USE OF PASSIVE SOLAR ADDITIONS

IN THE

ALASKAN CLIMATE

FINAL REPORT

by

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PREFACE

The original intent of this project was to determine whether or not passive solar additions could be used as a retrofit technique on existing buildings in various parts of Alaska, and if such a retrofit would prove to be an economically viable energy conservation measure. In recent years a general awareness of solar energy potential has led to an increasing number of proposals which would include passive solar additions in new as well as existing buildings here in Alaska in both the private and public sector and for both large and small buildings. Almost always such proposals justified the passive solar addition as a design solution which would be a positive energy conservation feature.

The problem was that the use and performance of passive solar additions had never been rigorously analyzed for Alaskan latitudes and weather conditions. The literature was all but devoid of engineering design criteria which a prospective user could apply to specific problems in the far North. As a result, the claims made for the solar energy gain potential of passive solar additions at high latitudes varied considerably ranging from the point of view that passive solar additions provided a panacea of solutions to our energy problems to the suspicion that advocacy of any scheme to use solar energy was the result of an international conspiracy aimed at undermining the moral fiber of America. Obviously, somewhere between these extremes there existed a range of values relating the energy-conserving potential of passive solar additions to current energy economics in Alaska. It proved convenient to examine this problem as a joint effort with RURAL-CAP since both the Department of Transportation and Public Facilities and RURAL-CAP had a major interest in lowering fossil fuel consumption in rural Alaska and the passive solar addition appeared it might be helpful in this regard.

The actual investigation to define the physical parameters of passive solar addition use in Alaska became rather more protracted than originally intended. There were a variety of reasons for this, but the most significant proved to be the need to examine both the "solar heating unit" and "sunspace-greenhouse" concepts as a result of the climatic extremes

experienced in Alaska. At last however, the results are in, and the conclusion is that neither "sunspace-greenhouse" nor "solar heating unit" applications appear to offer much in the way of economic attraction when evaluated purely as an energy conservation measure. This is not to say however, that applications will not be found where passive solar addition use results in a significant economic payback, nor does it suggest that energy conservation economics are the only factors that should be considered when evaluating the use of passive solar additions. We should further qualify our conclusions by stressing that this report is mainly the result of an analytical study with little measured data going into the analysis process. It may be that hard data will come to light in the future which will change the basic assumption on which this study was based.

The details of passive solar addition use in Alaska are presented in the following pages. This report has been written in a style which should make it quite readable to laymen as well as the design professionals. The reader may draw his or her own conclusions.

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NOTE TO THE READER

In the following text you will continually see references to: Passive Solar Additions (P.S.A.), Sunspaces, Solar Heat Unit (S.H.U.), Greenhouses, etc. Don't be confused. Each term is defined and the definitions have been selected to conform, as nearly as possible, to the terms used by the Alaska Department of Commerce Division of Business Loans in their Alternative Technology Loan Program. Such terms however, are somewhat arbitrary and should be carefully considered. In another publication you may encounter the same term which you see here but which has been refined differently. The discipline of solar engineering and the solar industry are too young to have developed a consistent glossary. So, use caution.

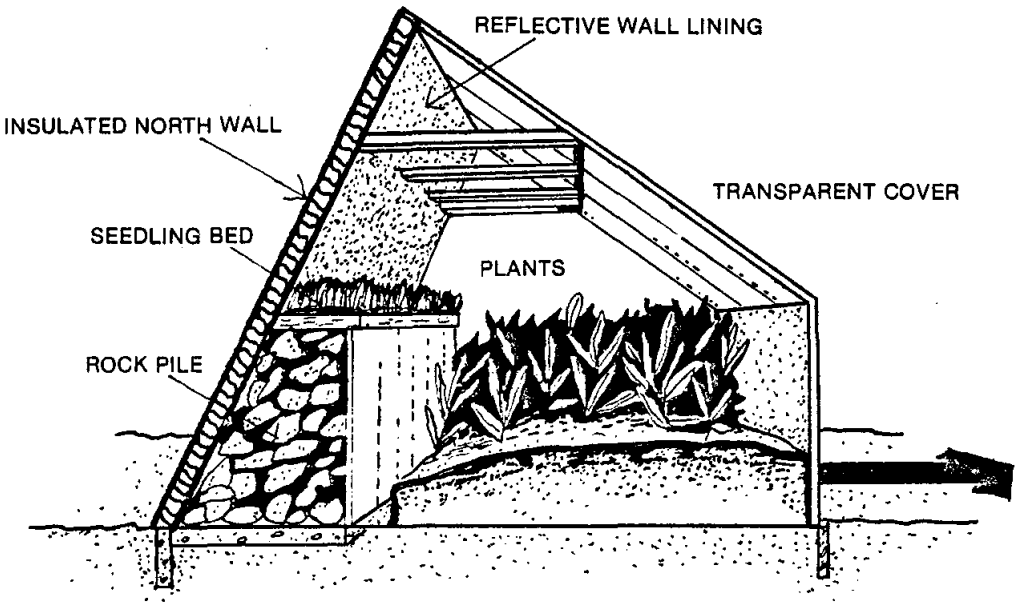
ACKNOWLEDGEMENTS

The authors greatfully acknowledge the preliminary analysis and text preparation of this report by Skip Roy and James Barkshire of Alaska Renewable Energy Associates (AREA). Appreciation is also expressed to John Rezek, P.E. for his in-depth technical editing, and to Bonnie Headley and Leslie Goss of RURALCAP (Rural Alaska Community Action Program) for support of this project.

INTRODUCTION

Passive solar additions are derived from greenhouses which first appeared in the 17th Century in the European Low Countries, where the climate is mild and cloudy, tempered by the Gulf Stream. The classic glasshouse greenhouse design worked well enough for growing plants because the sunlight is diffused by clouds and temperatures are not extreme. The English later brought the design to North America and, though the climate was different, energy costs were low enough to allow profitable four-season use for plant growing. The design stayed basically the same until 1973, when people at Laval University in Quebec City, Canada, began to study greenhouse shapes which might be more efficient in northern climates. See Figure 1.

New designs are called "solar greenhouses", "solariums", or "energy efficient greenhouses". They have gained in popularity recently, particularly because of their energy-conserving features. Passive solar additions--as they



Drawing Provided by AREA

FIGURE 1 - LAVAL GREENHOUSE

will be called in this manual--refer to an addition to an existing building or an integral feature of a new building which is specifically designed to collect solar energy. Collecting the energy inside the structure can create a warm bright "outdoor" environment during the colder parts of the year, can supplement space heating requirements as well as serve as low energy greenhouse which can greatly extend growing seasons in cold climates.

This manual is an attempt to help both Alaskan owners and designers who are interested in incorporating passive solar additions into their buildings. There are already several good books recently published on the subject. This manual will not attempt to duplicate all of the material presented in these; the reader is encouraged to use the bibliography and examine the other references.

The main intent of this manual is to help the reader understand those characteristics of passive solar additions which are peculiar to Alaska and are not covered in other publications. Both the climate and high latitudes found in Alaska will result in passive solar addition design, performance and use which differs from that in the lower 48 states and elsewhere. In addition, this manual presents weather and insolation information for specific Alaskan communities which is not found in other references.

There are two distinct types of passive solar additions which have been used with increasing frequency in recent years. The design, construction, operation, and behavior of these two types are quite different, and anyone interested in passive solar additions should understand these differences. It is regrettable that these differences are not always made clear in the literature.

The primary purpose of one of these types--referred to as a "solar heat unit"--is to supply supplementary heat to the building to which it is attached. The primary purpose of the other type--referred to as a "greenhouse" or "sunspace"--is to provide a conditioned (heated) space in which to grow plants or to provide a comfortable living environment. These two objectives are mutually exclusive to a large degree in the Alaskan environment; you cannot design a passive solar addition that will do both well.

Excess heat generated in a solar heat unit during the day is used almost immediately to heat the building to which it is attached; it is a large-volume hot air solar collector. If a solar heat unit has only a moderate amount of insulation and no backup heat source, it will cool off to a temperature nearly as cold as that outdoors soon after sunset. Because of

this, a solar heat unit is not an ideal environment for plant growth, although the growing season is somewhat longer inside it than outdoors.

Excess heat generated in a greenhouse during the day, however, is stored within the greenhouse (or beneath its floor) and used to keep the greenhouse warm at night. The same is true for a sunspace. This heat storage, coupled with better insulation of the room (including insulated shutters used on the windows during hours of darkness) results in a much better environment for plant growth and a much longer growing season or a more comfortable living space. Heat stored for use in the greenhouse, however, cannot be used to heat the building to which it is attached. The greenhouse, therefore, will not be a major contributor to the building's heating supply, although the heating load will be somewhat smaller than if the greenhouse were not there since the stored heat is needed for the growing environment. For a simple sun space the solar heat mixes continually with the space heat supplied by the conventional heating system.

Either type of passive solar addition can be designed to blend esthetically with the building to which it is attached and increase its value and marketability. Both will provide a warm "outdoor" area that can be enjoyed during sunny days for much of the year.

The major differences between Alaskan passive solar additions and those in most other locations are summarized below. These differences are discussed in greater detail later in the manual.

NIGHT INSULATION, INSULATED SHUTTERS: Shutters are essential if the passive solar addition is to be used as a living space during nighttime periods or if it is to be used as an extended-season greenhouse. Good shutters are troublesome to design and operate, and because of this they are often omitted from passive solar additions in warmer climates.

12-MONTH PLANT GROWTH: It is not practical to build a passive solar addition in Alaska in which frost-susceptible plants are to survive year-round without supplementary heat and light. This can be done in almost any location in the lower 48 states. Most designs and design procedures in other references have this in mind, but it simply does not work in Alaska, and should be kept in mind when reading other books.

VERTICAL WALLS: In lower latitudes, the "optimum" passive solar addition designs incorporate a glazed south wall tilted back in order to be more exposed to the sun. In Alaska, however, the sun is so low in the sky during

the colder months that the "perfect" tilt is almost, if not completely, vertical. This is an advantage, since it means an "optimum" design from a solar standpoint does not require tilted walls, which are hard to build and make weatherproof.

INSULATED ROOFS: Unlike nearly vertical surfaces, which get the most exposure to the winter sun in Alaska, nearly horizontal surfaces, such as most roofs, get very little solar exposure. As a result, it makes no sense to have a transparent passive solar addition roof in Alaska; it is better to build a conventional roof and insulate it to reduce heat losses. This too can be seen as an advantage over the lower 48, where a passive solar addition builder is faced with the difficulty of building a roof that is both transparent and strong enough to hold up under snow loads.

THE BASICS

The Sun and Solar Energy

The sun is about 93 million miles away from the earth, and has a temperature of about 10,000 degrees fahrenheit on the surface. At the edge of our atmosphere the sun's rays are short, high-frequency waves delivering 429 British thermal units* of heat per square foot-hour (429 Btu/sf-hr) of energy. About one third of this energy is reflected back out into space. An additional 10-15 percent is absorbed by the atmosphere; some is scattered by carbon dioxide, dust, and water vapor; and some penetrates to the earth's surface as direct and nearly parallel beams. It is difficult to measure the ratios between energy in the direct, the diffuse, and the reflected components that make up sunlight. Most of the energy, however, is in the direct-beam component--nearly 100 percent on sunny days and at least 50 percent on cloudy days.

The earth's north pole/south pole axis is tilted 23½ degrees from its axis of rotation around the sun. In the Alaskan summer the north pole is tipped towards the sun, and in the winter, away from the sun. We perceive this as the sun rising higher in the sky and earlier in the day during the summer, and as setting sooner and creeping along near the horizon--or below it--in the winter. This can create a severe shadow problem for sunspaces in northern latitudes. See Figure 2.

In this hemisphere, most solar energy comes from the southern sky. The majority of this energy comes between 8 AM and 4 PM, when the sun's rays shine most directly through the atmosphere. See Figure 3. To best take advantage of this energy, a building has to be sited with a long wall facing true south with a given margin of 25 degrees east or west. Studies performed with the FLOAD** computer program for Juneau, Homer, and Fairbanks showed that windows facing 20 degrees from south receive 92 to 95 percent as much solar energy as those facing due south.

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*One Btu raises the temperature of one pound of water one degree Fahrenheit, and is approximately equal to the heat given off by burning a wooden kitchen match.

**FLOAD is a copyrighted interactive program that calculates the heating load of residential or light commercial/industrial buildings. This program allows the incorporation of passive solar systems for heating as well as conventional heating systems.

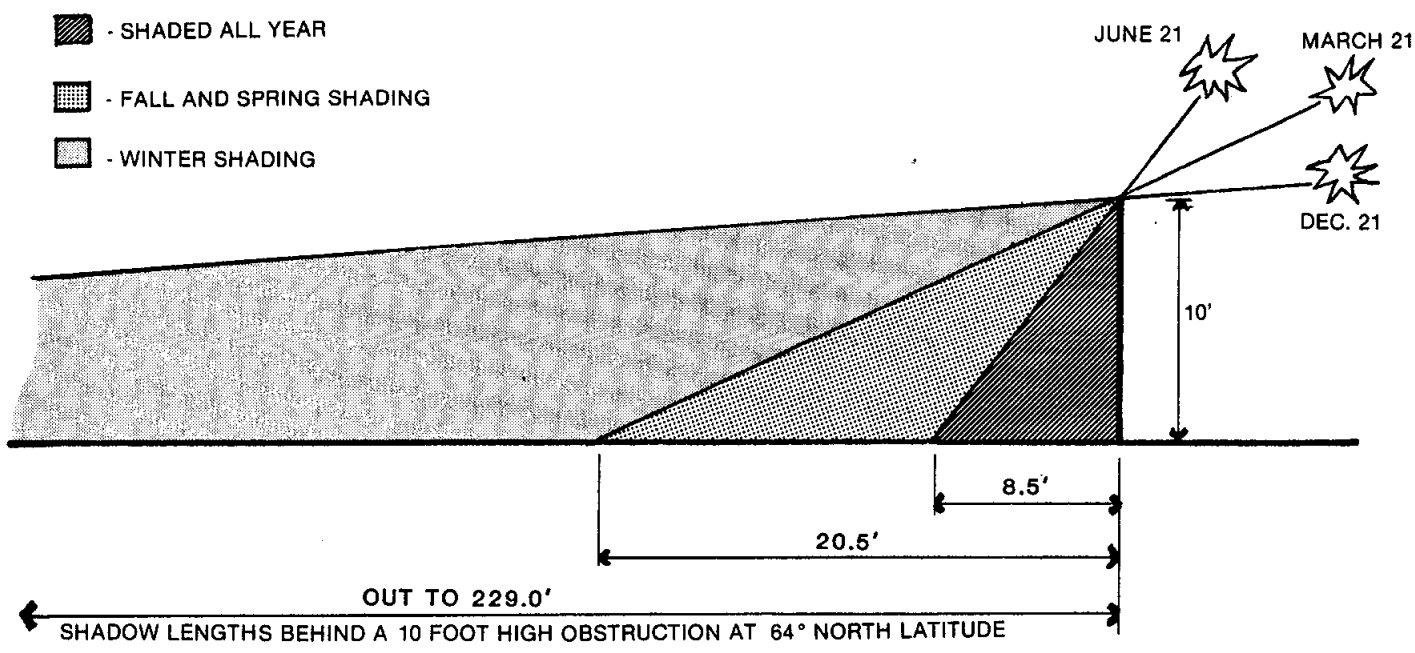
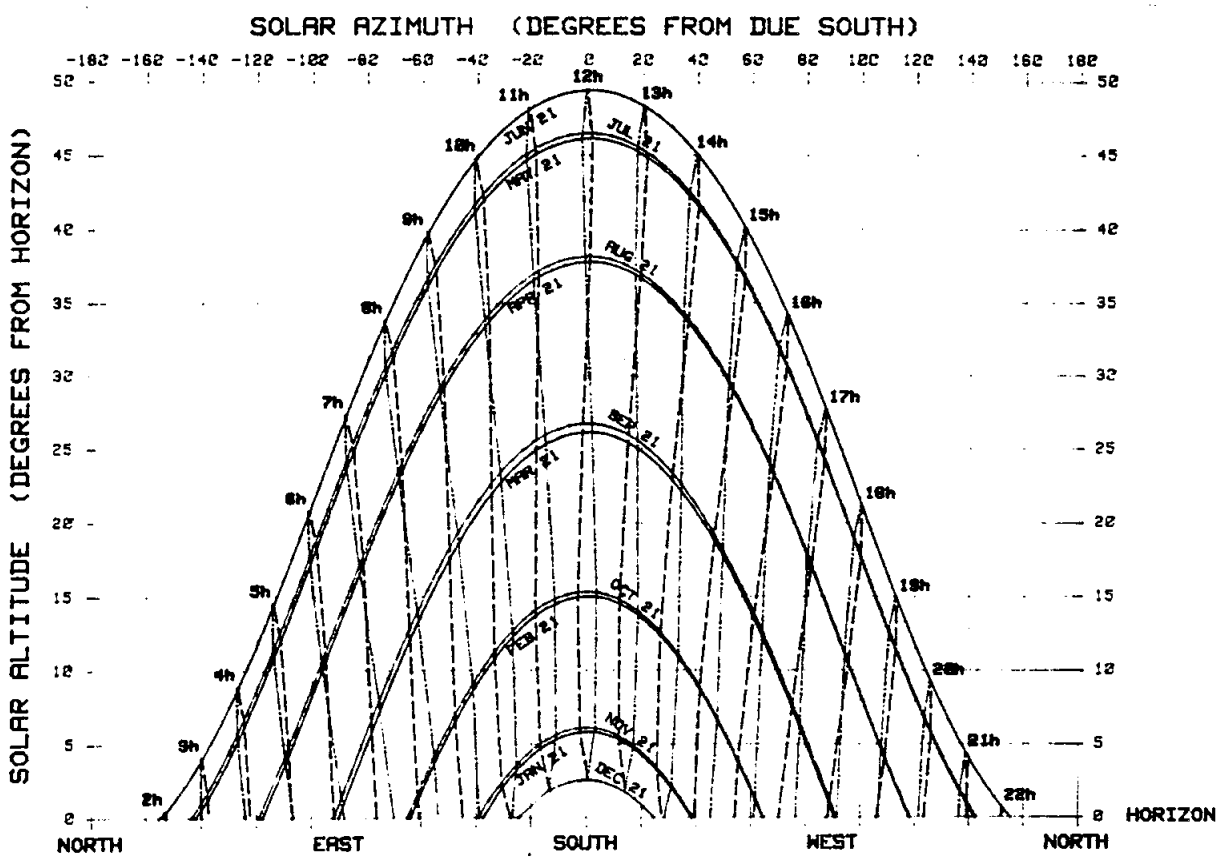


FIGURE 2- FAIRBANKS PROFILE SHADOWS AT NOON

Drawing Provided by AREA



THE ARCS REPRESENT THE SUN'S PATH IN THE SKY FOR EACH MONTH OF THE YEAR

FIGURE 3 - SUN PATH FOR 64° NORTH LATITUDE (FAIRBANKS)

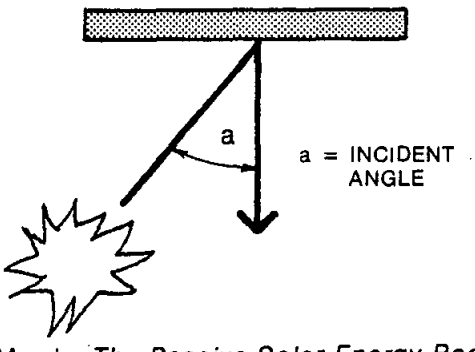
Drawing Provided by AREA

Since the sun's rays are nearly parallel, surfaces perpendicular to them intercept more energy than those at other angles. See Table 1. The intensity varies with the cosine of the angle of the incidence of the rays.

Table 1

Azimith Angle and Percent Solar Intercepts

Incident Angle (degrees)	Solar Intercepted (percent)
0°F	100.0%
5	99.6
10	98.5
15	96.6
20	94.0
25	90.6
30	86.6
35	81.9
40	76.6
45	70.7
50	64.3
55	57.4
60	50.0
65	42.3
70	34.2
75	25.9
80	17.4
85	8.7
90	-



Source: Mazria, *The Passive Solar Energy Book*, p. 14

> Perhaps the best way to imagine this is to think of the parallel rays of the sun as a handful of pencils held with their points touching a tabletop. The dots made by the points represent units of energy. When the pencils are held perpendicular to the tabletop, the dots are as compactly arranged as possible; energy density per square inch is at a maximum. As the pencils are inclined toward the parallel, the dots begin to cover larger and larger areas; energy density per square inch is decreasing. (Master's Thesis of Barbara Francis, University of New Mexico, 1976).

Many ancient cultures were aware of the Earth-sun relationship, as is indicated by their architecture. The cliff dwellings of southwest United States are a prime example. Modern society has neglected the Earth-sun relationships and is now in the process of rediscovery. Today we also have the advantage of using modern construction materials such as glass and other glazing materials.

A double-pane window made of plate glass transmits 77 percent of the light which strikes it at a right angle. This is its transmittance, and this percentage varies with different materials. Fiberglass, reinforced plastic, polyethylene, and acrylic plastic each has its own characteristic transmittance. Most of these materials, when new, have a transmittance value close to that of glass. Transmittance also varies when the sun's rays strike at other than right angles. The more acute the angle, the more the glazing behaves like a mirror, reflecting light instead of letting it through. At angles greater than 50 degrees, transmittance drops sharply. See Figure 4.

