ground, roof assumed at 20%

Month		Horiz.	15°	30°	45°	60°	75°	Vert.
August	Direct	1509	1632	1655	1573	1389	1117	778
	Diffuse	508	442	381	328	288	263	254
KT = 0.65	Reflected	0	52	101	143	175	195	202
	TOTAL	2017	2127	2137	2044	1852	1575	1234
September	Direct	1078	1318	1468	1518	1465	1312	1069
	Diffuse	400	348	300	259	227	207	200
KT = 0.62	Reflected	0	38	74	105	128	143	148
	TOTAL	1478	1705	1842	1881	1820	1661	1417
October	Direct	557	804	995	1119	1166	1134	1025
	Diffuse	298	259	224	193	169	154	149
KT = 0.53	Reflected	0	22	43	60	74	83	86
	TOTAL	855	1085	1262	1372	1410	1371	1260
November	Direct	259	453	617	738	809	825	785
	Diffuse	191	166	143	123	108	99	95
KT = 0.44	Reflected	0	12	22	32	39	43	45
	TOTAL	450	631	782	893	957	968	926
December	Direct	139	273	389	478	535	555	537
	Diffuse	145	126	109	94	82	75	72
KT = 0.36	Reflected	0	7	14	20	25	27	28
	TOTAL	284	407	512	592	642	657	638

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
SPOKANE, WASHINGTON

DEC-JAN	348	504	636	736	796	813	785
NOV-MARCH	609	794	941	1040	1084	1069	998
OCT-APRIL	792	973	1108	1187	1205	1161	1057
ALL YEAR	1317	1449	1516	1512	1437	1295	1098

PROSSER, WASHINGTON
46°15'

5-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

			Horiz.	15°	30°	45°	60°	75°	Vert.
January		Direct	263	466	637	766	841	860	820
		Diffuse	187	163	140	121	106	97	94
	KT = 0.45	Reflected	0	12	22	32	39	43	45
		TOTAL	450	640	800	918	986	1000	958
February		Direct	572	858	1085	1239	1307	1287	1179
		Diffuse	268	233	201	173	152	139	134
	KT = 0.56	Reflected	0	22	42	59	73	81	84
		TOTAL	841	1113	1328	1471	1532	1507	1397
March		Direct	896	1141	1309	1387	1371	1261	1066
		Diffuse	387	337	290	250	219	200	193
	KT = 0.58	Reflected	0	33	64	91	111	124	128
		TOTAL	1283	1512	1663	1728	1702	1585	1388
April		Direct	1436	1599	1658	1608	1451	1200	871
		Diffuse	481	419	361	311	273	249	240
	KT = 0.65	Reflected	0	50	96	136	166	185	192
		TOTAL	1917	2067	2115	2054	1890	1634	1303
May		Direct	1691	1731	1674	1516	1268	947	581
		Diffuse	573	499	429	370	325	296	286
	KT = 0.64	Reflected	0	59	113	160	196	219	226
		TOTAL	2264	2288	2216	2047	1789	1462	1093
June		Direct	1994	1967	1842	1615	1298	915	503
		Diffuse	576	501	432	372	326	298	288
	KT = 0.68	Reflected	0	67	128	182	223	248	257
		TOTAL	2570	2535	2402	2168	1847	1461	1048
July		Direct	2134	2141	2035	1811	1483	1075	624
		Diffuse	499	434	374	322	283	258	249
	KT = 0.72	Reflected	0	68	132	186	228	254	263
		TOTAL	2633	2643	2540	2320	1994	1588	1136