Incident Angle, Deg	Transmittance	
	Single Glazing	Double Glazing
0	0.87	0.77
10	0.87	0.77
20	0.87	0.77
30	0.87	0.76
40	0.86	0.75
50	0.84	0.73
60	0.79	0.67
70	0.68	0.53
80	0.42	0.25
90	0.00	0.00

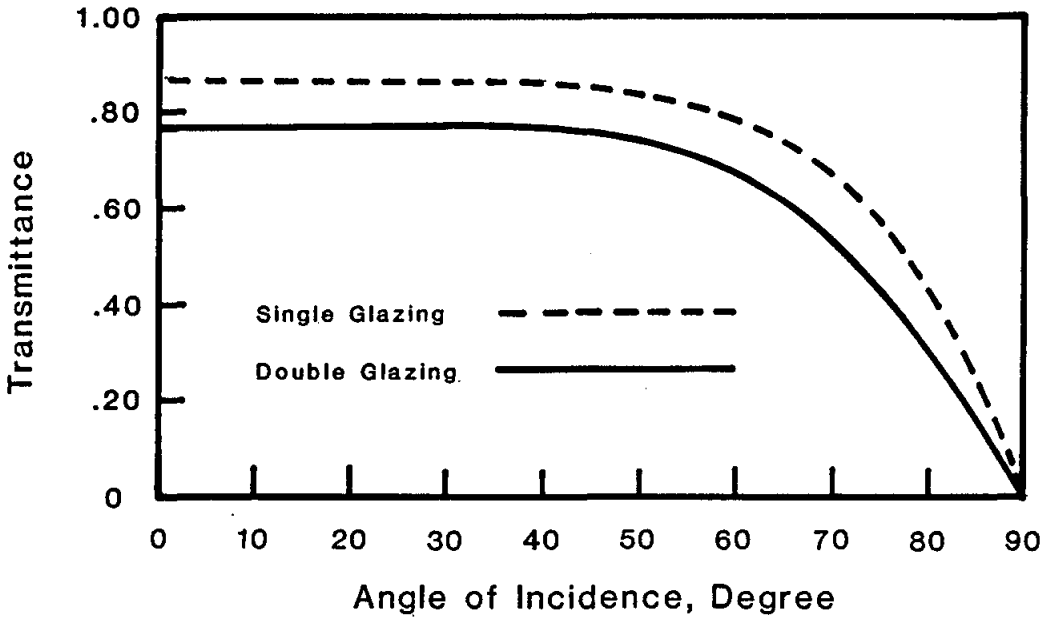


FIGURE 4 – Variation of Incident Angle of Transmittance for Single and Double Glazing

Once the light penetrates the glazing, it strikes an interior surface and is either reflected or absorbed. When is it absorbed, the light's energy heats the surface. Heated objects give off long wavelength infrared radiation that is felt as radiant heat. Infrared waves cannot escape from the glass (i.e., the transmittance of glass is nearly zero for this wavelength radiation). The energy is therefore trapped inside, creating temperatures higher than those outside. This is commonly referred to as the greenhouse effect. See Figure 5.

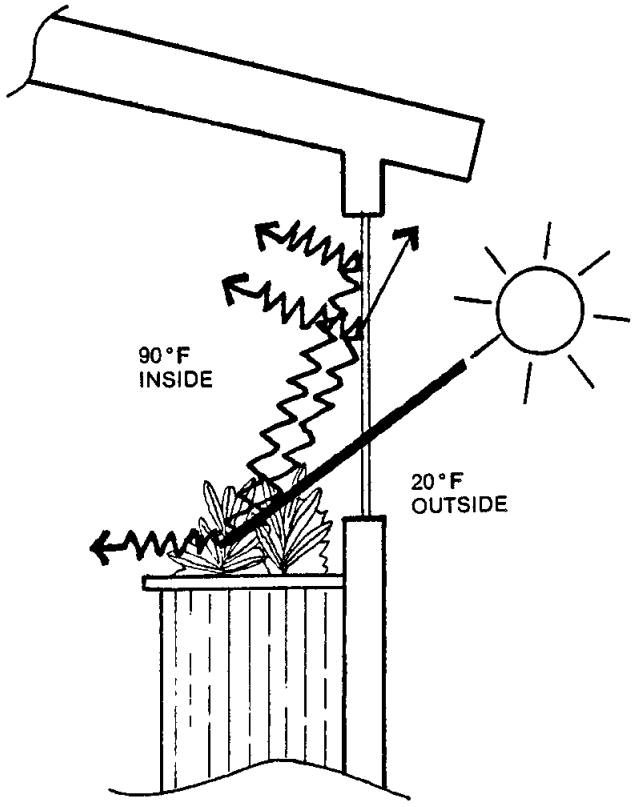


FIGURE 5 - GREENHOUSE EFFECT
Drawing Provided by AREA

The low sun during winter in Alaska is beneficial because it is nearly perpendicular to vertical walls. Winter snow, covering the ground in front of a vertical glazing, is also beneficial, acting as a reflector, which can increase the amount of energy falling on a south-facing window by as much as 60 percent.

In summer, when we do not need the maximum effect from solar energy for heating, the sun is higher in the sky. During this season not only do fewer rays strike the vertical south-facing glass of a passive solar addition, but they strike it at a sharper angle causing a higher percentage of rays to be reflected. This reflective process reduces the amount of solar energy entering the building which helps to keep buildings from overheating.

The rate at which a passive solar addition heats up in direct sunlight depends on what it is built of and what its contents are. Just as it takes longer to boil a large kettle of water than a small one, it takes longer for the temperature to rise in a passive solar addition containing a lot of "thermal mass" (i.e., water, masonry walls, rock beds, etc.) than in merely an insulated wood frame shell. Similarly, a passive solar addition with a lot of thermal mass will cool off more slowly at night than a passive solar addition without thermal mass. Thermal mass is beneficial (within limits) if the passive solar addition is to be used as a greenhouse or a sunspace. It keeps a greenhouse cooler in the day and warmer at night and thus makes the space a more livable environment for plants. If a passive solar addition is to be used as a solar heat unit only, thermal mass is deliberately avoided.

There is a great deal more to be learned on the subject of solar energy than can be presented in this report. Several of the references in the bibliography contain additional material; the reader may find helpful information in a local library as well. A Solar Design Manual For Alaska (listed in the bibliography) is a useful reference, particularly with regard to considerations for high latitude installations.

THE BUILDING SITE

This chapter explains how to look at the property and decide whether it is physically possible to use solar energy. If solar energy is feasible, this chapter explains how to select where to build and how to alter the site to maximize solar access.

Find True South

Use a topographic map or an existing land survey to find true south. If another method is needed, a compass can be used, but magnetic declination must be accounted for. A compass points toward the magnetic pole, not true north or south. The topographic map series (available from the United States Geological Survey, 508 W. 2nd Ave., Anchorage, Alaska 99501, and 101 12th Ave., Fairbanks 99701) shows the magnetic declination on the bottom margin. A simpler method is to locate the North Star on a clear night and drive two stakes in the ground directly in line with it. By going to the north end and siting back, true south can be determined. Lay out south lines from each corner of the south side of where the sunspace will be located.

Locate Objects That Will Shadow The Building

To locate obstructing objects, measure off an arc 45 degrees east from the east corner south line; then measure off an arc 45 degrees west from the west corner south line. See Figure 6.

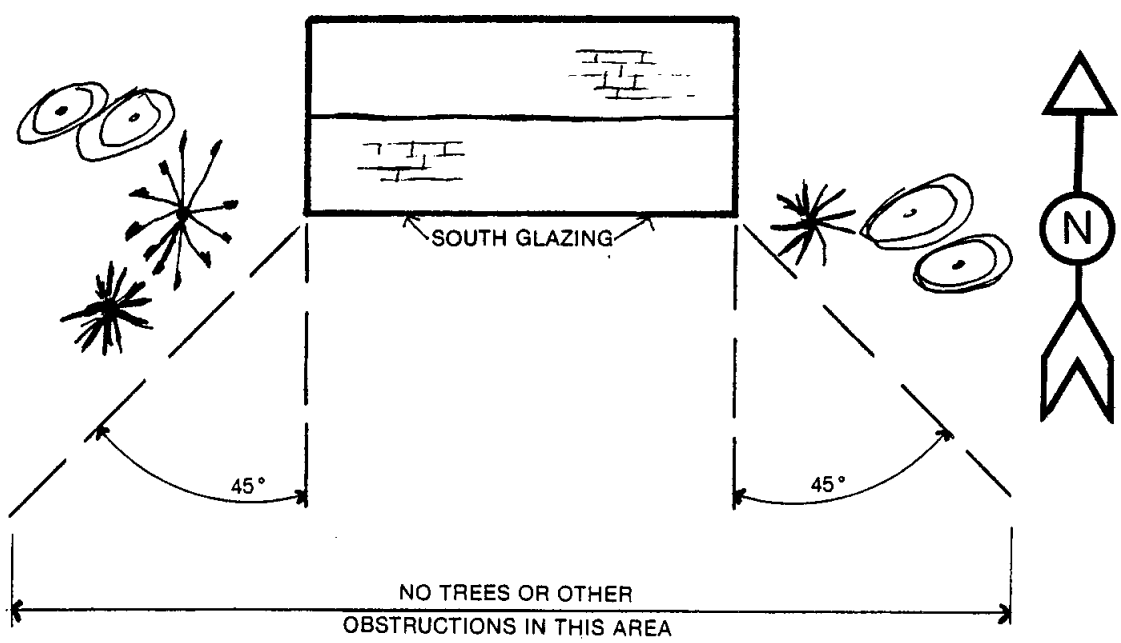


FIGURE 6 – SOLAR ACCESS WINDOW

Drawing Provided by AREA

Next, turn to the Sun Chart in Appendix G to find the latitude closest to the project, and trace off a copy. Then, using a clinometer, transit, builder's level, or the homemade device shown in Figure 7, measure the height (in degrees, not feet) of the objects in the arc staked out. Mark the approximate locations and heights of the objects on your copy of the sun chart. Keep in mind that these objects can be miles away (such as mountains).

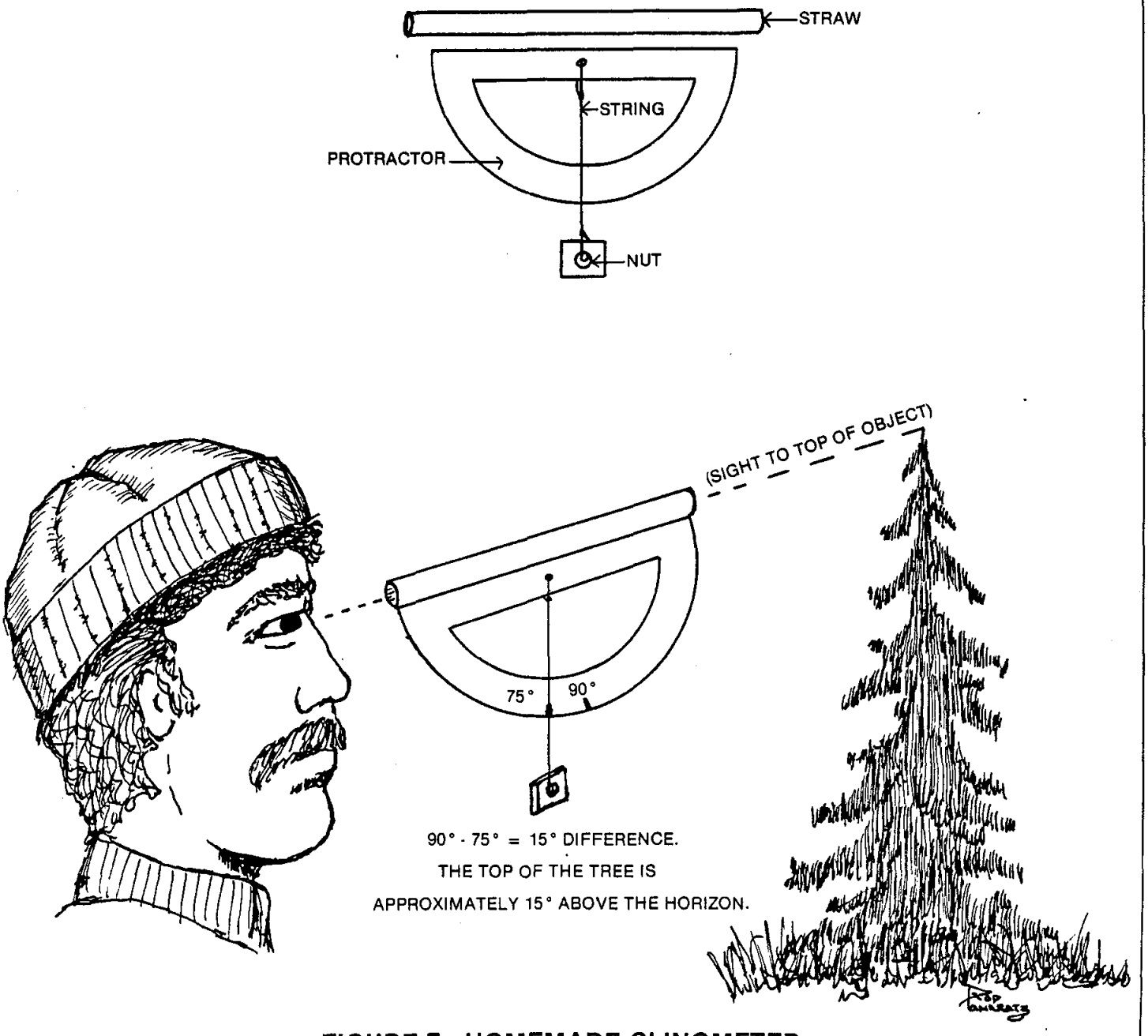


FIGURE 7 - HOMEMADE CLINOMETER

Drawing Provided by AREA

If there are objects that cannot be removed that block more than 25 percent of the arc during November and February, that presents a definite problem; perhaps a passive solar addition should not be attempted. See Figure 8. Birch and alder trees drop their leaves in the winter, but the trunks and branches of a thick grove can block a lot of light. Common sense should allow the observer to judge whether there are too many shadows. If planning a totally new building, an area can be chosen on the property with the fewest obstructions.

Slopes

In Alaska, a north slope of more than a few degrees height can cast shadows that can destroy solar access entirely. See Figure 9. A slope that faces due south is the most ideal location on which to build. A south slope decreases the effect of shadows cast by objects to the south.

Site Analysis and Siting

The microclimate of the area needs to be assessed also. Which way do the prevailing winds come from? Put the entrance door out of the path of the winds if possible. Can the passive solar addition share two walls with the building it is added to? Are there fogs in the morning, clouds in the afternoon--what is the pattern? Will snow or ice fall off the eave above the add-on and cause trouble? Use imagination to cycle a sunspace through a year's weather. Think how long leaves stay on willow trees in the fall, of how snow blows in screened vent holes or gets in the way of outward swinging doors by piling in drifts. Consider how many steps there are to the kitchen, to the garden, and to where the water is, and what the soil temperature is. Also consider any large rocks that might be in the way of the footings, possible glare reflected off the glass into a neighbor's living room, children and glass, setback zoning requirements, the way the passive solar addition will change the view out from the building, and the use of valuable sun space where people work and play. Note the location of existing windows, doors, and vents. Be sure there are not water, sewer, or power lines in the way.

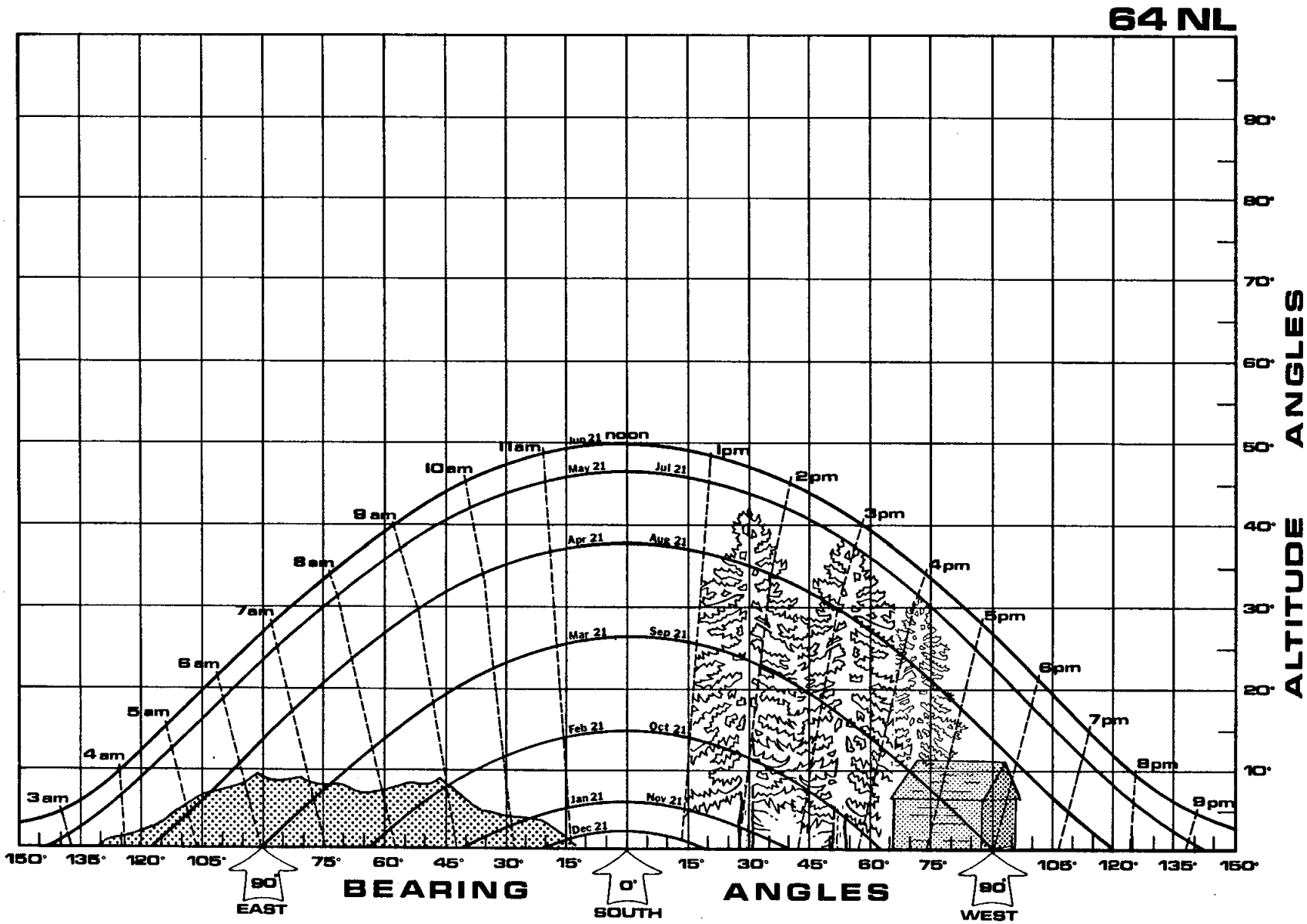
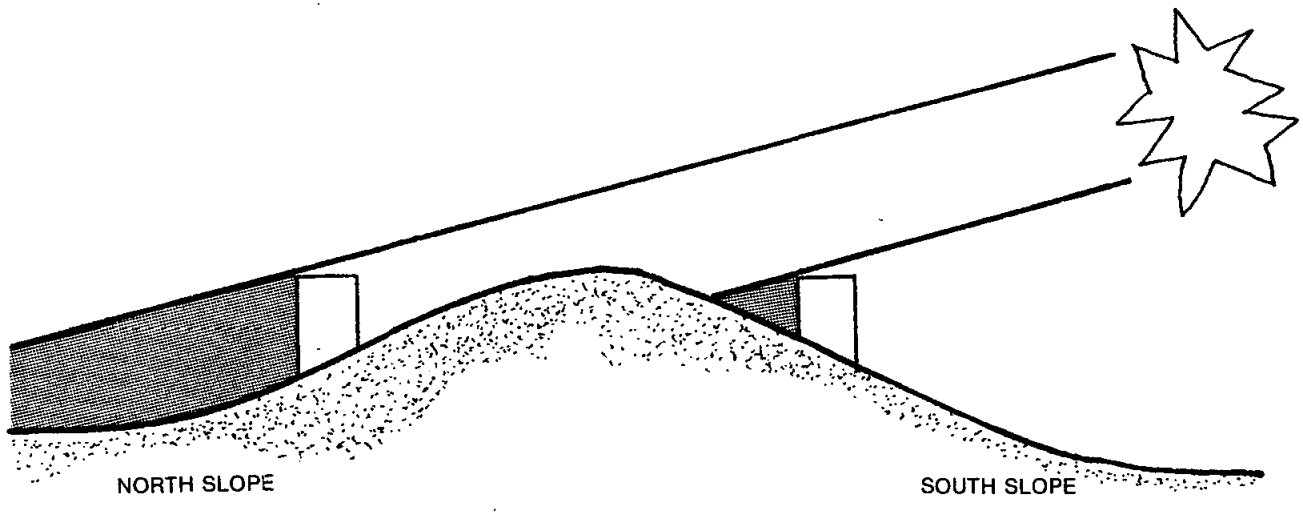


FIGURE 8. SUN PATH CHART AT 64° NL WITH SHADING OBJECTS SUPERIMPOSED

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



BUILDINGS ON A NORTH SLOPE WILL CAST LONGER SHADOWS

FIGURE 9 - SOUTH AND NORTH SLOPE SHADOWS

Drawing Provided by AREA

DESIGN

Plans are included in this manual both for an attached passive solar addition and a freestanding 10' x 20' greenhouse. To adapt these plans to your site or existing building or to design your own passive solar addition, it is necessary to understand the design requirements of these structures. Consult the references in the bibliography for detailed information about design. The following information should be a help to get started.

Physical Aspects

The length of a passive solar addition is limited to the space available on the southern wall of the building to which it is attached. Its width is determined by the use for which it is designed and by sun angles.

The width of planting beds in greenhouses is limited by the reach of a person's arms. Three feet is about as far as can be reached comfortably, so planting beds are limited to that width and often to only 30-32 inches. With a bed along the south wall and another along the north (which may be on top of a row of heat-storing water tanks), and with a comfortable walkway in between, greenhouse widths are usually 8 to 10 feet.

Other things being equal, the performance of a solar heat unit is better the narrower it is built as more heat will be available for use in the attached building. Widths less than 6 to 8 feet, however, can eliminate the usefulness of a solar heat unit as an "outdoor" space.

Use graphics, a protractor, and a scale drawing to determine where direct light will reach in a passive solar addition. In the example shown in Figure 10, it is illustrated that direct light will not hit the thermal storage area in mid summer. If the overhang were shorter or the passive solar addition narrower, the light would reach deeper.

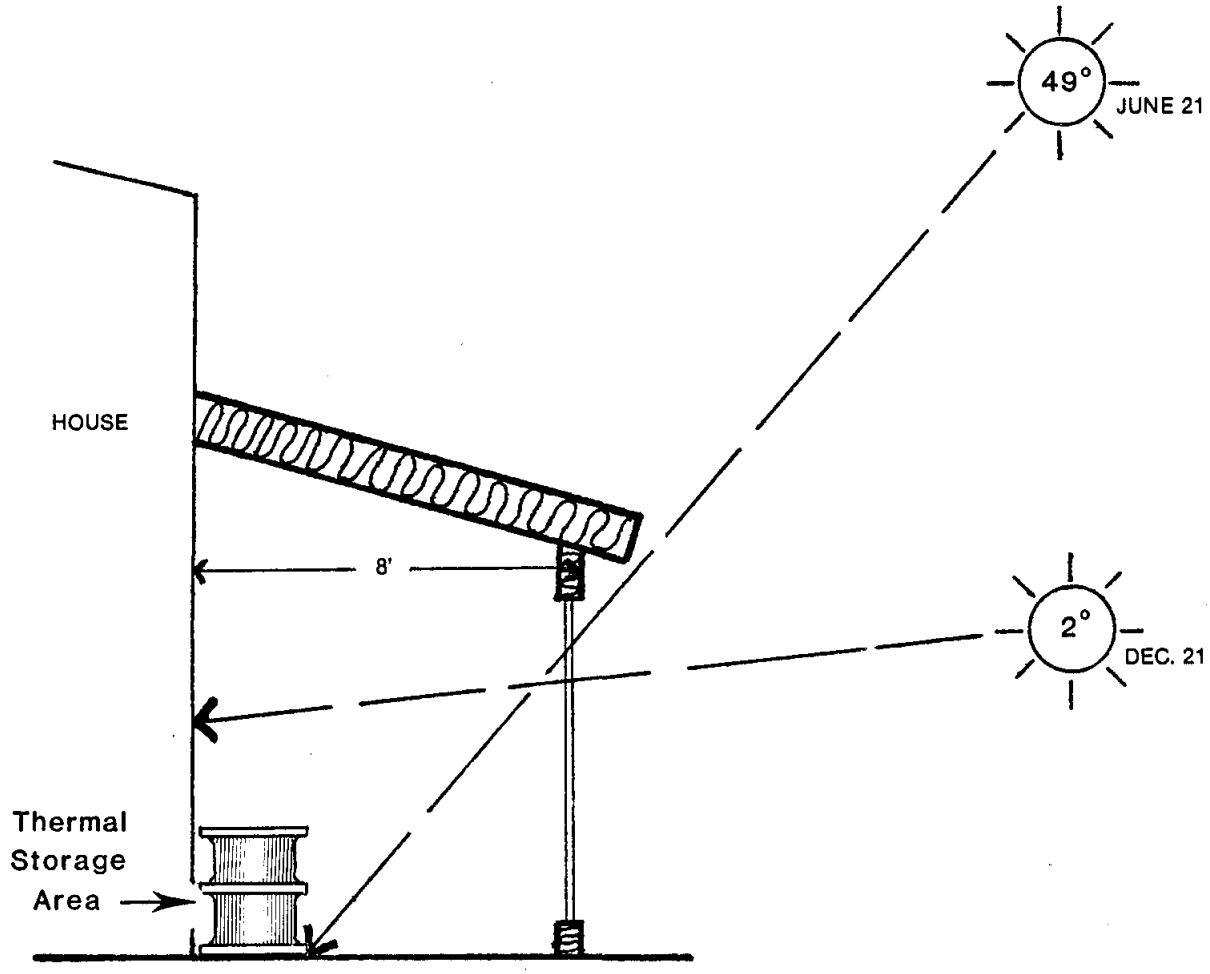


FIGURE 10 - SUN PENETRATRATION INTO GREENHOUSE AT 64½° N. LAT. (FAIRBANKS)
Drawing Provided by AREA

Energy Efficient Framing

Wood conducts heat (and cold) much more readily than insulation. Because of this, in places where framing extends through the entire thickness of a wall, the wall surface can become cold, causing greater heat loss, and likelihood of condensation problems. There are several methods now in use that help control these problems in building construction, and these techniques can be used to advantage in passive solar additions.

One of these techniques is double-wall construction, where two sets of studs are erected, one inside the other. Another technique is to build a traditional insulated stud wall, and then nail horizontal furring strips to the studs, creating a space where additional insulation can be added.

Truss joist I-beams (TJI's) are becoming increasingly popular for rafters and floor joists. These are "I" beams fabricated with a 3/8 inch plywood web and a 1 3/4" x 1 1/2" laminated flange. When using these beams, only the web extends through the entire roof or floor compared to the 1 1/2 inch of a typical solid rafter or floor joist. TJI's are lightweight and strong, but are somewhat more expensive than conventional framing members. Special care must be taken when insulating between TJI's because of their shape.

Interior Design

The interior of a greenhouse needs a planting bench with pots or soil beds, and a source of water and area to store tools, fertilizer, and pots. A compost pile can provide heat, soil, and needed carbon dioxide, which greatly aid growth. If the space is to be used as a solar heat unit only, the interior can be empty or might include furniture for use as an outdoor or sun porch when the weather conditions are right.

Some people plant in the dirt floor of the greenhouse. Others lay in a yard or two of gravel on the floor and build benches on which to plant. Commercial benches are made of aluminum pipe and have rot-proof corrugated asbestos hardboard bottoms. The usual height is 32-34 inches, with width about the same. Other greenhouses mix floor planting beds with raised ones. Planting baskets can be hung from the rafters and mullions. The organization of the furnishings is a very personal matter, depending on the uses the greenhouse will be put to and the owner's tastes. However, even in a greenhouse it is wise to leave room for a chair or two; the warm moist atmosphere can be a nice place for leisure activities. See Figure 11.

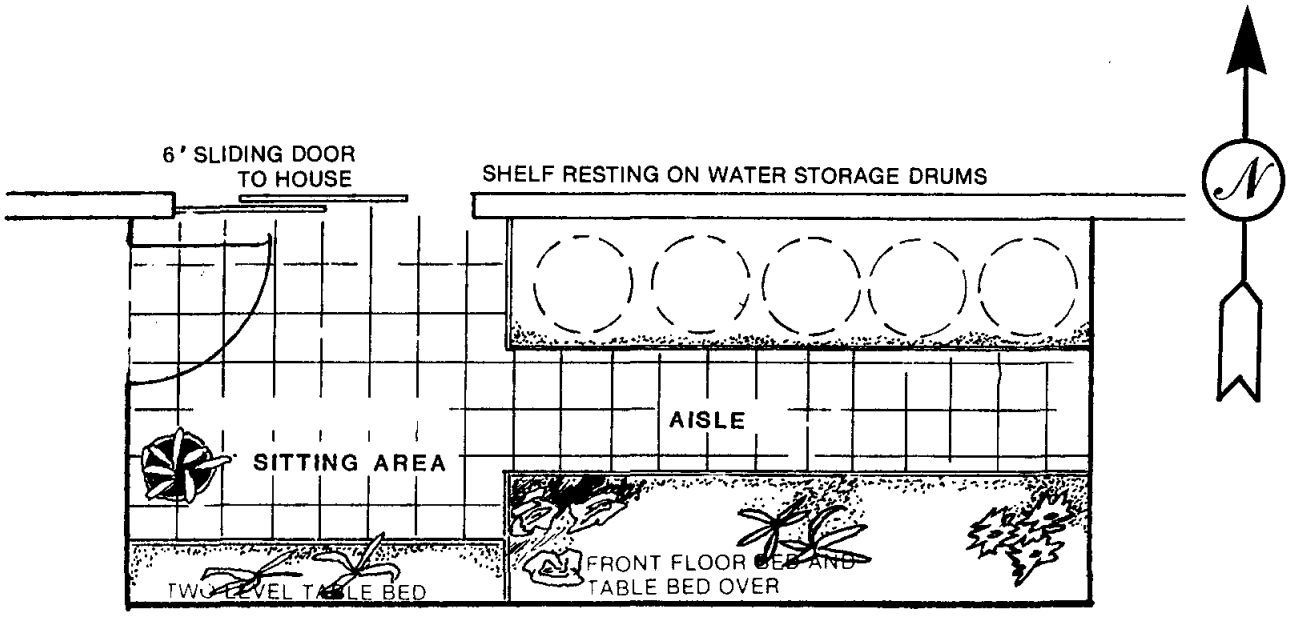


FIGURE 11 · TYPICAL GREENHOUSE FLOOR PLAN

Drawing Provided by AREA

Fighting Rot

Greenhouses are damp environments. Greenhouse wood rots quickly unless treated, and care must be taken not to use preservatives that are toxic to plants such as creosote and pentachloraphenol ("penta"). Copper and zinc napthenate are not as toxic and can be used. Copper napthenate stains wood green, which bleeds through light-colored paints; zinc napthenate is clear and can be painted over.

Glazing Materials

The four most commonly used glazing materials are glass, fiberglass, acrylics, and polycarbonates. Glass is the clearest, most long-lasting, and works best in vertical walls because of its weight. In slanted applications, it is best to use double-strength glass.

Translucent fiberglass reinforced plastics (FRP), such as Kalwall, Lasco-lite, and Filon, let through an even, diffused light, which helps prevent phototropism in plants and promotes plant growth better than glass. These plastics are not as durable and longlasting as glass. As the glass fibers

become exposed on the surface, ultraviolet rays and high temperatures (over 180 degrees) degrade these fibers. There are resurfacing liquids available to combat this problem. FRP materials are slightly more opaque to longwave (heat) transmittance than glass and have about the same transmissivity for visible light.

FRP with Tedlar UV resistant coating is the top of the line, although it has about 8 percent less transmissivity than glass and loses some of its transmissivity with time. FRP costs much less than glass, has good resistance to breaking, and manufacturers claim it will last 12 to 20 years.

Acrylics are available in single-wall (Plexiglass, Lucite, Acrylite) and double-wall (Acrylite SDP, Cor-X-Acrylic, 220 Twinwall, Ployux) versions at costs comparable to glass. Acrylic has insulation and transmission qualities similar to glass, weathers well, and resists impacts but scratches and sags at temperatures over 200 degrees. It is lightweight, has good span strength, is easy to handle, and looks good.

Polycarbonates (Merlon, Lexan, Tuffak, Twinwall) come in all thickness and are as clear as glass. These materials, some used in jet windows, have very high impact resistance and high service temperatures; but are relatively expensive, scratch easily, and get slightly brittle and whitish with time. Often, they are used as the interior glazing.

Tilted Glass

Debate continues as to the advantages gained by tilting the south wall of a sunspace. Comparing the performance of vertical glazing with glazing tilted to 70 degrees shows a difference of 12-16 percent in heat gain in most Alaska locations.

These annual totals are somewhat misleading. While it is true that 70 degree tilt is more often perpendicular to the sun's rays and thus is better at allowing them through the glazing, half the gains are in the summer when the extra heat is not needed. In winter, 70 degree to 90 degree glass have nearly equal performance. The sun's altitude is low enough to make its rays nearly perpendicular to 90 degree glass and the reflectance off snow cover adds more to 90 degree tilts. When the added construction problems--beveling plates, installing glazing and insulating shutters at an off-vertical angle, and getting an air-tight joint between the tilted glazed section and the roof system--are considered, the vertical south wall option seems more reasonable.

However, a reasonable approach would be to say as a rule of thumb that solar heat unit walls should be vertical since at Alaskan latitudes they would let in more sun during cold months when sun angles are low while cutting down on light admitted during summer months when heat is less likely to be needed. On the other hand in a plant-raising greenhouse a tilted south wall admits more direct sunlight during the growing months and allows greater depth penetration into the space making more floor area suitable for growing plants.

Roof Glass

Roof glass is not thermally effective in Alaska and should be avoided, with the possible exception of use in Southeast Alaska for commercial plant-raising structures.

Two or Three Glazing Panes

Annual calculations show that it is always more cost-effective to use double-pane glass <u>with night insulation</u> for solar gain than it is to use triple-pane with night insulation.

Movable Insulation

Movable insulation for windows is not an easily solved problem, but it is absolutely a necessity for greenhouses in Alaska if the intention is to begin plant growth well before the end of the freezing season and/or extend the growing season into the late autumn or early winter with solar energy alone. Solar heat units which are intended only to gather heat, not store it, and which will not be kept heated in cold weather do not have the same problem. In solar heat units movable insulation is optional.

For greenhouse night insulation there are products on the market and there is considerable disagreement over design and with good reason since the difficulties posed by the Alaskan climate are not simple to overcome. Condensation and frosting problems are reduced if the night insulation is located on the outside of the glazing. However, it is difficult to design something with insulating material that is eight feet long and at least two feet wide which is stable in high winds, works well when exposed to ice and snow, is easy to operate, and inexpensive.

Therefore, people tend to install night insulation on the inside of the passive solar additions. Spatial and mechanical problems still exist. If

rigid insulation boards are used, it is awkward to move them about in the crowded interior and there is a storage problem. That leaves roll or fold-up designs which require hardwire (i.e., pulleys, tracks, winding springs) which can rust over the summer, edge seals to prevent heat loss by chimney effect, and considerable attention to detail in construction. Such designs do work, but they are expensive, and to achieve respectable insulative value they have to be at least two inches thick, so there is still a bulk problem.

Do-it-yourself systems are available from the Center for Community Technology, 1121 University Avenue, Madison, WI 53715. They have a Roman shade system made of layers of fabric, fiberfill and polyethylene. Window Quilt is the same sort of sandwich manufactured and equipped with a roller and edge tracks and it is widely distributed. There are other manufacturers, scores of them. Reviews of their effectiveness and a thorough discussion of other situations can be found in Thermal Shutters and Shades: Over 100 Schemes for Reducing Heat Loss Through Windows, by William Shurcliff (Brick House, 238 pp., $12.95) or in Movable Insulation, by Bill Langdon (Rodale Press, $12.95).

Thermal Mass

Water, soil, masonry, or phase-change materials are very useful parts of a solar greenhouse. See Table 2. They absorb excess heat which enters during the day thus keeping the greenhouse from overheating. See Figure 12. At night, these materials slowly release the absorbed heat helping to heat the space during the coldest and darkest times. Each pound of water, or five pounds of masonry, absorbs one Btu for each degree of temperature increase. For example, a dark-colored, 55-gallon drum of water heated to 75 degrees Fahrenheit during the day can contribute 16,035 Btu's to the greenhouse at night if the temperature drops to 40 degrees Fahrenheit. (55 gal. x 8.33 lbs. per gal. x $35^{o}F$ = 16,035 Btu's.) See Table 2.

TABLE 2

Specific Heat and Heat Capacities of Various Substances

	Specific Heat Btu/lb-°F	Density (lb/ft³)	Total Heat Storage Btu/Ft³-°F
Brick	0.20	120	24
Concrete	0.23	150	34.5
Earth	0.21	95	20
Sand	0.20	110	22
Steel	0.12	490	59
Stone	0.21	165	34.6
Water	1.00	62.4	62.4
Wood	0.33	32	10.6
50/50 Antifreeze Water Mix	0.80	66.5	53.2

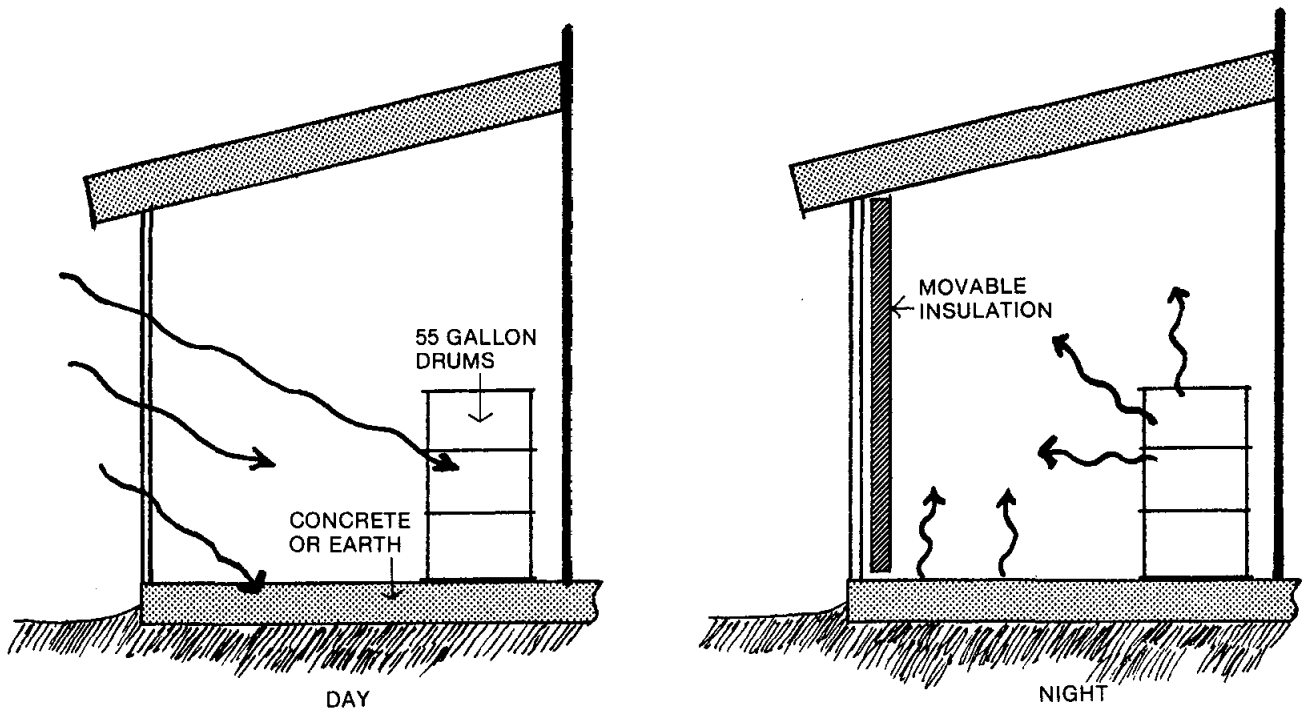


FIGURE 12 - THERMAL MASS AND MOVABLE INSULATION

Drawing Provided by AREA

Another form of storage is phase-change salts that change from solid to liquid at temperatures around 80 degrees Fahrenheit. It takes considerable energy to make materials change phase. The advantage of the phase-change salts is that they take less space (6:1) and weigh less (10:1) than water for equivalent heat storage, and they tend to stabilize the temperature at the point they change from solid to liquid. Two trade names of these salts are Thermalrod-27 and Texxor HeatCell.

It is a good idea to mix sizes and types of thermal storage. Smaller sizes store and release heat quicker; larger sizes will be slower, providing long-term storage. It is possible to overmass the greenhouse. The question of how much thermal mass to include depends mostly on the primary use--greenhouse or solar heat unit. A low-mass structure will tend to heat up rapidly, reaching 80 degrees or more on a sunny day by mid-morning even in mid winter. That heat can be vented into the building. However, when the temperature drops at night, it will also drop rapidly in the solar heat unit.

The heat transfers between a building and passive solar addition are complex and not easily modeled. Edward Mazria, with others at the University of Oregon, used a computer to predict the temperature variations of a space into which the sun shines directly on masonry and water-masses.[1] They examined water walls and masonry walls between greenhouse and house and rock bed storage. The goal was to size the thermal mass to keep temperature fluctuation in the living space comfortable.

The following rule of thumb was developed for the lower 48:

> "When using an interior water wall for heat storage, locate it in the space so that it receives direct sunlight between the hours of 10:00 a.m. and 2:00 p.m. Make the surface of the container exposed to direct sunlight a dark color, of at least 60% solar absorption, and use about one cubic foot (7½ gallons) of water for each one square foot of solar window. (One cubic foot of water weighs 62.4 pounds.)[2]

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[1] Mazria, Baker and Wessling, "Predicting the Performance of Passive Solar Heated Buildings," Proceedings of the Annual Meeting of the American Section of the International Solar Energy Society, Vol. 1, Sec. 2, 1977.

[2] Edward Mazria, The Passive Solar Energy Book, Rodale Press, Emmaus, PA, 1979, p. 185.

"In cold climates (average winter temperatures 20° to 30°F.), use between 0.43 and 1.0 square feet of south-facing double-glazed masonry thermal storage wall for each one square foot for area."[3]

In Alaska, if plant raising is the main consideration for the passive solar addition, go for the top end of the range, or even higher, up to 1.5 square feet. If the main consideration is space heating, then mass should be minimized.

Rock Bed Storage

For fan-forced (active) rock bed storage in a cold climate,

"use roughly 3/4 to 1 1/2 cubic feet of fist-sized rock...for each one square foot of south-facing greenhouse glass. This should be 75% to 100% of the floor's surface area...."[4]

With low temperature differentials, large areas are needed to get effective heat transfer. The rock bed is usually under a floor or in a wall, and air from the greenhouse has to be at least 10 degrees Fahrenheit warmer than the rock for it to work effectively. The air can be moved by a squirrel-cage fan. Rock beds should be 3 1/2 feet to 4 feet (minimum) by 8 feet to 10 feet (maximum) wide. More than 3 cubic feet of rock per square foot of glazing will not improve performance.