Reflectivity from ground, roof assumed at 20%

			Horiz.	15°	30°	45°	60°	75°	Vert.
August		Direct	1706	1835	1850	1746	1531	1219	834
		Diffuse	477	415	357	308	270	246	238
	KT = 0.69	Reflected	0	56	109	154	189	211	218
		TOTAL	2183	2306	2316	2209	1990	1676	1291
September		Direct	1380	1670	1847	1898	1819	1617	1305
		Diffuse	349	304	262	226	198	181	175
	KT = 0.71	Reflected	0	45	86	122	150	167	173
		TOTAL	1729	2019	2195	2246	2167	1965	1652
October		Direct	724	1027	1259	1405	1456	1408	1263
		Diffuse	293	255	220	190	166	152	147
	KT = 0.60	Reflected	0	26	51	72	88	98	102
		TOTAL	1018	1308	1530	1667	1711	1658	1512
November		Direct	324	550	739	878	957	970	918
		Diffuse	207	180	155	134	117	107	104
	KT = 0.48	Reflected	0	14	27	38	46	51	53
		TOTAL	531	744	921	1049	112[illegible]	1128	1074
December		Direct	212	400	561	683	760	784	755
		Diffuse	161	140	121	104	91	83	80
	KT = 0.43	Reflected	0	10	19	26	32	36	37
		TOTAL	372	549	700	814	883	903	873

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
PROSSER, WASHINGTON

DEC-JAN	411	595	750	866	935	952	915
NOV-MARCH	694	909	1079	1192	1240	1220	1133
OCT-APRIL	914	1131	1291	1383	1404	1342	1213
ALL YEAR	1486	1646	1729	1725	1634	1463	1225

ASTORIA, OREGON
46° 9'

18-Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
January		Direct	138	245	335	402	441	451	430
		Diffuse	182	159	137	118	103	94	91
	KT = 0.32	Reflected	0	8	16	23	28	31	32
		TOTAL	321	412	488	542	572	576	553
February		Direct	326	488	617	704	743	731	669
		Diffuse	275	239	206	178	156	142	137
	KT = 0.40	Reflected	0	16	30	42	52	58	60
		TOTAL	601	743	853	924	951	931	867
March		Direct	601	765	877	929	917	844	712
		Diffuse	409	356	307	265	232	212	205
	KT = 0.46	Reflected	0	26	51	71	87	98	101
		TOTAL	1010	1147	1234	1265	1237	1153	1018
April		Direct	858	955	989	959	865	715	518
		Diffuse	554	482	416	358	314	287	277
	KT = 0.48	Reflected	0	37	71	100	122	136	141
		TOTAL	1412	1474	1476	1417	1302	1138	937
May		Direct	1153	1179	1140	1032	863	644	394
		Diffuse	654	569	490	423	371	338	327
	KT = 0.51	Reflected	0	47	90	128	156	175	181
		TOTAL	1807	1795	1721	1583	1390	1156	902
June		Direct	1121	1106	1035	906	728	513	281
		Diffuse	704	613	528	455	399	364	352
	KT = 0.49	Reflected	0	47	91	129	158	176	183
		TOTAL	1825	1766	1654	1491	1285	1053	816
July		Direct	1252	1256	1193	1062	869	629	364
		Diffuse	669	582	502	432	379	346	334
	KT = 0.53	Reflected	0	50	96	136	166	186	192
		TOTAL	1921	1888	1791	1630	1414	1161	891

Reflectivity from ground, roof assumed at 20%

Month	KT		Horiz.	15°	30°	45°	60°	75°	Vert.
August		Direct	1106	1189	1198	1131	991	788	539
		Diffuse	579	504	434	374	328	299	289
	KT = 0.53	Reflected	0	44	84	119	146	163	168
		TOTAL	1685	1737	1717	1624	1465	1250	997
September		Direct	868	1050	1160	1192	1142	1014	818
		Diffuse	445	387	333	287	252	230	222
	KT = 0.54	Reflected	0	34	66	93	114	127	131
		TOTAL	1313	1471	1559	1572	1508	1371	1171
October		Direct	459	650	797	889	920	889	798
		Diffuse	315	274	236	204	179	163	158
	KT = 0.46	Reflected	0	20	39	55	67	75	77
		TOTAL	774	944	1072	1147	1166	1127	1033
November		Direct	211	357	479	569	619	628	594
		Diffuse	202	176	152	131	115	105	101
	KT = 0.37	Reflected	0	11	21	29	36	40	41
		TOTAL	413	544	652	729	77[illegible]	772	736
December		Direct	108	204	286	348	387	399	384
		Diffuse	157	137	118	102	89	81	79
	KT = 0.30	Reflected	0	7	13	19	23	26	27
		TOTAL	265	348	417	468	499	506	489