The previously mentioned rules of thumb are basically for new construction, not retrofit, and are general guidelines, not exact formulas. They will transfer well to Alaska's coastal and temperate zones during about 10 months of the year, but will have to be used with care in the coldest parts of the interior and in the darkest months of the year. Heat gain/loss calculations should be done for a few normal winter days, for the winter extremes, for spring/fall and for summer norms and extremes. For example, do a couple of clear day inputs followed by three cloudy or partly cloudy days with little input. The idea is to project storage temperatures at the end (start with a reasonable guess) by "walking" temperatures from day to night to day, etc.

Passive solar additions retrofitted to frame buildings do not pass much heat through the frame wall and the frame wall has little storage capacity. However, the relationships between the amount of glazed area and storage size hold true.

[3]Ibid., p. 145.

[4]Ibid., p. 153.

Venting

Overheating is a problem that must be solved by good design. Cross-ventilation, a low vent on the upwind end of the passive solar addition and a larger (by 1/3 to 1/2) high vent on the other end, coupled with attention to the sun angles, takes care of most summer problems. Yanda (see bibliography) recommends that the total vent area should be about one sixth of the floor area. Consider the door at half its actual square footage. Since vents are a potential source of cold air leaks in the winter, they must be carefully built, insulated, and weatherstripped. If the end walls of the passive solar additions are embraced by the building and not exposed to outside air, a good design for heat conservation, then double the amount of venting because there will not be any cross-ventilation.

Excess heat in the spring and fall can be used by the building regardless of whether the primary use is greenhouse or solar heat unit. Basically, what is needed is a low vent from the building into the passive solar addition and a high vent, not directly over the low one, which will transfer warmed air back into the building. Try for the maximum amount of vertical separation possible. Bill Yanda's experience says that to get useful heat (75 degrees) into the house and keep the greenhouse warm enough (70-80 degrees), the optimum ventilation rate is 4-6 cubic feet per minute per square foot of south-facing glazings, or an air change of the total volume of greenhouse air every 2 1/2 minutes. His recommendation is to have 10-15 percent of the wall area covered by the passive solar addition in windows and doors, or 6-8 percent in high and low vents with the high vent larger. The size of the vents is of primary importance, but increasing the vertical distance between them also increases air flows.

When evening comes, the passive solar addition cools and air flow reverses; warm air from the building flows through the top vent, cools, falls in the passive solar addition and comes back into the building via the low vent. This is called reverse thermosiphoning, and it can be used to keep a greenhouse from freezing on cold nights if that is desired. As cold drafts are generally not wanted in the building, polyethylene flaps stapled over the vents on the building side of the high one and passive solar addition side of the low one will solve this. The thin films are easily moved by convecting air and form a barrier to reverse thermosiphoning. If you are planning a solar heat unit, which may get very cold during the winter, install insulating plugs in the vents during the cold weather.

Devices called heat motors can be used to control summer vents. An expanding internal fluid (reacting to a temperature rise) in a piston thrusts an actuating ram from the cylinder opening the vent. As the fluid heats and expands, the ram is extended and the vent door opens, expelling excess heat. As the fluid cools and contracts, the ram is retracted by the load as the temperature drops closing the opening. The heat motors can be set to operate at any temperature between 60 degrees and 100 degrees. (Sources are California Greenhouse Controls Corporation, 3266 N. Rosemead Blvd., El Monte, CA 91731; or John Hoffman, Inc., Sierra Madre, CA 91024.)

Another useful device is the solar fan--a 600 cubic feet per minute, 12-volt DC unit that runs off a small photovoltaic array. One energy conserving combination is a heat motor opening a vent and the solar fan boosting the circulation. During the winter, the fan can aid warm air moving into the house, and it can also be switched to provide a trickle charge into a 12-volt battery. This fan is made by William Lavit Co., and is available from Brother Sun, Route 6, Box 10A, Santa Fe, NM 87501.

Backup Heating

The system used to supply backup heat to a greenhouse must be large enough to maintain acceptable temperatures during the most extreme weather conditions. The "acceptable" indoor temperature might be just warm enough to prevent plants from freezing, approximately 40 degrees Fahrenheit, or it might be 70 degrees Fahrenheit, depending on the owner's wishes. The most extreme weather conditions for a particular location are usually known by the owner (or a local heating contractor). The hourly heat loss for this indoor-outdoor temperature difference can be computed using standard methods, (see Calculation Procedures; Heat Loss) and the backup system should be sized to provide this amount of heat, plus an approximate 50 percent margin of safety.

Often the existing heating system in a building is adequate to handle the load from the attached greenhouse. In this case, the addition of new ducts, or even merely opening doors and windows into the greenhouse from the building can keep the greenhouse warm enough.

A 10 foot by 20 foot attached greenhouse similar to the one shown in Appendix H can lose somewhere around 80 Btu/hr/degree Fahrenheit with the shut-

ters in place. If the temperature was kept at 40 degrees Fahrenheit during -60 degrees Fahrenheit weather (a 100 degree Fahrenheit temperature difference) the heat loss would be 80 x 100 = 8,000 Btu/hr. The heating system installed should be more than adequate to handle this load, perhaps 10,000 or 12,000 Btu/hr.

If the heating system of the original building were to be used, the same greenhouse might add about 60 Btu/hr degrees Fahrenheit to its load. The greenhouse would still require 80 Btu/hr/degree Fahrenheit but part of the original building's wall, previously exposed to cold air, now would face the heated greenhouse, saving perhaps 20 Btu/hr/degree Fahrenheit. In this case, the additonal load on the heating system would be 60 x 100 = 6,000 Btu/hr, plus a margin of safety.

The figures used in these examples are for illustration purposes only; the designer should, in all cases, perform his own calculations for the particular installation and site.

Electric Lighting for Plant Growth

In Alaska there is not enough natural light to support plant growth in the winter. Therefore, it is necesasry to use flourescent lights in greenhouses at a rate of 4 watts per square foot. The starting date in the fall for light use has not been determined and depends greatly on location, but it ranges between October 1 and November 15. Although the electricity must be paid for, it has an extra benefit. The waste heat from the lights furnishes heat to the greenhouse. The recommended number of hours for lighting is 14 per day. If the lights are turned on at night with the glass shuttered, almost all the heat will be beneficial. For example, in a 200 square foot greenhouse, 800 watts of lighting would be needed with an additional 160 watts used by the ballasts. Since each watt of lighting converts to 3.41 Btu per hour of heat energy, the hourly heat generation is 960 watts x 3.41 Btu/watt-hr = 3,274 Btu/hr.

Freestanding Greenhouses

Freestanding solar greenhouses follow the same design principles as attached greenhouses but are usually built on a larger scale than attached greenhouses and often have different roof and wall angles to promote maximum collection and reflection. Generally, the north wall is tilted at the altitude of the sun at summer solstice. Often, the greenhouse is dug in and

bermed with earth. An effective, relatively inexpensive design is Reed E. Mae's A-frame (Environmental Research Institute, Ann Arbor, MI 48107). See Figure 13. Other plans are available from the Brace Institute, c/o McDonald College, McGill University, Quebec, Canada. Please include a self-addressed, stamped envelope.

Permafrost Foundation Design

When building on permafrost, it is necessary to use a different foundation system than the one shown in the accompanying plans. See Appendix E. Permafrost is ground that is frozen year-round. In permafrost regions it is seldom possible to excavate below the frostline to put in a concrete foundation. Heat that might be transferred from the greenhouse through the foundation is detrimental, as it will melt the permafrost and cause the structure to sink.

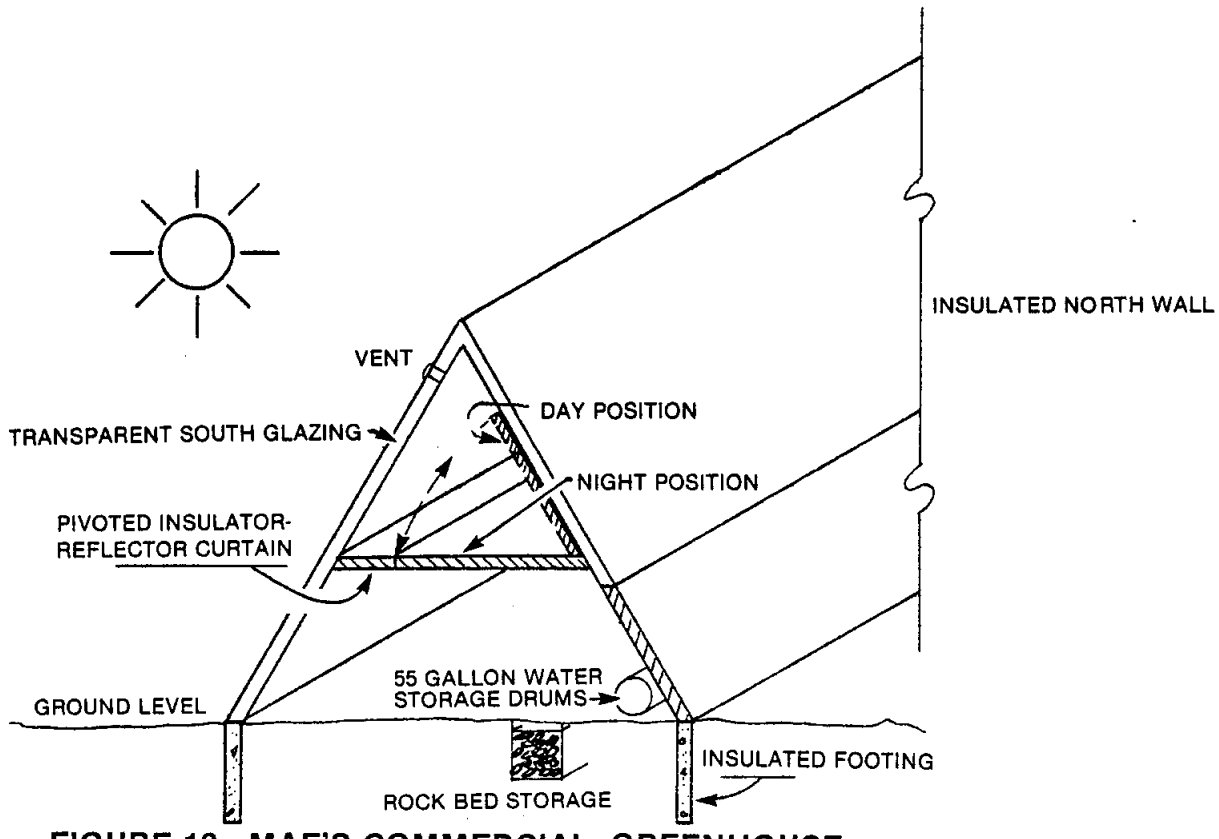


FIGURE 13 · MAE'S COMMERCIAL GREENHOUSE

Drawing Provided by AREA

Figure 14 shows two solutions that have been used successfully in the past in permafrost areas. It is extremely important to go out and observe those systems that are in use in your area. There are no "blanket" solutions to the permafrost problem.

In the first system shown in Figure 14, wood pilings are set at each of the four corners of the building, beams are laid on top of them, and the suspended floor joists rest on the beams. Pilings are set to a minimum depth of 8 feet and often much deeper. Wood I-beam joists (TJI's) are used as the floor joists to minimize conduction losses and are filled with 9 inches of fiberglass insulation. The polyethylene vapor barrier is placed directly on top of the subfloor on the warm side of the floor before a final plywood deck is laid.

In Example 2, the floor framing is essentially the same. Pilings are not used in this method; the support beam rests on lengths of 6 x 12 lumber placed at each end of the beam. In this system it is necessary to remove the permafrost to a depth of 2 feet around the 6 x 12's, replacing it with a sand pad; 4 inches of rigid insulation is placed below the sand pad

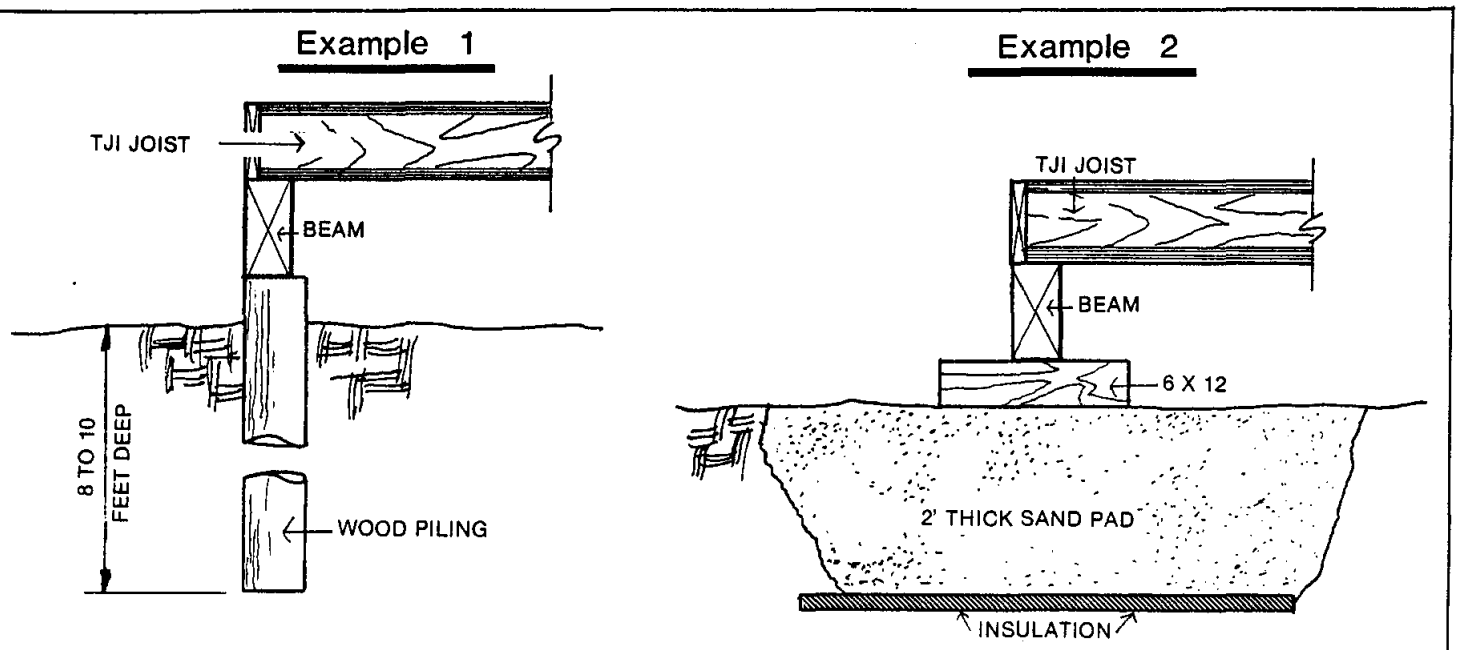


FIGURE 14 - PERMAFROST FOUNDATION DETAILS

Drawing Provided by AREA

Some heat from the structure will transfer to the permafrost when using this method, causing settlement. Because of this, most builders place wood shims between the support beams and the 6 x 12's, and adjust them each year to level the building.

The main support beams carry the entire floor load, and must be sized accordingly. Always consult a structural engineer when designing a suspended floor. The modest amount of money will be more than worthwhile in the peace of mind of having a solid structure.

When designing suspended floors for greenhouses, the weight of thermal storage has to be considered. Refer to the earlier discussion concerning thermal mass for loading requirements. As shown in the calculations below, a greenhouse with 160 square foot of south glazing might use 9984 pounds of water as thermal mass or the equivalent of twenty-two 55-gallon drums.

160 s.f. glazing x 1 c.f. H_2O x 62.4 lb/c.f. = 9984 lbs.

55 gal/drum x 8.33 lb/gal = 458 lb/drum

$$\frac{9984 \text{ lbs.}}{458 \text{ lb/drum}} = 21.8 \text{ or } 22 \text{ drums}$$

Since the drums are about 24 inches in diameter and the greenhouse/house wall is 20 feet long with a door in it, the best arrangement is an eight-barrel row with another stacked on top. That is a live load considerably larger than the usual residential live load specificed in national codes and construction manuals. Here again, it is advised to consult an engineer.

Low Cost Approaches

The construction cost of passive solar additions is comparable to that of conventional residential remodeling. Solar greenhouses will probably be somewhat more expensive if large thermopane windows are used as glazing, rather than fiberglass or plastic glazing, due to their high cost. Heat storage systems, if they are more sophisticated than water drums, can also lead to higher costs. In general, solar heat units are less costly to build than greenhouses because of the absence of heat storage and night insulation systems and the reduced amount of insulation required.

The cost of passive solar additions can be considerably higher than conventional remodeling if the appointments are fancy--teak paneling and

trim, photoelectric or thermal electric controls on fans and shutters, built-in misting systems, time-controlled heating elements and lights for the growing beds, hydroponic or aquaculture tanks, redwood hot tubs, sauna/greenhouse interfaces, etc.

There are other ploys that are not as effective, will not last as long, and may not meet codes, but they are lower in cost. Lay railroad ties or logs as few feet from the south side of the building, construct mullions which attach to the logs and the house, glaze with polyethylene. One man with a fairly large overhanging roof put salvaged conduit on 2-foot centers from the overhang down to railroad ties, wove the polyethylene in and out of the conduit, and stapled the edges down carefully to minimize infiltration. The lash-up froze out as soon as winter got serious, but gathered heat at 85-90 degrees anytime the sun shone, extended the growing season by a month at each end, and, by keeping wind off, lowered heat loss out of the south wall. It took one day to put up, one day to take down, and the polyethylene lasted almost two seasons. To move the warm air into the house, he opened a window and put a fan in it.

A more elaborate version is to build a wall (logs, salvaged block, rock) 3 feet out and 3 feet high on the south side of the building. Insulate the outside surface with closed-cell foamboard and protect that with asbestos hardboard, stucco, or roll roofing. Fill the space with soil to create a raised-bed cold frame. It will gather some heat, which can come in a window covered by the glazing. See Figure 15.

Glazed frames can be built to cover south-facing windows. They will not add significant heat, but they do provide another place to put houseplants.

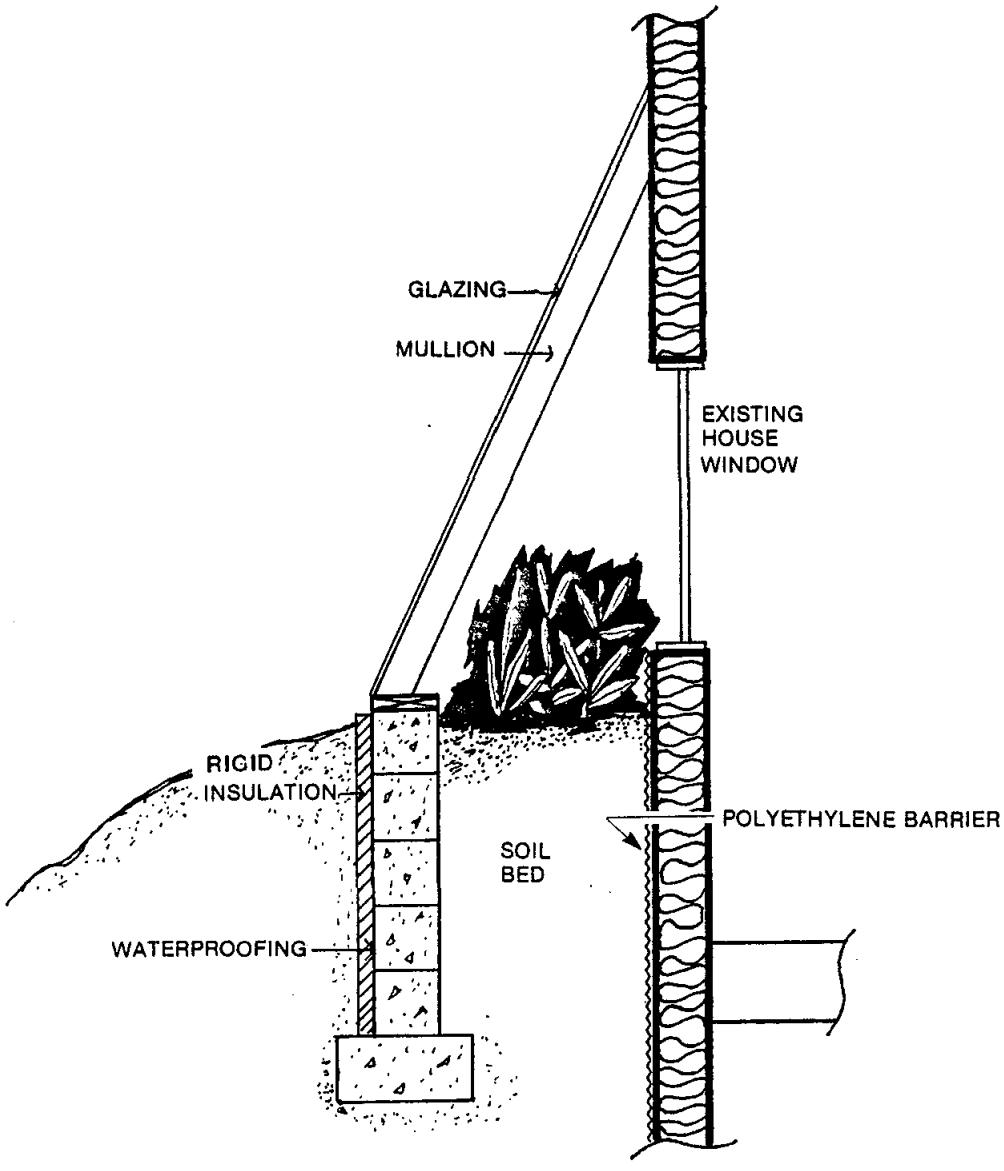


FIGURE 15 - A LOW COST APPROACH

Drawing Provided by AREA

CONSTRUCTION STEPS

The construction procedure described here is for one 8 foot by 20 foot attached greenhouse using a concrete foundation. The same general procedures can be used for free-standing structures or a greenhouse of your design. If building on permafrost, use the drawings in this manual for general reference. It is important to observe what has worked well in your area in the past for foundation systems.