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
ASTORIA, OREGON

DEC-JAN	293	380	452	505	536	541	521
NOV-MARCH	521	637	727	783	803	785	730
OCT-APRIL	684	801	883	926	927	885	803
ALL YEAR	1115	1191	1221	1200	1130	1016	867

CORVALLIS, OREGON
44°38'

8 -Year Averages
on horizontal surface

BTU/SQ. FT./DAY
Insolation on south-facing surfaces
Reflectivity from ground, roof assumed at 20%

Month		Component	Horiz.	15°	30°	45°	60°	75°	Vert.
January		Direct	174	298	401	477	521	529	501
		Diffuse	198	173	149	128	112	103	99
	KT = 0.34	Reflected	0	10	19	26	32	36	37
		TOTAL	372	480	569	632	666	667	637
February		Direct	242	355	443	501	525	514	467
		Diffuse	285	248	214	184	162	148	143
	KT = 0.33	Reflected	0	14	26	37	46	51	53
		TOTAL	527	617	683	723	733	712	662
March		Direct	460	578	657	691	678	618	517
		Diffuse	414	360	310	268	235	214	207
	KT = 0.39	Reflected	0	23	44	62	76	84	87
		TOTAL	874	961	1011	1020	988	917	811
April		Direct	679	750	772	743	665	544	388
		Diffuse	552	481	414	357	313	285	276
	KT = 0.41	Reflected	0	32	62	87	107	119	123
		TOTAL	1231	1263	1248	1187	1085	948	787
May		Direct	1078	1097	1053	947	784	576	342
		Diffuse	663	577	497	428	376	343	331
	KT = 0.49	Reflected	0	45	87	123	151	168	174
		TOTAL	1740	1718	1637	1498	1310	1087	848
June		Direct	1249	1226	1140	991	788	545	287
		Diffuse	698	608	524	451	396	361	349
	KT = 0.52	Reflected	0	50	97	138	169	188	195
		TOTAL	1947	1884	1761	1580	1352	1094	831
July		Direct	1477	1474	1392	1229	996	710	397
		Diffuse	643	560	482	416	365	333	322
	KT = 0.58	Reflected	0	55	106	150	184	205	212
		TOTAL	2120	2089	1980	1795	1544	1247	930

Reflectivity from ground, roof assumed at 20%

Month		Component	Horiz.	15°	30°	45°	60°	75°	Vert.
August		Direct	1161	1240	1241	1163	1011	794	532
		Diffuse	579	504	435	375	329	300	290
	KT = 0.55	Reflected	0	45	87	123	151	168	174
		TOTAL	1740	1789	1763	1661	1490	1262	995
September		Direct	886	1061	1163	1186	1128	994	792
		Diffuse	456	397	342	295	258	236	228
	KT = 0.54	Reflected	0	35	67	95	116	130	134
		TOTAL	1342	1492	1572	1576	1503	1359	1154
October		Direct	450	626	759	840	864	829	738
		Diffuse	328	285	246	212	186	170	164
	KT = 0.44	Reflected	0	20	39	55	67	75	78
		TOTAL	778	931	1044	1107	1118	1074	980
November		Direct	168	277	367	432	467	471	442
		Diffuse	215	187	161	139	122	111	108
	KT = 0.32	Reflected	0	10	19	27	33	37	38
		TOTAL	383	474	547	598	622	619	588
December		Direct	85	154	213	257	284	291	278
		Diffuse	169	147	127	109	96	88	85
	KT = 0.27	Reflected	0	7	13	18	22	25	25
		TOTAL	254	308	353	384	402	403	388

AVERAGE DAILY TOTAL INSOLATION FOR SPECIFIC PERIODS (BTU/SF/DAY)
CORVALLIS, OREGON

DEC-JAN	313	394	461	508	534	535	513
NOV-MARCH	482	568	632	671	681	663	617
OCT-APRIL	631	719	779	808	802	763	694
ALL YEAR	1113	1171	1184	1149	1070	951	802