Preliminary Steps

Many areas, particularly municipalities and larger towns, require a building permit which must be posted on-site in a conspicuous place. Zoning regulations also apply in many locations. Research these thoroughly. Minimum setbacks from lot lines are required under all zoning laws, and in many cases, the city has the right to come out and tear down the structure if these setbacks are infringed upon. It pays to be careful.

Construction of a sunspace is, for the most part, essentially the same as any other light building construction, as layout, excavation, foundation installation, framing, roofing, and insulating procedures are identical. Refer to standard books or to experienced people if help is needed in these areas. A brief discussion of glazing and vapor barriers, which are of particular importance in greenhouses, is given below.

Glazing

If using glass, refer to the manufacturer's specifications or carpentry books for details. Be aware that glass can expand and contract as much as 1/16 of an inch with temperature changes; leave room for this or cracked windows will result. When using double glazing it is more important to achieve a tight seal on the inner window; otherwise, moisture from inside will become trapped between the panes and cause condensation and icing.

Fiberglass-reinforced plastic (FRP) is easy to handle--usually available in 4 feet by 50 feet rolls, cuts with a knife or shears, and is lightweight. "Kalwall" is clear and comes in up to 49½ inch widths, making it easy to get a full lap when framing at two feet on center. Filon is less expensive and readily available in Alaska. Because it is only four feet wide, the wall

framing may have to be slightly less than 2 feet center to get a full overlap onto the studs. Refer to the glazing detail on the plans.

When mounting FRP, the minimum overlap should be 3/4 inch. Hold nails 3/4 inch from the edge as the material is brittle and can chip and split. Some people pre-drill holes in the fiberglass before nailing. Begin by setting the first nail at top center, but do not sink it. Having several people will help, as you must work the material towards the corners to get it to lay flat. Tack as you go, slanting the nails to the outside edge to pull the sheet tight. Some people caulk between each layer, as shown in the accompanying plans; others simply run a bead of caulk around the edges of the outer sheet. The first method is a far superior seal; the second is faster, less expensive, and not as messy. The entire job will be easier if the FRP is unrolled, cut to length, and allowed to lie flat for 24 hours before installation.

Vapor Barrier

Although vapor barriers are certainly one of the most important factors in helping the greenhouse to perform efficiently, they are the most misunderstood detail of building in cold climates. Spaces for plants have a high moisture content; fiberglass insulation (and most other types) are highly susceptible to water. Tests show that batts with a 3 percent moisture content suffer a 25 percent reduction in their ability to cut heat loss.

Use a minimum of 6-mil polyethylene as the vapor barrier; 10-mil is much better, but difficult to find in Alaska. Tape or caulk all joints, such as where the walls meet the roof. Caulk the vapor barrier onto the wood frame around all doors and windows, and at all other "holes" in the wall (electrical, plumbing, etc.). The idea is to make a complete envelope separating the inside from the outside.

THERMAL PERFORMANCE OF PASSIVE SOLAR ADDITIONS IN ALASKA

The thermal performance of greenhouses in Alaska (the amount of energy required to heat them) is excellent when compared with virtually any other kind of habitable space. Neither greenhouses nor solar heat units, however, perform well as solar-driven heating systems for the buildings to which they are attached. The reason for this is simple--the climate in Alaska is too cold and the winter days are too short. Even in southern areas of Alaska, where the winter days are longer, cloud cover tends to reduce the potential for solar heating.

The two generic types of passive solar additions examined in this report are greenhouses ("mass passive solar additions" for plant growing) and solar heat units ("massless passive solar additions"). The first type, mass, contains heat storage to moderate temperature swings and are kept at room temperature all year. The thermal performance of this type is similar to that of any building space heated by direct-gain glazing areas (sunspace).

The second type, massless passive solar additions, contains a minimum of heat storage to encourage large temperature variations. During sunny periods hot air is "robbed" from the solar heat unit and blown into the adjacent building; during cold and dark periods the solar heat unit cools and temperatures drop to near ambient. The thermal performance of this type of sunspace is analogous to that of a hot air solar collector.

Intermediate types of passive solar additions, both in construction and in operation, are possible between these two extremes. The thermal performance of both mass and massless type passive solar additions is discussed in greater detail in the following pages and is followed by a discussion of the performance of intermediate types.

Greenhouse Performance

Nearly all greenhouses built in Alaska will have a net annual heat loss if kept at room temperature all year; that is, it will be necessary to add more supplementary heat to them in cold, dark periods than is gained from them in sunny, warmer periods. It is possible under exceptional conditions, however, to build greenhouses which will have a net annual heat gain in any of the Alaskan cities for which weather data is available. These exceptional

conditions must include a completely unobstructed south-facing site, "superinsulation" of the greenhouse walls, roof, and floor, very tight construction, attachment of the greenhouse to a building with a large heating load (so that little of the excess heat generated by the greenhouse has to be vented outdoors), and well-insulated window shutters optimumally year-round. In some cold northern cities, "proper" shutter operation requires them to be closed entirely for up to three months.

Conditions are rarely this good, however. A less-than-perfect site is often chosen that has partial shading of the greenhouse because of obstructions and does not face due south. Slight settlement after construction, which is normal for any building, can enlarge cracks and therefore increase the infiltration of cold air to an initially very tight greenhouse. The condensation of moisture in the walls can somewhat degrade the effectiveness of the insulation. This problem is particularly difficult to control in greenhouses because of their moist environment. The shutters can warp, insulating the windows less effectively than planned; and the owners can forget to open and close the shutters at the proper times each day.

Even under less than perfect conditions, however, a solar greenhouse will have much lower heating loads in the long run than a conventional room of the same size. Yet a greenhouse's heat losses on the coldest, darkest days (the design heating conditions) are likely to be larger than those of a conventional room.

The most critical factors in greenhouse performance found in preparing this report are tight construction and good shutters. This is because the largest heat losses, even in a moderately insulated greenhouse, are from air infiltration and conduction through window areas. For a superinsulated greenhouse, these two losses are by far the greatest.

Heat storage--whether in the form of drums of water, rock beds, or whatever--also is important to good greenhouse performance. If the storage is insufficient, overheating results, and much of the solar heat gained will need to be vented outdoors. Two likely storage design errors are 1) placing of water storage containers in shaded areas, and 2) providing insufficient fan size for rock bed storage systems. Either error will result in poor performance from the storage system. Calculations indicate that fans should be sized to provide at least 5 cubic feet per minute air flow per square foot of greenhouse glazing.

An important point sometimes overlooked is that any south-facing windows on an existing building already yield direct solar gain benefits to the building. Additional solar gain, as a result, comes only from that amount of glazing in an attached greenhouse that is greater than that which was already on the south wall of the building.

The results of mathematically modeling greenhouses using a computer for various Alaskan locations are presented at the end of this section.

Solar Heat Unit Performance

Unlike a greenhouse kept at room temperature, a solar heat unit (massless greenhouse) always yields a net benefit to a building's heat load. This is obvious since no supplemental heat is ever used in the solar heat unit. The gains derived from a solar heat unit, however, will never be great enough in Alaska to make such an installation economically worthwhile for energy reasons alone.

Since the solar heat unit is allowed, and expected, to get cold at night, shutters and infiltration rates are of much less importance than with the classic solar greenhouse design. Shutters, in fact, are probably unwarranted on a sunspace used solely as a solar heat unit, just as they would be on a flat plate solar collector.

Another difference from the solar heat unit design and a classic solar greenhouse design is that heat storage mass is undesirable in a solar heat unit. The intention of a solar heat unit is to have temperatures rise as quickly as possible when the sun comes up, so that hot air can be blown into the adjacent building. Any storage mass will detract from this and from overall solar heat unit performance. There will be some unavoidable mass in the framing and floor of a solar heat unit; however, this should be kept to a minimum. For example, a wooden, insulated floor is better than a dirt floor.

The color of the back wall and floor of a solar heat unit is more important than it is in the solar greenhouse. A beam of light entering a solar greenhouse will almost surely be absorbed there, even if it is reflected off the first surface it hits, since only one of its six sides (the south wall) is transparent. The solar heat unit, however, can have four transparent sides--three walls and the roof--and, moreover, has few if any contents, so if light is relfected off the wall or floor it may well pass back out of the solar heat unit, and its energy will be lost. For this reason, the back wall and floor of a solar heat unit should be a dark color.

A flat black is the best for energy purposes, and will absorb more than 90 percent of the incident sunlight. Other dark colors will perform adequately (see Appendix F) and may be chosen for esthetic reasons.

Ventilation between a solar heat unit and the adjacent building is an important factor in effective solar heat unit performance. Since there is a minimum of thermal storage in a solar heat unit, very high temperatures can occur on sunny days. At high temperatures, the large glazed surfaces of a solar heat unit will lose large amounts of heat, thereby wasting energy. To prevent this, solar heat unit air should be moved into the adjacent building at temperatures not much above room temperature. Calculations indicate that as much as 60 cubic feet per minute of air flow is necessary for each lineal foot of solar heat unit attached to a building in order to keep the temperature difference between the solar heat unit and the building at less than 15 degrees Fahrenheit. If the solar heat unit is more than 10 to 12 feet long, merely opening a door and a window between the building and the solar heat unit may not be enough. For best performance forced ventilation is necessary. A large fan operated automatically by a differential thermostat, plus a return air opening, is usually very effective.

Good ventilation is also a safety requirement. A tightly sealed massless passive solar addition can reach extremely high stagnation temperatures on warm, sunny days (more than 200 degrees Fahrenheit). Many standard building materials deteriorate at such temperatures, and can even become fire hazards.

The amount of useful heat that can be gained from a solar heat unit greatly depends on the heating characteristics of the adjacent building. Since there is no heat storage, any hot air generated in the solar heat unit must be used immediately or it is wasted. Even in March, the solar heat unit can produce more heat than can be used on sunny days if the adjacent building's heating needs are small. Conversely, a building with a large heating load might be able to use all the solar heat unit's heat for nearly the entire year. The net energy benefit of a solar heat unit, therefore, will be proportionately much greater if it is attached to a warehouse, gymnasium, or a poorly insulated building than if it is attached to a small, super-insulated building.

The thermal behavior of passive solar additions is complex, and predicting their performance is difficult. Nevertheless, by using various assumptions about heat losses and gains, a general idea can be gained of how passive solar additions work under various conditions. Both solar heat units

and classic solar greenhouses are modeled for this report at several Alaska locations, with varying levels of insulation and construction quality. The results of these studies are presented as follows.

The major uncertainty in modeling solar gains is due to the variability of the weather. Weather conditions rarely seem to be "average", so even a perfect analysis of passive solar addition behavior using "average" weather data does not reflect real behavior most of the time. Improved weather data, particularly for solar insolation levels, would be helpful. There is also some uncertainty in the figures used for the transmissivity of glazing surfaces and the absorbtivity of surfaces within a passive solar addition, but these are relatively minor compared with weather data uncertainties.

Uncertainties are also found in modeling heat losses. Air infiltration, for example, is the largest single factor in heat losses from the passive solar additions analyzed, yet infiltration rates are notoriously hard to predict. The second largest factor in passive solar addition heat loss is conduction through the glazed surfaces. While reasonably accurate heat loss projections can be made by assuming the number of hours insulated shutters will be in place, the actual use of shutters can be quite different. A passive solar addition owner might leave shutters off well into the evening in order to enjoy the view, for example, or forget to take them off in the morning.

Greenhouse Analysis Results

It appears possible to build a classic solar greenhouse that will yield a net annual heat gain in any of the Alaskan cities for which data were available. In a few areas--Annette, Homer, Matanuska, and Kodiak--it even seems possible that a net gain can be achieved during all 12 months of an average year. This "best" case assumes a perfect site, exceptional greenhouse construction (superinsulation) and operation, and an attached building with heating loads large enough to avoid wasting significant amounts of solar heat during the warm months. Even under these ideal conditions, it appears that a classic solar greenhouse will have a net loss for a period of 2 to 4 months per year in most Alaskan locations. See Table 3.

Few Alaskan locations show a net annual heat gain from a classic solar greenhouse when more typical conditions prevail. The FLOAD computer program showed net losses in all locations except Homer, Matanuska, and Kodiak under assumptions of good greenhouse construction (R-19 insulation in walls and

R-30 in the ceiling), good operation, and an attached building with moderate heating loads, even though the site was still assumed to be excellent. Net heat losses were found for periods of 2 to 8 months out of a year, with 4 to 6 months typical.

The results of the analysis of the "good" and "best" greenhouses are shown in Table 3. The net heat loss for a conventional room in the same location and built in the same general manner as the "good" greenhouse are also shown. The heat savings of the "good" greenhouse compared to the conventional room addition are also translated into dollar amounts using oil costs of $1.25 per gallon. This can be done for other fuels and prices using the differences in heating needs shown in Table 3 and the space heating costs given in Table 4.

The analysis summarized in Table 3 was made for a 10 ft. by 20 ft. greenhouse, similar to the one shown in the plans in Appendix E. It was assumed that the greenhouse was attached to a building with insulated 2 x 6 inch wood frame walls, and covered one door and one medium sized window in the existing building.

TABLE 3

10' x 20' Attached Greenhouse Performance Analysis Results

Location	"Best" Greenhouse		"Good" Greenhouse			
	10^6Btu Net Annual Heat Gain (Loss)	Months with Net Heat Loss	10^6Btu Net Annual Heat Gain (Loss)	Months with Net Heat Loss	Conventional Room 10^6Btu Net Annual Heat Gain (Loss)	Annual Savings "Good" vs. Conventional with oil heat @ $1.25/gal
Annette	7.5	0	(0.2)	3	(7.6)	$100
Barrow	N/A	N/A	(14.4)	8	N/A	N/A
Bethel	7.4	2	(4.3)	4	(15.7)	$154
Bettles	5.3	4	(9.6)	6	(19.2)	$130
Big Delta	6.2	2	(6.2)	4	(16.0)	$132
Fairbanks	4.6	3	(8.3)	5	(17.1)	$119
Gulkana	10.0	3	(5.6)	4	(16.3)	$144
Homer	13.8	0	0	4	(11.7)	$158
Juneau	7.6	2	(2.3)	5	(10.4)	$109
King Salmon	11.5	1	(1.0)	4	(13.3)	$166
Kodiak	11.0	0	0.9	2	(9.7)	$143
Kotzebue	4.5	4	(8.4)	6	(19.9)	$155
Matanuska	13.6	0	0.1	3	(11.9)	$162
McGrath	5.2	3	(7.7)	6	(17.4)	$131
Nome	4.6	4	(5.8)	5	(17.6)	$159
Summit	4.8	4	(4.7)	4	(17.1)	$167
Yakutat	N/A	N/A	(2.0)	4	N/A	N/A

Assumptions

"Best": Site, insulation, infiltration amount, operation--excellent;
Attached building heating requirements--large;
Window area--104 ft^2.

"Good": Site--excellent;
Insulation, infiltration amount, operation--good;
Attached building heating requirements--moderate;
Window area--104 ft^2.

Conventional Room: site, size, insulation, infiltration amount--same as "good";
Window area--16 ft^2.

TABLE 4

SPACE HEAT ENERGY COSTS ($/MMBtu)

To Get the Approximate Price in Dollars Per Million Btu:

Multiply oil price ($/gal) by 10.8[1]

Multiply electricity price (¢/kwh) by 2.93[2]

Multiply natural gas price ($/therm) by 13.3[3]

Multiply natural gas price ($/$10^3$ft^3) by 1.29[4]

Multiply LPG price ($/lb) by 62.0[5]

Multiply LPG price ($/gal) by 13.6[6]

Multiply sub-bituminous price ($/ton) by 0.118[7] (Healy) coal in airtight stove

Multiply wood (dry birch) price ($/cord) by 0.091[8] (airtight stove)

Multiply wood (dry spruce) price ($/cord) by 0.111[9] (airtight stove)

1. Assumes 138,000 Btu/gal and conversion efficiency of 67%.
2. Assumes 3413 Btu/kwh and conversion efficiency of 100%.
3. Assumes 100,000 Btu/therm and conversion efficiency of 75%.
4. Assumes 1030 Btu/ft^3 and conversion efficiency of 75%.
5. Assumes 21,500 Btu/lb and conversion efficiency of 75%.
6. Assumes 98,000 Btu/gal and conversion efficiency of 75%.
7. Assumes 17 x 10^6 Btu/ton and conversion efficiency of 50%.
8. Assumes 22 x 10^6 Btu/cord and conversion efficiency of 50%.
9. Assumes 18 x 10^6 Btu/cord and conversion efficiency of 50%.

Solar Heat Unit Analysis Results

Solar heat unit performance could not be modeled on the FLOAD computer program; the analysis was performed by hand in the manner described in the calculations chapter. The results are listed in Table 5 using the example of a 10 ft. by 20 ft. attached heatroom. The analysis was performed using two methods for determining solar heat unit benefits. The first method assumed "average" amounts of solar insolation for each day of the month studied. The second methods assumed "clear day" amounts of insolation for part of the month, and no insolation for the remainder of the month. The total monthly insolation in both cases agreed with the SOLMET figures found in Appendix A. As is discussed in the calculations chapter, the first method is expected to underestimate performance and the second, to overestimate performance. Due to the complexity of the analysis, it was performed for only five Alaskan locations.

These analyses assumed an unobstructed site and good construction and operation of the solar heat unit. It was also assumed that the adjoining building required no heat until ambient temperatures fell below 55 degrees Fahrenheit, and that the solar heat unit could supply a maximum of 25 percent of the total building heating load in any month. The thermal system of a solar heat unit is very dynamic and complex, so the figures given in Table 5 should be considered only as approximations.

TABLE 5

10' x 20' Attached Heatroom Performance Analysis Results

LOCATION	ANNUAL HEAT SAVINGS (MILLION BTU)	
	METHOD 1	METHOD 2
Big Delta	8.6	9.6
Fairbanks	7.5	8.8
Homer	10.2	11.6
Juneau	4.6	8.1
Nome	6.3	9.4

Mixed-Operation Passive Solar Additions

It can be advantageous to operate a passive solar addition in a manner somewhere between the two extremes of the "classic solar greenhouse" and the "solar heat unit." An example of this would be to operate the passive solar addition as a greenhouse, with heat storage and shutters, only during the part of the year when moderate temperatures can be maintained without supplemental heat. This would allow for an extended growing season for plants and/or use of the room as a living area for much of the year. When temperatures and sunlight fall to a point where supplemental heat is required, the heat storage should be removed (in the case of water storage) or turned off (in the case of fan-driven rock bed storage). Thereafter, until spring, the passive solar addition will be operated as a solar heat unit, with cold temperatures prevailing but occasional periods where the air in the passive solar addition heats up enough to be vented into the attached building.

This method of operation preserves some of the best features of both the classic solar greenhouse and the solar heat unit. While the net annual heat gain to the attached building is smaller than in the case of the solar heat unit, a growing season is extended approximately 3 months longer than would be possible outdoors. In a solar heat unit, the growing season is not extended very much. The net annual heat gains to attached buildings for such an installation is given as follows in a few Alaskan cities. The figures were computed for an installation similar to that of the "good" 10 feet by 20 feet greenhouse previously discussed. The heat gain is between 35 percent and 50 percent of that of the solar heat units in the same locations.

LOCATION	NET ANNUAL HEAT GAIN (million Btu)
Annette	1.7
Big Delta	3.0
Fairbanks	3.2
Homer	4.1
Juneau	2.4
Nome	2.7

Another type of "mixed operation" passive solar addition is to operate as a greenhouse for as much of the year as moderate temperatures could be maintained without supplemental heat. Instead of then converting the passive solar addition to a solar heat unit, however, the shutters would be placed

over all, or nearly all, of the windows for the cold months. In winter, this sunspace would be basically a conventional room. This saves the owners the trouble of opening and closing shutters on large window areas during the part of the year when the solar gain through them is minimal. The heat savings attributed to solar gain are less using this method of operation than with the other methods mentioned in this report, but a sunspace is still a pleasant addition to a building, easier to operate, and provides extended-season growing area.

PASSIVE SOLAR ADDITIONS ECONOMICS

Greenhouse Costs

Greenhouse additions appear to cost approximately the same as any comparable building addition sized and finished to the same standards. The well-insulated greenhouse shown in the plans in Appendix E would cost approximately $6,000 to $6,500 if furnished with a slab floor, minimal electrical service, and glazed with fiber-reinforced plastics. This estimate was made at early 1982 prices in the Fairbanks area; labor costs account for about one-third of the total price. This estimate does not include any cost for interior furnishings or heat storage. This is equivalent to about $40 to $45 per square foot of usable interior space and is nearly the same as the estimate made for an equally sized conventional room with a couple of thermopane windows. Most of the materials are identical for both.

Glazing with large-pane thermopane, instead of FRP, would add at least $1,000 to the cost of the greenhouse if purchased at standard retail prices. To save on costs, it is possible to find seconds, discontinued lines, or salvaged glass at greatly reduced prices.

A lower cost approach might include substituting T-111 for exterior wood siding, a gravel floor for the slab, providing no electrical outlets, leaving the extra layer of Thermax off insulated walls, and using some salvaged materials. If this is done and the owner supplied his own labor, the price of the greenhouse can be cut in half and still be attractive in appearance.

Solar Heat Unit Costs

Traditional lean-to greenhouses (with glazed roof and sides), which are suitable for use as solar heat units are available from commercial sources. Most of these produce an attractive structure with minimal installation time. High quality ones, with glass glazing, can cost as much as the solar greenhouses or conventional additions already discussed by the time the cost of a full foundation and floor are included.

The cheapest commercially available solar heat units are made of light metal frames covered with two layers of treated polyethylene. A 20 foot solar heat unit of this type, installed on a simple insulated wood floor resting on pads on the ground, can cost as little as $2,000, including approximately

$300 for installation labor. In locations where frost heaving is a problem, this type of foundation does not perform well and more expensive methods are necessary.

Even less expensive solar heat units can be built if the owner donates the labor for installation. An 8 foot by 20 foot solar heat unit framed with 2 x 4's at 2 feet on center, with double FRP glazing and a couple of storm doors, can probably be built for about $1,200 to $1,400 for materials alone, based on early 1982 Fairbanks prices. These figures again assume that the solar heat unit can be supported by pads directly on the ground; more elaborate foundations will increase costs. It is doubtful that this type of solar heat unit would be cheaper than the inexpensive commerical ones if the installation labor had to be paid for.

Economic Value of Energy Savings

Solar Heat Unit:

The investment made in a solar heat unit will yield a return in the form of reduced heating bills for the adjoining building. Similarly, a classic solar greenhouse, when compared with a conventional room addition, will result in lower heating bills. The same methods of economic analysis used to examine any other investment can be used to examine passive solar addition investments (e.g., after tax return on investment, life-cycle costs, net present value, or payback period).

Using the cost and performance estimate developed in this report, it can be concluded using any of these methods that the investment in a solar heat unit is not worthwhile if energy savings is the only considered benefit. The only exception to this is an owner-built structure (where the labor is considered to be free) that is financed by a subsidized loan (i.e., 5 percent). Even in this case, looking at the energy savings alone, the economic benefit of the structure is questionable.

This conclusion is based on the current and foreseeable price of oil. If the price of energy were high enough, of course, the solar heat unit would bring a worthwhile return on the investment made in it. There might be locations today in Alaska where the price of electric heating, for example, is high enough to make a solar heat unit appear to be a good investment. Yet under these conditions, an investment in an oil furnace or a wood stove to replace the electric heat is an even better investment. The costs used in this report are based on those in Fairbanks in early 1982, and oil prices in

remote locations greatly exceed these costs. Costs of construction are also much higher in these remote locations, however, so the same general conclusions are valid there.

This is not to say that a solar heat unit is not a good idea, only that it is not an inexpensive furnace. A solar heat unit is not only a furnace, however. It is also an extra room that can be enjoyed for much of the year in which extended growing seasons are possible, and which can add to the value of the building to which it is attached. The energy benefits, then, only justify part of the cost of a solar heat unit; the decisive factors are the values placed on other benefits.

Greenhouse:

In Alaska classic solar greenhouses heated all year were found to yield somewhere between a very small net heat gain and a moderate heat loss, depending upon the locations (as discussed in the performance chapter). As a furnace for the adjoining building, then, this type of greenhouse does not perform even as well as a solar heat unit. The heating loads appear quite favorable when compared to a conventional room addition, however. (See the performance chapter.) Like a conventional addition, the space is usable all year. Unlike a conventional addition, the classic solar greenhouse has window shutters that must be opened and closed daily. Since the cost of a classic solar greenhouse is about the same as the cost of that for a conventional addition, the proper question when comparing the two is, "Are the energy savings from a greenhouse worth the bother of operating the shutters?" The prospective owner must make this decision for himself. Automatic shutter operating devices can be built, but will be expensive.

Some people prefer the aesthetics of a greenhouse over that of a conventional room (or vice versa); this, too, must be considered. Some people enjoy the bright "outdoor" atmosphere of a greenhouse; others find the light harsh and glaring and object to the faded furniture that results. Similarly, some people relish home-grown vegetables while others do not find them worth the trouble.

A Note on Federal Tax Credits

Many advertisements for greenhouses cite the possibility of receiving a 40 percent tax credit for the costs of building a passive solar addition. This tax credit rarely applies to a passive solar addition under a strict interpretation of the tax law. Expenses to build a room in which you will

live or grow plants generally will not apply because the room has a substantial use other than energy production. This eliminates most, if not all, expenses for a classic solar greenhouse. At the other extreme, a solar heat unit does not qualify if there is no provision for energy storage somewhere in the system. Consult a qualified tax advisor before assuming that any tax advantages will be available.

CALCULATION PROCEDURES

A few of the basic procedures for determining heat gains and losses from a passive solar addition are presented here briefly. There are many references available that deal with this subject in greater depth and clarity than is possible in this report. The bibliography in this report and a local library will be useful in finding further information. The ASHRAE Handbook of Fundamentals is probably the best single source of information.

Heat Loss

The primary heat losses from buildings (including passive solar additions) are due to the conduction of heat through walls, windows, etc., and infiltration of cold air through cracks.

Conduction heat losses for any one part of a building's exterior are given by the following formula:

$$Q = \frac{A}{R} \times \Delta T \times t$$

where: Q = heat loss in Btu

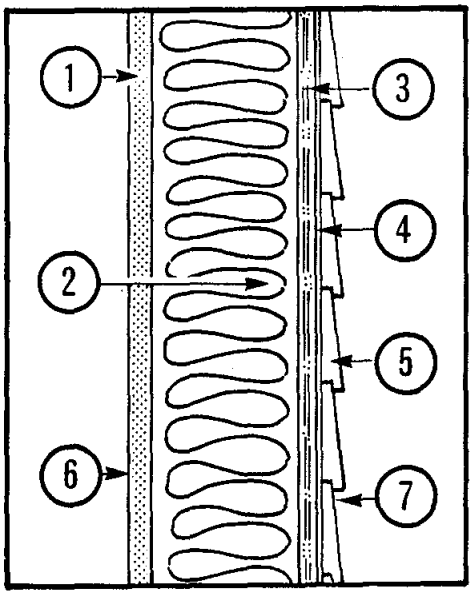
A = surface area of the part of the building under consideration, square feet

ΔT = difference between indoor and outdoor temperatures, in Fahrenheit degrees

t = length of time, in hours

R = resistance to heat conduction of the part of the building under consideration, in sf-^{o}F-hr/Btu

"R" values for a number of building materials are given in Appendix C. The "R" value for a part of the building's exterior is equal to the sum of the "R" values of the materials of which it is built, e.g., plywood, insulation, drywall, glass. An example calculation of the "R" value of a frame wall is shown in Figure 16.



List of Construction Components	R (at stud)	R (insulated cavity)
1. ½" gypsum wallboard	0.45	0.45
2. 2" x 6" wood stud	7.03	--
or 6" fiberglass insulation	--	19.00
3. ½" plywood sheathing	0.62	0.62
4. Building paper	0.06	0.06
5. Bevel wood siding (3/4" x 10", lapped)	1.05	1.05
6. Inside surface air film	0.68	0.68
7. Outside surface air film	0.17	0.17
Total Resistance R Value	10.06	22.03

FIGURE 16 - CALCULATIONS OF R-VALUES

Conduction loss calculations for each type of surface on the building's exterior can be calculated, using the proper area and "R" value, and added together to find the total conduction losses. For a passive solar addition the types of exterior surfaces generally include:

Windows
Doors
Wall areas filled with insulation
Wall areas filled with wood (i.e., studs)
Roof areas filled with insulation
Roof areas filled with wood (i.e., joists or rafters)
Vents
Floor

Conduction losses from a floor set on grade or below grade are difficult to calculate, but are small if proper insulation is applied. It has been estimated that the losses from an unheated slab-on-grade floor of a house are about 10 percent of the total building heat loss.[5]

Normally the designer will be interested in window losses both with and without shutters in place; separate "R" values must be computed for each case. The designer will probably also be interested in losses in various temperatures and time periods, such as losses per hour at extremely low temperatures, losses per day during average weather in January, etc. These losses are found by adjusting the ΔT and t figures in the preceding formula.

Infiltration heat losses due to leaks of cold air through cracks around windows, doors, vents, sill plates, etc., are very hard to determine with any accuracy. The amount of cold air seepage into a building depends not only on how well it was sealed and weatherstripped when built, but also on the amount of settlement of the building that occurs, the wind speed, the temperature, the frequency with which doors are opened, and, in some cases, even the humidity.

The simplest commonly used method for estimating these losses is the "air change" method. Here, infiltration losses are given by the following formula:

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[5] ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, 1977, Chap. 24.5.

$$Q = V \times ACH \times \Delta T \times t \times 0.018$$

where: Q = infiltration losses in Btu

V = volume of the building in cubic feet

ACH = air chages per hour

ΔT = difference between indoor and outdoor temperatures in Fahrenheit degrees

t = length of time in hours

0.018 = specific heat of air (approximate) in Btu/cf-^{o}F (cf=cubic foot)

Estimates of the number of air changes per hour (ACH) that can be expected for various types of construction are given in Table 6.

TABLE 6

Estimated Air Changes per Hour

.25 - Very tight new house with heat exchanger.

.50 - New house with special attention to caulking and vapor barrier.

1.0 - Standard new construction.

1.5 - 3-4 year old standard house with leaks.

2± - Old house with leaks.

Table 7 shows an example of a heat loss calculation typical of a passive solar addition. The example is for a March day in Homer; the data sheet in Appendix A shows that the average temperature in March in Homer is 28.4 degrees Fahrenheit and the passive solar addition is assumed to be a greenhouse kept at 65 degrees Fahrenheit. Therefore, the figure used for ΔT is 65 - 28.4 = 36.6. It can be seen that the calculations also assume that the windows are shuttered for 12 hours of the day. Also note that floor losses are simply estimated as adding 10 percent to the total of other conduction losses. There are better methods for estimating floor heat losses but they require more detailed treatment than can be given in this report.

TABLE 7

Sample Heat Loss Calculation-Greenhouse on Typical March Day in Homer

Conduction Losses

Building Element	A/R	x	ΔT	x	t	=	Q
Windows (shuttered)	104/12	x	36.6	x	12	=	3,806
Windows (open)	104/2	x	36.6	x	12	=	22,838
Door	20/10	x	36.6	x	24	=	1,757
Wall (insulation filled)	120/22	x	36.6	x	24	=	4,791
Wall (wood filled)	65/10	x	36.6	x	24	=	5,710
Roof (insulation filled)	180/33	x	36.6	x	24	=	4,791
Roof (wood filled)	30/13	x	36.6	x	24	=	2,027
Vents	25/12	x	36.6	x	24	=	1,830
SUBTOTAL							47,550
Slab Floor--add 10%							4,755
TOTAL CONDUCTION LOSSES							52,305

Infiltration Losses

$$V \times ACH \times \Delta T \times t \times 0.018 = Q$$

$$1600 \times 1.0 \times 36.6 \times 24 \times 0.018 = 25{,}298$$

Conduction Losses	52,305
Infiltration Losses	25,298
Total Heat Losses in 24 Hours	77,603 Btu

Note on units: $A = ft^2$, $R = ft^2\text{-hr-}°F/Btu$, $\Delta T = °F$, $t = hr$, $Q = Btu$, $V = ft^3$

ACH = Air Changes per Hour;

0.018 = approximate specific heat of air; $Btu/ft^3\text{-}°F$

Heat Gain

The major source of heat gains for a passive solar addition obviously is the solar gain. Other sources of heat include backup heating systems (if used) and "internal gains." The only major internal gain likely in a passive solar addition is the heat given off by any lights used. A watt-hour of energy is equal to 3.41 Btu, so a 100-watt light bulb will give off, in one hour, 100 x 3.41 = 341 Btu of energy, all of which helps to heat the passive solar addition. Similar calculations will give the internal gain for any level of lighting and length of time.

Solar Gain

The amount of solar gain within a passive solar addition depends on several things. First, of course, is the amount of solar energy (the insolation) that reaches the window areas. Other factors include the size of the windows, their transmissivity of sunlight, and the fraction of sunlight which, having entered the passive solar addition, is absorbed there. The amount of solar gain will equal:

$$Q_{solar} = INS \times A \times t \times \zeta \times \alpha$$

where: Q_{solar} = solar gain (Btu)

INS = insolation on passive solar addition windows (Btu/sf-hr or day)

A = window area (sf)

t = length of time (hours or days, whichever agrees with the units used for INS)

ζ = transmissivity of windows (dimensionless)

α = absorbtivity of sunspace (dimensionless)

The amount of insolation reaching the windows of a passive solar addition depends on the direction the windows face, the time of day and year, the weather, and the latitude of the building site. Appendix A contains ASHRAE insolation figures for two latitudes (56 degrees N and 64 degrees N), by hour of day, for the twenty-first day of each month, for surfaces oriented in several directions. These figures assume clear sky conditions and thus represent the maximum insolation that can be expected.* Also in Appendix A

*Greater amounts of insolation are possible on exceptionally clear days and on surfaces where additional light is reflected onto the surface from, for example, snow-covered ground.

are figures from a computer program called SOLMET for average daily insolation for each month for the various Alaskan locations. The SOLMET figures are not for clear sky conditions; they include reductions for average cloud cover. Both sets of figures have been calculated, not measured, so their accuracy is questionable. Unfortunately, they are the best figures available as reliable measured data are lacking almost everywhere inside and outside of Alaska.

Appendix A also contains data for insolation on a horizontal surface based on actual measurements in four Alaskan cities (Annette, Barrow, Bethel, and Fairbanks). In all four locations, the average observed insolation is greater than the "average" figures given in the SOLMET data. The difference ranges from 9 percent annually (in Fairbanks) to 30 percent more annually (in Barrow). Solar recording stations are often known to have problems and provide inaccurate information; however, these data seem to indicate that the SOLMET figures for Alaska might be significantly low.

The transmissivity of a passive solar addition's glazing depends on the angle of incidence of the incoming sunlight striking the glazing, on the type and number of panes of glazing, and on how clean the glazing is. The angle of incidence depends on the time of day and year, the latitude, and the orientation of the glazing. Table 8 lists transmissivity figures for clean, double-pane vertical glass facing south that are accurate enough for use in most Alaskan locations. Figures are given for each daylight hour for the twenty-first of each month; a weighted daily average is also given. Values for the transmissivity of windows with more or fewer panes can be approximated by the following formula:

$$\zeta_n = \zeta_z^{(n/2)}$$

where: ζ_n = transmissivity of a window with n panes

ζ_2 = transmissivity of a window with 2 panes (given in Table 8)

n = number of panes.

For a passive solar addition with opaque side walls and roof, a minimal amount of the insolation which penetrates the glazing will be reflected back out of the passive solar addition. This is especially true if the passive solar addition is filled with plants, furniture, heat storage drums, etc. In such cases, it is reasonable to assume that the absorbtivity of the passive solar addition is 1.00 (i.e., 100 percent).

TABLE 8

Transmissivity of Double-Pane, South-Facing, Vertical Glass

For Use in Alaskan Calculations
(Clear sky assumed)

	4 AM 8 PM	5 AM 7 PM	6 AM 6 PM	7 AM 5 PM	8 AM 4 PM	9 AM 3 PM	10 AM 2 PM	11 AM 1 PM	Noon	Avg Day Long
Jan						.75	.76	.77	.77	.77
Feb					.68	.74	.75	.76	.77	.76
Mar				(.46)	.62	.71	.74	.75	.75	.73
Apr		(.72)	(.72)	(.45)	(.52)	.66	.71	.74	.74	.71
May	(.72)	(.72)	(.72)	(.60)	(.42)	.58	.67	.71	.72	.67
Jun	(.72)	(.72)	(.72)	(.65)	(.37)	.55	.65	.69	.70	.65
July	(.72)	(.72)	(.72)	(.60)	(.42)	.58	.67	.71	.72	.67
Aug		(.72)	(.72)	(.45)	(.52)	.66	.71	.74	.74	.71
Sep				(.46)	.62	.71	.74	.75	.75	.73
Oct					.68	.74	.75	.76	.77	.76
Nov						.75	.76	.77	.77	.77
Dec						.75	.76	.77	.77	.77

Notes: Calculations were made for the 21st of the named months using ASHRAE Data.

Numbers in parentheses were estimated to account for the large fraction of light which is diffuse during these periods.

Those figures not in parentheses are accurate within ±.02 for latitudes from 56°N to 64°N.

Sample Calculation:

As an example of solar gain calculations, consider the greenhouse in Homer on an average day in March that was used for a heat loss calculation example. The data sheet in Appendix A lists average daily insolation for Homer in March as 1142.5 Btu/sf-day on a vertical, south-facing surface. Assume a window area of 104 square feet (as was done for the heat loss example), and an average transmissivity of 0.73 (from Table 8). If an absorbtivity of 1.00 is assumed, the solar gain equation is:

$$Q_{solar} = (1142.5 \text{ Btu/sf-day}) \times (104 \text{ sf}) \times (1 \text{ day}) \times (0.73) \times (1.00)$$
$$= 86{,}739 \text{ Btu}$$

The heat loss calculation in Table 7 shows a total of 77,603 Btu heat loss. There is therefore a surplus of heat generated in the greenhouse for the day of about 9,136 Btu's which would be available for venting into the attached building to aid its heating. By making similar calculations for each month, net heat gains and losses for the greenhouse throughout the entire year can be estimated. The largest net gains, of course, will appear in the summer months. Unfortunately, the attached building does not need heat at this time and the surplus of heat would have to be vented to the outdoors and lost. During periods that show a net loss, the greenhouse will need backup heat, either given off by lights or from a stove or furnace, or a combination of these.

Calculations such as the ones in the previous example can be made for any passive solar addition, at any time and location, and in any weather. Their accuracy, however, cannot be greater than that of the information used in making them. One should make sure the values (R values, areas, etc.) accurately reflect the building being considered. If there is shading of the windows at the site, adjustments to the insolation values used should be made. It is probably wiser to be conservative in making performance estimates, and later be pleasantly surprised by actual performance, than it is to overestimate performance and be disappointed thousands of dollars later.

Predicting Passive Solar Addition Temperatures

The calculations previously given work well for a greenhouse where the temperature is to be kept relatively constant. This may not always be the case for a greenhouse and is never the case for solar heat units. In these cases, different techniques are needed.

If all the heat in the greenhouse example used previously had been kept in the greenhouse, rather than vented, the greenhouse's temperature would have exceeded 65 degrees. This warmer temperature can be estimated without much difficulty if steady-state conditions are assumed (that is, if it is assumed that the indoor and outdoor temperatures and the rate of heat gain and loss are constant throughout the day).

The heat loss was calculated to be 77,603 Btu's/day and the ΔT was 36.6 degrees Fahrenheit. If the ΔT were twice as large, the heat losses would be twice as great. In general, the heat losses will be equal to:

$$\frac{77,603}{36.6} = 2,120 \text{ Btu's/day-}^{o}\text{F}$$

Under steady-state conditions, the total heat gain is equal to the total heat loss. The total heat gain for this greenhouse in Homer on an average March day is 86,739 Btu's, as was already calcuated. We can thus find the following:

$$\text{HEAT GAIN} = \text{HEAT LOSS}$$

$$86{,}739 = (2{,}120) \times (\Delta T)$$

Solving this equation, we find $\Delta T = 86{,}739/2{,}120 = 40.9$ degrees Fahrenheit. The ΔT is the difference between indoor and outdoor temperatures. Therefore, if the outdoor temperature is the average 28.4 degrees Fahrenheit for March in Homer, the average indoor temperature must be 28.4 + 40.9 = 69.3 degrees Fahrenheit.

Of course, steady-state conditions do not really exist. Both indoor and outdoor temperatures are usually higher during the day than at night. Heat gains and losses are not the same either; the gains are greater than the losses when the greenhouse is heating up, and vice versa when cooling off. Because of this, there are some inaccuracies in the calculations. The results are probably accurate enough though for most practical applications. Even if the equations used were perfect, the inaccuracies in the information used (especially insolation levels, ambient temperatures, and infiltration rates) would result in a less-than-perfect answer.

Solar Heat Unit Performance

The thermal behavior of a solar heat unit is very complex, thus accurate modeling of this behavior would be very difficult and is almost certainly not worth the effort for practical applications. The following method contains numerous simplifying assumptions, but can be useful for roughly estimating solar heat unit performance. It would be of great help if the results predicted by this method could be checked with actual results from real solar heat units; unfortunately, this has not been done to any great extent. The method is probably more accurate for determining which of two designs will work better than it is for determining exactly how a particular design will work. While it is not mathematically difficult, it is a tedious method. The use of a computer or programmable calculator to perform the repetitive calculations would save a lot of work.

There are three principal ways in which a solar heat unit can reduce the heating load of the building to which it is attached. The most obvious is due to the hot air produced in the solar heat unit and vented or blown into the

building. The second is that the wall of the building that faces into the solar heat unit will have smaller conduction losses than otherwise, since the temperature in the solar heat unit is normally greater than ambient (outdoor). The third reduction is that the solar heat unit itself acts as a thermal "buffer"--an extra insulating layer--to the part of the attached building which it covers. The method presented addresses all three of these effects. There can also be a reduction in infiltration of cold air into the building due to the solar heat unit's acting as an "arctic entry" or vestibule. The opposite effect can occur, however, if vents or other openings into the solar heat unit are added to the building's wall. The effect of changed infiltration is not considered in the following method; the designer can use his own judgment regarding this.

In order to calculate how much hot air can be vented from the solar heat unit into the adjoining building, calculate the temperature inside the solar heat unit for every daylight hour, for each month of the heating season. Hot air is drawn from the solar heat unit during the hours its temperature exceeds a certain level, the "fan operation temperature" (e.g., 80 degrees Fahrenheit).

The amount of heat gained from vented hot air is calculated as follows (again assuming steady-state conditions). At the predicted temperature, and without vents or fans operating, the energy balance is as before:

$$Q_{solar} = Q_{heat\ loss\ @\ predicted\ \Delta T}$$

If, instead, the solar heat unit temperature is kept at 80 degrees Fahrenheit by venting the excess heat, the heat balance equation is:

$$Q_{solar} = Q_{heat\ loss\ @\ (80^{o}\text{-ambient})} + Q_{vented\ hot\ air}$$

Since Q_{solar} is the same in both cases, the right sides of these two equations are equal. Combining these equations and simplifying, we find:

$$Q_{vented\ hot\ air} = Q_{heat\ loss\ @\ \Delta T'}$$

where: $\Delta T' = \text{predicted } T - 80^{o}$

In other words, the amount of heat vented is the difference between what the heat loss from the solar heat unit would have been <u>at the predicted temperature</u> and the heat loss is <u>when the temperature is kept at 80 degrees</u>. It must

then be decided whether the vented hot air will actually benefit the adjoining building at the specific time of the year it is available; the building might not need the heat in summer, for instance.

In order to calculate the other two benefits of the solar heat unit--increasing the temperature that the covered part of the adjoining building is exposed to and providing a "buffer" with some insulating value--the predicted solar heat unit temperatures are needed again. The two features can be combined into one calculation (with a small loss in accuracy) using the following method.

First the heat losses from the part of the building covered by the solar heat unit are calculated by the standard method, as if the solar heat unit were not there (i.e., as if exposed to ambient temperatures). Then these heat losses can be calculated again by using predicted solar heat unit temperatures instead of ambient ones and by increasing the "R" value of all parts of the wall slightly. The higher temperatures and greater "R" values will result in smaller heat losses than before and the difference is the saving provided by the solar heat unit. Note that when solar heat unit temperatures are above room temperatures there will be heat gains, not losses, through the wall. Also remember that when predicted solar heat unit temperatures exceed 80 degrees Fahrenheit, assume that the temperature is 80 degrees Fahrenheit because it will be held there by venting excess heat.

Approximate "R" value equivalents for passive solar additions have been determined. These are shown in Table 9 and can be used for increasing the "R" value of the building wall in the calculations described above. These "R" value equivalents were calculated by finding (for steady-state conditions) how much warmer the passive solar addition would be than outdoors (due to having a heated room behind the back wall), how much this elevated temperature would reduce heat losses from the building's wall, and finally, to what increase in "R" value this reduction is equivalent.

Table 9

Approximate Insulating Value of an Attached Passive Solar Addition to a Building Wall

Sunspace Type	"R" Value Equivalent
Well-built greenhouse, open	2.5
Well-built greenhouse, shuttered	4.3
Minimally built greenhouse, open	1.5
Minimally built greenhouse, shuttered	1.9
Well-built solar heat unit, open	0.9
Minimally built solar heat unit, open	0.7

Notes: "Well-built" greenhouse has R-19 insulation in roof and end walls, 1 air change per hour, and R-12 shutters.

"Minimally built" greenhouse has R-11 insulation in roof and end walls, 3 air changes per hour and R-7 shutters.

"Well-built" solar heat unit has 1 air change per hour and double glazing on all surfaces (roof and three walls).

"Minimally built" solar heat unit has 3 air changes per hour and double glazing on all surfaces (roof and three walls).

An example solar heat unit performance calculation is shown in Table 10 for a clear day in Fairbanks in February. Refer to this example to clarify the procedure. The large ΔT calculated in the table (139.4 degrees Fahrenheit) would probably never be reached in a real solar heat unit for a number of reasons. These reasons include infiltration with this large a temperature difference, noticeable losses through the back wall, the fact that steady-state conditions do not exist, and the possibility of significant radiative heat losses with the large temperature difference. All of these reasons would tend to make the heat loss equation used to calculate ΔT incorrect. However, since the temperature difference will be limited in a real solar heat unit by venting, the heat loss rate figure will be accurate enough if calculated as previously described.

The calculation in Table 10 would have to be repeated using insolation figures for all hours of the day to get a total daily benefit from the solar heat unit on clear February days. It would have to be repeated again, using different insolation and ambient temperature figures, for other months.

Table 10

Example 8' x 20' Solar Heat Unit Performance Calculation
Fairbanks, Clear Day, February 21st, 11 a.m. (or 1 p.m.)

Assume: Heat loss rate from solar heat unit* = 145 Btu/hr-°F

Heat loss rate from portion of building covered by solar heat unit* = 12.6 Btu/hr-°F

Same as above, adjusted for increased "R" value due to solar heat unit* = 9.7 Btu/hr-°F

Solar heat unit glazing area (vertical, S-facing) = 135 ft^2

Ambient temperature (Feb. average, see Appendix A) = -2.2°F

ΔT Calculation: (solar heat unit vs. ambient)

$$\frac{(197\ Btu/ft^2\text{-}hr)^{**}(135\ ft^2)(0.76)^{\dagger}}{145\ Btu/hr\text{-}°F} = 139.4°F$$

Solar Heat Unit Predicted Temperature = Ambient + ΔT = 137.2°F

Hot Air Vented: (145 Btu/hr-°F)(139.4 - 80°F)(1 hr) = 8,613 Btu

Heat Losses: From covered portion of building if solar heat unit was not there. (12.6 Btu/hr-°F)(68-(-2.2)°F)(1 hr) = 885 Btu

From covered portion of building with solar heat unit in place. (9.7 Btu/hr-°F)(68 - 80°F)†† (1 hr) = -116 Btu$^{\phi}$

Building Benefit from Reduced Heat Losses: 885 - (-116) = 1,001 Btu

Net Benefit from solar heat unit = 8,613 + 1,001 = 9,614 Btu

*Conduction and infiltration

**Insolation from Appendix A @ 64°N latitude

†Transmissivity from Table 8

††Solar heat unit is kept at 80°F by venting excess heat.

ϕNegative value indicates heat is gained, not lost, through the wall.

The sample calculation in Table 10 is for a clear day and obviously not all days are clear. In addition, the net benefit from the solar heat unit might not always be useful (e.g., summer months). Adjustments must be made, then, for cloudy days and for periods when heat is not needed.

An idea of the number of sunny days that can be expected can be found from the SOLMET and ASHRAE insolation figures in Appendix A. The SOLMET tables, for example, might show only half as much insolation on an average October day as the ASHRAE tables show for a clear October day. One way to adjust the solar heat unit performance estimate is to use half the values (for this example) of hourly insolation in the ASHRAE tables when performing the calculations. Another way is to use the ASHRAE clear day values, but for only half the month, and then calculate heat losses for the rest of the month assuming no solar gain at all. The former method results in an underestimation of solar heat unit performance; the latter results in an overestimation. Other methods can be invented which would result in performance estimates somewhere between these two.

To determine when the adjoining building needs the heat produced in the solar heat unit, and the amount of heat needed, heating load calculations should be made, at least for the questionable months. It can probably be assumed that all the solar heat unit's heat will be useful in mid-winter. Due to its internal gains (from lights, people, machinery, etc.) which provide some heat all of the time, a typical small building might not need additional heat until the outdoor temperature drops below 55 degrees or so. This figure might be greater for a warehouse or gymnasium and smaller for a super-insulated building. Even when the building needs heat, the solar heat unit will not be able to provide the heat at night or on cloudy days, since there is no heat storage. Therefore, it is unlikely that a solar heat unit will ever be able to supply more than about a quarter of the building's heating load during the short term (monthly); the contribution will be less than this over the whole year.

SUMMARY

The conclusion of this study is that in the Alaskan climate the energy savings potential from classic solar greenhouses and solar heat units is not great enough to justify their expense. In the vast majorities of cases, energy savings do exist (although rarely) for heated greenhouses except when compared with conventional additions, but the value of the energy savings is not great enough to be the sole justification to someone contemplating building one.

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A Solar Design Manual For Alaska, Richard D. Seifert, Institute of Water Resources, University of Alaska, Fairbanks, Alaska 99701, $12.00

SUPPLIERS AND CATALOGS:

Solar Catalog, Solar Components Corp., P.O. Box 237, Manchester, New Hampshire 03105, Phone 603-668-8186, $3.00.

Solar Age Catalog, Solar Vision Inc., Manchester, New Hampshire. $8.50.

People's Solar Sourcebook, Solar Usage Now, Box 306, Bascom, Ohio 44809, 352 pp., $5.00.

GREENHOUSE SUPPLIERS:

The following companies have extensive catalogs carrying all types of greenhouse products and accessories.

Alaska Greenhouses, Inc.
1301 Muldoon Road
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Anchorage, Alaska 99502 (Phone 276-8888)

Bell's Nursery
7653 Cranberry
Anchorage, Alaska 99502 (Phone 243-1020)

National Greenhouse Company
Pana, Illinois 62557

George J Ball, Inc.
Box 335
West Chicago, Illinois 60185

Four Seasons Greenhouses
910 Route 110
Farmingdale, New York 11735 (Phone 516-694-4400)

Solar Room Company
Box 1848
Taos, New Mexico 87571 (Phone 505-758-9344)

APPENDIX A

Insolation Data for Alaskan Locations

Solar Intensity and Solar Heat Gain Factors* for 56 Deg North Latitude, Conventional Units

Date	Solar Time am	Direct Normal Btuh · ft²	Solar Heat Gain Factors, Btuh · ft² N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	HOR	Solar Time pm
Jan 21	9	78	3	3	3	21	49	67	74	70	55	30	4	3	3	3	3	3	5	3
	10	170	7	7	7	13	74	126	156	162	143	100	38	7	7	7	7	7	21	2
	11	207	9	9	9	10	40	116	169	194	190	156	96	21	9	9	9	9	34	1
	12	217	10	10	10	10	11	71	144	190	205	190	144	71	11	10	10	10	40	12
	HALF DAY TOTALS		23	23	24	46	163	343	468	517	487	378	206	61	24	23	23	23	80	
Feb 21	8	115	4	4	21	64	95	109	107	88	55	12	4	4	4	4	4	4	10	4
	9	203	10	10	11	71	139	183	197	182	136	66	10	10	10	10	10	10	36	3
	10	246	13	13	13	28	115	184	223	227	196	133	45	14	13	13	13	13	65	2
	11	262	15	15	15	16	57	148	210	239	232	188	112	25	15	15	15	15	84	1
	12	267	16	16	16	16	17	86	171	225	244	225	171	86	17	16	16	16	91	12
	HALF DAY TOTALS		49	50	66	182	409	666	821	846	737	509	253	89	50	49	49	49	241	
Mar 21	7	128	6	16	65	101	121	122	105	70	21	6	6	6	6	6	6	6	14	5
	8	215	12	13	61	136	185	205	194	152	84	15	12	12	12	12	12	12	49	4
	9	253	16	16	23	105	179	224	233	207	148	61	17	16	16	16	16	16	89	3
	10	272	19	19	20	46	136	203	238	236	198	128	39	20	19	19	19	19	122	2
	11	282	21	21	21	22	68	156	215	241	230	184	106	27	21	21	21	21	142	1
	12	284	22	22	22	22	24	86	170	222	241	222	170	86	24	22	22	22	149	12
	HALF DAY TOTALS		85	97	200	419	699	956	1071	1016	800	502	258	118	86	85	85	85	491	
Apr 21	6	122	13	58	95	118	121	107	75	29	7	7	7	7	7	7	7	7	18	6
	7	201	15	51	123	173	195	188	152	91	21	14	14	14	14	14	14	14	56	5
	8	239	19	23	95	167	211	223	201	148	68	20	19	19	19	19	19	19	101	4
	9	260	23	24	44	126	190	223	223	189	126	44	24	23	23	23	23	23	140	3
	10	272	26	26	27	63	142	196	220	212	171	102	33	26	26	26	26	26	170	2
	11	278	28	28	28	30	74	147	195	213	200	156	86	31	28	28	28	28	189	1
	12	280	28	28	28	28	31	79	149	194	210	194	149	79	31	28	28	28	195	12
	HALF DAY TOTALS		139	226	430	694	951	1132	1147	982	699	437	252	154	132	131	131	131	772	
May 21	5	93	36	68	89	95	88	66	33	7	6	6	6	6	6	6	6	7	14	7
	6	175	33	99	148	174	173	147	97	31	14	14	14	14	14	14	14	14	48	6
	7	219	21	77	149	195	212	197	152	81	22	19	19	19	19	19	19	19	92	5
	8	244	25	38	115	179	215	218	189	131	52	25	24	24	24	24	24	24	135	4
	9	259	28	30	62	136	189	213	206	168	102	36	28	28	28	28	28	28	171	3
	10	268	31	31	33	75	141	185	200	187	145	80	33	31	31	31	31	31	199	2
	11	273	32	32	32	35	76	135	174	187	172	131	71	35	32	32	32	32	216	1
	12	275	33	33	33	33	36	71	129	168	181	168	129	71	36	33	33	33	222	12
	HALF DAY TOTALS		222	391	644	906	1112	1202	1120	878	604	392	256	187	172	170	170	173	986	
Jun 21	4	21	13	19	22	21	18	11	3	1	1	1	1	1	1	1	2	5	3	8
	5	122	53	94	119	126	115	85	40	10	9	9	9	9	9	9	9	12	25	7
	6	185	42	111	160	185	182	152	97	30	16	16	16	16	16	16	16	17	62	6
	7	222	25	86	156	199	213	195	147	74	24	22	22	22	22	22	22	22	105	5
	8	243	27	46	122	181	213	213	181	122	46	27	26	26	26	26	26	26	146	4
	9	257	30	32	69	139	187	206	196	156	91	34	30	30	30	30	30	30	181	3
	10	265	33	33	36	79	139	178	190	174	132	71	35	33	33	33	33	33	208	2
	11	269	34	34	35	38	76	129	164	174	159	119	65	37	34	34	34	34	225	1
	12	271	35	35	35	35	38	68	119	155	168	155	119	68	38	35	35	35	231	12
	HALF DAY TOTALS		275	473	738	989	1162	1207	1082	822	562	376	160	103	190	189	189	196	1070	
Jul 21	5	91	37	69	89	95	88	66	33	8	7	7	7	7	7	7	7	8	16	7
	6	169	34	98	145	170	170	143	95	31	15	14	14	14	14	14	14	15	50	6
	7	212	23	77	147	192	208	193	148	79	23	20	20	20	20	20	20	20	93	5
	8	237	26	40	115	177	211	214	185	128	51	26	25	25	25	25	25	25	135	4
	9	252	29	31	63	135	186	209	201	164	99	36	29	29	29	29	29	29	171	3
	10	261	32	32	34	76	139	181	196	182	142	78	35	32	32	32	32	32	198	2
	11	265	33	33	33	37	76	133	171	183	168	128	70	36	33	33	33	33	215	1
	12	267	34	34	34	34	37	71	126	164	177	164	126	71	37	34	34	34	221	12
	HALF DAY TOTALS		231	398	646	901	1097	1180	1096	859	593	390	259	193	179	177	177	180	987	
Aug 21	5	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	7
	6	112	14	56	91	111	114	101	71	28	8	8	8	8	8	8	8	8	20	6
	7	187	16	51	119	165	186	179	144	86	22	15	15	15	15	15	15	15	58	5
	8	225	20	25	94	162	203	214	192	142	66	22	20	20	20	20	20	20	101	4
	9	246	25	26	46	124	184	216	215	182	121	44	26	25	25	25	25	25	140	3
	10	258	28	28	30	65	139	191	213	204	165	99	34	28	28	28	28	28	169	2
	11	264	30	30	30	32	74	143	189	206	193	152	84	33	30	30	30	30	187	1
	12	266	30	30	30	30	30	78	145	188	203	188	145	78	33	30	30	30	198	12
	HALF DAY TOTALS		149	235	429	680	923	1092	1104	946	678	431	256	163	142	140	140	141	771	
Sep 21	7	107	6	15	56	87	104	105	90	60	19	6	6	6	6	6	6	6	14	5
	8	194	12	14	58	126	171	189	179	140	78	16	12	12	12	12	12	12	48	4
	9	233	17	17	24	100	170	211	220	195	140	59	18	17	17	17	17	17	86	3
	10	253	20	20	21	46	131	194	227	225	189	123	39	21	20	20	20	20	118	2
	11	263	22	22	22	24	67	150	206	230	220	176	103	28	22	22	22	22	137	1
	12	266	23	23	23	23	25	85	163	213	231	213	163	85	25	23	23	23	144	12
	HALF DAY TOTALS		89	99	191	391	652	893	1004	958	761	484	255	121	90	89	89	89	474	
Oct 21	8	104	4	5	20	59	87	100	98	81	50	11	4	4	4	4	4	4	10	4
	9	193	10	10	11	68	132	173	186	171	129	63	11	10	10	10	10	10	37	3
	10	231	14	14	14	28	111	176	213	216	186	127	44	14	14	14	14	14	64	2
	11	248	16	16	16	17	56	142	202	229	222	180	108	25	16	16	16	16	84	1
	12	253	16	16	16	16	18	83	164	216	234	216	164	83	18	16	16	16	91	12
	HALF DAY TOTALS		52	52	68	177	390	633	779	804	702	487	246	90	53	52	52	52	240	
Nov 21	9	76	3	3	3	21	48	66	72	69	54	29	4	3	3	3	3	3	6	3
	10	165	7	7	7	13	72	122	152	157	139	98	37	7	7	7	7	7	21	2
	11	201	9	9	9	10	39	113	165	190	186	152	94	21	9	9	9	9	35	1
	12	211	10	10	10	10	11	70	140	186	200	186	140	70	11	10	10	10	40	12
	HALF DAY TOTALS		24	24	24	47	161	336	457	505	475	369	202	61	24	24	24	24	81	
Dec 21	9	5	0	0	0	1	3	4	5	5	4	2	0	0	0	0	0	0	0	3
	10	113	4	4	4	7	47	82	103	107	96	68	27	4	4	4	4	4	9	2
	11	166	6	6	6	7	30	92	135	156	154	127	78	17	6	6	6	6	19	1
	12	180	7	7	7	7	8	59	120	159	171	159	120	59	8	7	7	7	23	12
	HALF DAY TOTALS		14	14	14	20	88	217	311	354	343	277	163	47	15	14	14	14	40	
			N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE	HOR	PM

Half Day Totals Computed by Simpson's Rule with Time Interval equal to 10 minutes.
*Total Solar Heat Gains for DSA Glass.
Based on a ground reflectance of 0.20 and values in Tables 1 and 27.

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Solar Intensity and Solar Heat Gain Factors* for 64 Deg North Latitude, Conventional Units

Date	Solar Time am	Direct Normal Btuh · ft²	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	HOR	Solar Time pm
			Solar Heat Gain Factors, Btuh · ft²																	
Jan 21	10	22	1	1	1	1	9	16	20	21	19	13	5	1	1	1	1	1	1	2
	11	81	3	3	3	3	15	45	67	77	75	62	38	8	3	3	3	3	6	1
	12	100	3	3	3	3	4	33	67	89	96	89	67	33	4	3	3	3	8	12
	HALF DAY TOTALS		5	5	5	6	25	79	121	142	141	119	75	23	5	5	5	5	11	
Feb 21	8	18	1	1	3	10	15	17	17	14	9	2	1	1	1	1	1	1	1	4
	9	134	5	5	6	43	89	118	128	119	90	45	6	5	5	5	5	5	13	3
	10	190	8	8	8	18	87	144	176	180	157	108	38	9	8	8	8	8	28	2
	11	215	10	10	10	11	44	122	177	202	197	160	97	20	10	10	10	10	41	1
	12	222	11	11	11	11	12	73	147	194	210	194	147	73	12	11	11	11	45	12
	HALF DAY TOTALS		29	30	33	89	244	446	578	617	560	411	212	66	30	29	29	29	106	
Mar 21	7	95	4	11	47	74	90	91	79	53	17	4	4	4	4	4	4	4	9	5
	8	185	9	10	46	113	158	177	170	135	78	14	9	9	9	9	9	9	32	4
	9	227	13	13	16	88	159	203	215	194	143	64	14	13	13	13	13	13	59	3
	10	249	16	16	16	35	122	190	226	228	194	130	42	16	16	16	16	16	84	2
	11	260	17	17	17	18	60	148	209	236	228	184	109	25	17	17	17	17	99	1
	12	263	18	18	18	18	19	85	168	221	239	221	168	85	19	18	18	18	105	12
	HALF DAY TOTALS		68	74	150	334	596	854	984	958	779	504	257	104	68	68	68	68	335	
Apr 21	5	27	8	18	24	27	26	20	12	2	1	1	1	1	1	1	1	1	2	7
	6	133	12	59	102	127	132	118	84	35	8	8	8	8	8	8	8	8	21	6
	7	194	14	41	113	163	189	185	153	96	25	13	13	13	13	13	13	13	51	5
	8	228	17	19	79	153	201	217	201	153	79	19	17	17	17	17	17	17	85	4
	9	248	21	21	32	111	180	219	225	197	138	55	22	21	21	21	21	21	116	3
	10	260	23	23	24	51	134	194	225	221	185	118	38	24	23	23	23	23	140	2
	11	266	24	24	24	26	68	148	202	225	214	171	99	29	24	24	24	24	155	1
	12	268	25	25	25	25	27	83	159	208	224	208	159	83	27	25	25	25	160	12
	HALF DAY TOTALS		131	218	410	671	943	1150	1186	1036	763	487	273	149	121	120	120	120	651	
May 21	4	51	30	44	51	51	43	28	8	3	3	3	3	3	3	3	3	10	6	8
	5	132	48	95	125	135	125	96	50	11	9	9	9	9	9	9	9	11	26	7
	6	185	28	97	150	181	183	158	109	40	15	15	15	15	15	15	15	15	55	6
	7	218	21	63	138	189	211	201	161	94	24	19	19	19	19	19	19	19	90	5
	8	239	23	28	97	167	209	220	198	146	68	25	23	23	23	23	23	23	124	4
	9	252	26	27	45	122	183	215	215	184	123	46	27	26	26	26	26	26	152	3
	10	261	28	28	30	61	135	188	212	205	167	102	36	28	28	28	28	28	174	2
	11	265	30	30	30	32	72	141	188	207	195	154	87	33	30	30	30	30	188	1
	12	267	30	30	30	30	33	78	146	189	204	189	146	78	33	30	30	30	192	12
	HALF DAY TOTALS		247	425	680	950	1177	1291	1218	985	708	465	288	191	169	168	168	176	911	
Jun 21	4	93	53	83	96	94	78	50	14	7	7	7	7	7	7	7	7	21	16	8
	5	154	62	114	148	158	145	110	55	14	12	12	12	12	12	12	12	14	39	7
	6	194	36	107	162	191	192	163	110	39	18	17	17	17	17	17	17	18	71	6
	7	221	24	71	145	193	213	200	158	89	25	22	22	22	22	22	22	22	105	5
	8	239	25	33	104	170	208	216	192	139	62	27	25	25	25	25	25	25	137	4
	9	251	28	29	51	124	181	210	208	175	115	43	29	28	28	28	28	28	165	3
	10	258	30	30	32	65	134	183	204	195	157	94	36	30	30	30	30	30	186	2
	11	262	32	32	32	34	72	137	180	196	184	144	82	35	32	32	32	32	199	1
	12	263	32	32	32	32	35	76	138	179	193	179	138	76	35	32	32	32	203	12
	HALF DAY TOTALS		322	533	801	1061	1253	1317	1195	946	679	455	296	211	192	190	191	213	1021	
Jul 21	4	53	32	47	55	54	46	29	9	4	4	4	4	4	4	4	4	11	8	8
	5	128	49	94	123	133	124	95	50	11	10	10	10	10	10	10	10	11	28	7
	6	179	30	96	148	177	180	155	106	39	16	15	15	15	15	15	15	15	57	6
	7	211	22	64	137	186	207	197	157	92	25	20	20	20	20	20	20	20	92	5
	8	231	24	30	97	165	205	215	193	142	67	26	24	24	24	24	24	24	124	4
	9	245	27	28	47	121	180	211	211	179	120	46	28	27	27	27	27	27	152	3
	10	253	29	29	31	62	134	185	208	200	164	100	37	29	29	29	29	29	174	2
	11	257	31	31	31	33	72	139	185	202	191	151	86	34	31	31	31	31	187	1
	12	259	31	31	31	31	34	78	143	185	200	185	143	78	34	31	31	31	192	12
	HALF DAY TOTALS		258	434	684	946	1163	1269	1193	965	697	462	292	198	177	175	175	185	918	
Aug 21	5	29	9	20	27	30	28	22	13	2	2	2	2	2	2	2	2	2	3	7
	6	123	13	58	97	121	125	111	80	34	9	9	9	9	9	9	9	9	23	6
	7	181	15	42	109	157	180	176	145	92	26	14	14	14	14	14	14	14	53	5
	8	214	19	21	78	148	193	208	192	147	76	21	19	19	19	19	19	19	87	4
	9	234	22	22	34	109	174	211	217	189	133	55	23	22	22	22	22	22	117	3
	10	246	25	25	26	52	131	188	217	214	178	114	39	25	25	25	25	25	140	2
	11	252	26	26	26	28	69	144	196	217	207	166	97	31	26	26	26	26	154	1
	12	254	27	27	27	27	29	82	155	201	217	201	155	82	29	27	27	27	159	12
	HALF DAY TOTALS		142	226	410	657	914	1109	1141	997	740	478	275	158	131	130	130	130	656	
Sep 21	7	77	4	10	39	62	74	75	65	44	15	4	4	4	4	4	4	4	8	5
	8	163	10	10	43	103	143	160	154	123	71	14	10	10	10	10	10	10	31	4
	9	206	14	14	17	83	148	189	200	181	133	61	15	14	14	14	14	14	57	3
	10	229	16	16	17	35	116	179	213	214	183	123	41	17	16	16	16	16	81	2
	11	240	18	18	18	19	59	141	198	224	216	174	104	26	18	18	18	18	96	1
	12	244	19	19	19	19	21	82	160	209	227	209	160	82	21	19	19	19	101	12
	HALF DAY TOTALS		71	77	142	307	547	787	910	891	731	480	249	106	72	71	71	71	324	
Oct 21	8	17	1	1	3	10	14	16	16	13	8	2	1	1	1	1	1	1	1	4
	9	122	5	5	6	40	82	109	118	110	83	42	6	5	5	5	5	5	13	3
	10	176	9	9	9	18	83	135	165	169	147	102	36	9	9	9	9	9	29	2
	11	201	11	11	11	11	43	116	167	191	186	152	92	20	11	11	11	11	41	1
	12	208	11	11	11	11	13	70	140	184	199	184	140	70	13	11	11	11	46	12
	HALF DAY TOTALS		31	31	34	86	231	420	542	580	527	388	202	66	32	31	31	31	108	
Nov 21	10	23	1	1	1	1	10	17	21	22	20	14	5	1	1	1	1	1	1	2
	11	79	3	3	3	3	15	44	65	75	74	61	37	8	3	3	3	3	6	1
	12	97	4	4	4	4	4	32	66	87	93	87	66	32	4	4	4	4	8	12
	HALF DAY TOTALS		5	5	5	6	26	79	120	141	140	117	74	23	6	5	5	5	11	
Dec 21	11	4	0	0	0	0	1	2	3	4	4	3	2	0	0	0	0	0	0	1
	12	16	0	0	0	0	1	5	11	14	15	14	11	5	1	0	0	0	1	12
	HALF DAY TOTALS		0	0	0	0	1	5	9	11	11	10	7	3	0	0	0	0	1	
			N	NNW	NW	WNW	W	WSW	SW	SSW	S	SSE	SE	ESE	E	ENE	NE	NNE	HOR	PM

Half Day Totals computed by Simpson's Rule with time interval equal to 10 minutes.
*Total Solar Heat Gains for DSA Sheet Glass.
Based on a ground reflectance of 0.20 and values in Tables 1 and 27.

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

SOLMET
RADIATION DATA

These data were "manufactured" from local weather data and then correlated with similar weather conditions in the Lower 48. In the case of coastal sites in Alaska, the correlations were done using data from Seattle. If the sites were continental or arctic climates, the correlations were made using data from Great Falls, Montana. These are not ideal data, but they are in a useful format. Tapes of SOLMET data are available from the National Climatic Center, NOAA, Asheville, NC 28801.

To convert solar radiation in BTU per square foot to kilojoules per square meter, multiply by the conversion factor 0.088 $KJ/m^2/BTU/ft^2$. To convert solar radiation data in BTU per square foot to langleys (calories per square centimeter), multiply by the conversion factor 0.271246 $langleys/BTU/ft^2$.

SOURCE: A Solar Design Manual for Alaska by Richard D. Seifert

TABLE B1: ANNETTE SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	177.9	448.4	180.6	0	976	33.8
Feb	374.7	660.7	353.6	0	792	37.4
Mar	717.1	851.6	603.2	0	828	39.2
Apr	1,149.5	886.7	846.7	0	666	42.8
May	1,473.1	880.6	1,025.8	138.7	484	50.0
Jun	1,465.6	803.3	983.3	286.7	319	55.4
Jul	1,439.2	816.1	977.4	232.3	230	57.2
Aug	1,162.3	790.3	822.6	71.0	211	59.0
Sep	812.2	766.7	613.3	0	329	53.6
Oct	422.2	603.2	361.3	0	562	46.4
Nov	218.6	493.3	216.7	0	752	39.2
Dec	122.5	325.8	122.6	0	902	35.6
Annual[1]	794.6	694.2	593.7	61.1	7,051	45.7

[1]All are annual means except degree days; this value is the yearly total.

TABLE B2: BETHEL SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	96.8	432.3	129.0	0	1,858	5.0
Feb	316.7	850.0	378.6	0	1,589	8.6
Mar	738.5	1,238.7	800.0	0	1,661	12.2
Apr	1,200.4	1,136.7	1,040.0	0	1,215	24.8
May	1,453.2	948.4	1,074.2	48.4	772	39.2
Jun	1,518.4	886.7	1,073.3	206.7	401	51.8
Jul	1,289.7	787.1	909.7	206.5	319	55.4
Aug	920.0	661.3	667.7	87.1	394	51.8
Sep	700.7	753.3	573.3	0	599	44.6
Oct	370.3	729.0	367.7	0	1,078	30.2
Nov	135.2	493.3	163.3	0	1,435	17.6
Dec	48.7	235.5	64.5	0	1,879	5.0
Annual[1]	732.4	766.8	603.8	46.0	13,201	28.7

[1]All are annual means except degree days; this value is the yearly total.

TABLE B3: BETTLES SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	10.0	119.4	19.4	0	2,425	-13.0
Feb	172.3	717.9	253.6	0	2,038	-7.6
Mar	615.6	1,364.5	793.5	0	1,969	1.4
Apr	1,228.3	1,393.3	1,240.0	0	1,336	21.2
May	1,698.7	1,238.7	1,425.8	0	722	41.0
Jun	1,857.2	1,166.7	1,453.3	0	270	55.4
Jul	1,562.6	1,032.3	1,222.6	19.4	230	57.2
Aug	1,075.1	890.3	893.5	0	407	51.8
Sep	672.2	926.7	653.3	0	751	39.2
Oct	252.1	735.5	309.7	0	1,395	19.4
Nov	40.3	366.7	73.3	0	1,993	-2.2
Dec	0	0	0	0	2,392	-13.0
Annual[1]	765.4	828.2	696.2	1.6	15,926	21.3

[1]All are annual means except degree days; this value is the yearly total.

TABLE B4: BIG DELTA SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	45.9	309.7	71.0	0	2,167	-4.0
Feb	247.1	832.1	328.6	0	1,724	3.2
Mar	711.3	1,409.7	851.6	0	1,634	12.2
Apr	1,244.3	1,300.0	1,166.7	0	1,067	30.2
May	1,669.7	1,161.3	1,329.0	0	580	46.4
Jun	1,782.6	1,083.3	1,336.7	56.7	257	57.2
Jul	1,613.8	1,032.3	1,225.8	29.0	182	59.0
Aug	1,229.0	996.8	1,000.0	0	322	55.4
Sep	766.9	983.3	703.3	0	643	42.8
Oct	326.1	803.2	364.5	0	1,235	24.8
Nov	92.6	540.0	140.0	0	1,742	6.8
Dec	9.1	51.6	12.9	0	2,146	-4.0
Annual[1]	811.5	874.2	712.9	7.12	13,700	27.5

[1]All are annual means except degree days; this value is the yearly total.

SOURCE: A Solar Design Manual for Alaska by Richard D. Seifert

TABLE B5: FAIRBANKS SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	30.1	206.5	45.2	0	2,383	-11.2
Feb	221.4	778.6	300.0	0	1,890	-2.2
Mar	674.2	1,361.3	819.4	0	1,721	10.4
Apr	1,193.9	1,256.7	1,126.7	0	1,084	28.4
May	1,603.6	1,122.6	1,280.6	0	549	46.4
Jun	1,751.9	1,073.3	1,323.3	63.3	211	59.0
Jul	1,542.5	993.5	1,171.0	58.1	148	60.8
Aug	1,118.0	900.0	900.0	0	304	55.4
Sep	709.4	906.7	653.3	0	617	44.6
Oct	292.6	729.0	329.0	0	1,235	24.8
Nov	74.1	466.7	116.7	0	1,867	3.2
Dec	2.5	9.7	3.2	0	2,336	-11.2
Annual[1]	767.8	816.4	673.9	10.1	14,344	25.7

[1]All are annual means except degree days; this value is the yearly total.

TABLE B6: GULKANA SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	72.8	374.2	103.2	0	2,241	-7.6
Feb	286.4	839.3	357.1	0	1,712	3.2
Mar	757.7	1,390.3	864.5	0	1,564	14.0
Apr	1,304.4	1,316.7	1,190.0	0	1,044	30.2
May	1,614.4	1,083.9	1,238.7	0	657	44.6
Jun	1,757.8	1,043.3	1,290.0	93.3	333	53.6
Jul	1,612.0	1,006.5	1,196.8	58.1	254	57.2
Aug	1,251.4	980.6	990.3	0	365	53.6
Sep	795.0	956.7	700.0	0	643	42.8
Oct	390.0	900.0	422.6	0	1,184	26.6
Nov	116.3	503.3	153.3	0	1,768	6.8
Dec	28.5	148.4	35.5	0	2,173	-5.8
Annual[1]	832.2	878.4	713.2	12.6	13,937	26.8

[1]All are annual means except degree days; this value is the yearly total.

TABLE B7: HOMER SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	121.6	496.8	151.6	0	1,352	21.2
Feb	333.9	807.1	364.3	0	1,123	24.8
Mar	759.3	1,145.2	725.8	0	1,159	28.4
Apr	1,248.3	1,100.0	1,006.7	0	900	35.6
May	1,582.6	1,019.4	1,171.0	0	704	42.8
Jun	1,750.6	1,003.3	1,250.0	4.0	490	48.2
Jul	1,598.0	964.5	1,151.6	3.3	394	51.8
Aug	1,188.7	877.4	893.5	0	391	51.8
Sep	791.4	860.0	650.0	0	540	46.4
Oct	437.1	871.0	438.7	0	857	37.4
Nov	175.3	636.7	213.3	0	1,103	28.4
Dec	64.0	267.7	77.4	0	1,352	21.2
Annual[1]	837.6	837.0	676.2	7.3	10,364	36.5

[1]All are annual means except degree days; this value is the yearly total.

TABLE B8: JUNEAU SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	116.3	354.8	125.8	0	1,287	23.0
Feb	282.4	542.9	278.6	0	1,037	28.4
Mar	610.0	771.0	529.0	0	1,026	32.0
Apr	1,045.9	850.0	793.3	0	783	39.2
May	1,291.3	806.5	909.7	4.9	503	46.4
Jun	1,414.4	806.7	970.0	7.9	355	53.6
Jul	1,278.4	758.1	880.6	7.3	288	55.4
Aug	984.5	690.3	703.2	2.9	331	53.6
Sep	638.8	610.0	486.7	0	473	50.0
Oct	320.4	480.6	280.6	0	718	41.0
Nov	148.6	386.7	156.7	0	976	32.0
Dec	61.9	183.9	64.5	0	1,168	26.6
Annual[1]	682.7	603.6	515.9	23.0	9,005	40.3

[1]All are annual means except degree days; this value is the yearly total.

SOURCE: A Solar Design Manual for Alaska by Richard D. Seifert

TABLE B9: KING SALMON SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	146.4	571.0	180.6	0	1,600	14.0
Feb	377.3	907.1	410.7	0	1,355	15.8
Mar	799.1	1,180.6	754.8	0	1,382	21.2
Apr	1,205.6	1,026.7	950.0	0	1,004	32.0
May	1,482.3	938.7	1,071.0	2.2	695	42.8
Jun	1,540.5	876.7	1,070.0	6.7	428	50.0
Jul	1,383.6	822.6	964.5	6.3	326	53.6
Aug	1,045.4	745.2	758.1	1.9	347	53.6
Sep	777.9	810.0	623.3	0	531	46.4
Oct	474.0	925.8	471.0	0	974	33.8
Nov	203.7	710.0	246.7	0	1,287	21.2
Dec	91.0	396.8	112.9	0	1,652	12.2
Annual[1]	793.9	824.7	635.3	17.1	11,583	33.2

[1]All are annual means except degree days; this value is the yearly total.

TABLE B10: KODIAK SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	149.3	496.8	171.0	0	1,073	30.2
Feb	355.9	753.6	364.3	0	941	32.0
Mar	781.9	1,090.3	716.1	0	1,021	32.0
Apr	1,207.8	1,006.7	936.7	0	842	37.4
May	1,376.3	854.8	974.2	4.2	677	42.8
Jun	1,529.9	863.3	1,053.3	7.2	459	50.0
Jul	1,408.2	829.0	977.4	6.4	338	53.6
Aug	1,164.2	829.0	851.6	0.5	313	55.4
Sep	794.0	810.0	626.7	0	450	50.0
Oct	489.2	909.7	474.2	0	752	41.0
Nov	206.5	630.0	233.3	0	905	35.6
Dec	97.1	358.1	112.9	0	1,087	30.2
Annual[1]	796.7	785.5	625.2	18.3	8,860	40.7

[1]All are annual means except degree days; this value is the yearly total.

TABLE B11: KOTZEBUE SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	8.5	19	6.5	0	2,130	-3.7
Feb	164	382	157	0	1,940	4.3
Mar	594	990	590	0	2,031	-0.5
Apr	1,181	1,136	1,026	0	1,560	13.0
May	1,642	1,139	1,268	100	1,060	30.8
Jun	1,836	1,136	1,336	320	645	43.5
Jul	1,528	971	1,080	387	375	52.9
Aug	1,044	748	751	245	443	50.7
Sep	648	670	523	0	717	41.1
Oct	256	439	239	0	1,283	23.6
Nov	33	90	30	0	1,719	7.7
Dec	0	0	0	0	2,136	-3.9
Annual[1]	745	643	583	88	16,039	20.9

[1]All are annual means except degree days; this value is the yearly total.

TABLE B12: MATANUSKA SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days °F-day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	119.3	777.4	193.5	0	1,645	12.2
Feb	339.3	1,053.6	435.7	0	1,285	19.4
Mar	893.5	1,748.4	1,058.1	0	1,240	26.6
Apr	1,313.0	1,306.7	1,186.7	0	859	35.6
May	1,606.5	1,071.0	1,222.6	0	558	46.4
Jun	1,703.3	1,003.3	1,236.7	126.7	302	53.6
Jul	1,506.5	932.3	1,096.8	119.4	232	57.2
Aug	1,158.1	883.9	890.3	0	304	53.6
Sep	730.0	823.3	616.7	0	518	46.4
Oct	367.7	774.2	380.6	0	947	33.8
Nov	140.0	620.0	186.7	0	1,328	21.2
Dec	54.8	403.2	87.1	0	1,627	14.0
Annual[1]	830.1	946.6	638.9	20.9	10,847	35.0

[1]All are annual means except degree days; this value is the yearly total.

SOURCE: A Solar Design Manual for Alaska by Richard D. Seifert

TABLE B13: McGRATH SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	57.9	319.4	83.9	0	2,291	-9.4
Feb	258.5	782.1	325.0	0	1,825	-0.4
Mar	692.7	1,264.5	790.3	0	1,739	8.6
Apr	1,187.8	1,186.7	1,073.3	0	1,156	26.6
May	1,488.2	1,003.2	1,135.5	154.8	648	44.6
Jun	1,586.7	950.0	1,153.3	160.0	284	55.4
Jul	1,379.7	864.5	1,003.2	0	220	59.0
Aug	1,019.1	774.2	780.6	0	396	53.6
Sep	659.0	810.0	600.0	0	635	44.6
Oct	317.0	687.1	332.3	0	1,231	24.8
Nov	100.2	466.7	136.7	0	1,800	5.0
Dec	19.5	109.7	25.8	0	2,300	-9.4
Annual[1]	733.5	767.4	620.8	26.3	14,487	25.2

[1]All are annual means except degree days; this value is the yearly total.

TABLE B14: NOME SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	30	58	23	0	1,829	6.0
Feb	224	471	207	0	1,674	5.2
Mar	631	897	568	0	1,786	7.4
Apr	1,186	1,057	967	0	1,383	18.9
May	1,573	1,048	1,151	219	936	34.8
Jun	1,753	1,063	1,230	390	585	45.5
Jul	1,414	877	958	458	462	50.1
Aug	993	677	680	312	490	49.2
Sep	673	633	513	0	687	42.1
Oct	306	493	264	0	1,132	28.5
Nov	65	143	53	0	1,482	15.6
Dec	3	3	3	0	1,879	4.4
Annual[1]	738	618	551	115	14,325	25.6

[1]All are annual means except degree days; this value is the yearly total.

TABLE B15: SUMMIT SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft²				Degree Days °F·day	Mean Temperature °F
	Horizontal Surface	Vertical Surface				
		South	East/West	North		
Jan	55.9	341.9	83.9	0	1,966	1.4
Feb	250.9	778.6	321.4	0	1,634	6.8
Mar	698.0	1,309.7	809.7	0	1,669	10.4
Apr	1,239.4	1,270.0	1,143.3	0	1,246	23.0
May	1,632.8	1,119.4	1,277.4	0	857	37.4
Jun	1,632.9	983.3	1,196.7	136.7	481	48.2
Jul	1,411.2	890.3	1,035.5	135.5	403	51.8
Aug	1,043.4	803.2	806.5	0	508	48.2
Sep	703.3	836.7	616.7	0	752	39.2
Oct	344.3	819.4	380.6	0	1,271	24.8
Nov	106.8	580.0	156.7	0	1,660	10.4
Dec	16.5	100.0	22.6	0	1,924	3.2
Annual[1]	761.3	818.4	655.3	22.7	14,369	28.3

[1]All are annual means except degree days; this value is the yearly total.

SOURCE: A Solar Design Manual for Alaska by Richard D. Seifert

INSOLATION ON A HORIZONTAL SURFACE (MEAN RECORDED VALUES)

All Figures in BTU/Ft^2 - Day

CITY	ANNETTE	BARROW	BETHEL	FAIRBANKS
Yrs. of Observation	20	11	16	30
Jan.	203	34	136	59
Feb.	435	144	413	265
Mar.	878	664	1010	785
Apr.	1309	1142	1622	1383
May	1622	1910	1685	1726
Jun.	1615	2009	1641	1884
Jul.	1600	1593	1372	1633
Aug.	1191	966	940	1176
Sep.	863	442	737	682
Oct.	417	151	424	302
Nov.	206	18	162	103
Dec.	133	0	85	22
Annual*	874	759	853	837

*Mean average

Source: Climates of the U.S., Vol. 2, NOAA, U.S. Dept. of Commerce, Water Information Center, Inc., Port Washington, N.Y. 11050

APPENDIX B

Design Data

Appendix B: Design Data

Source: U.S. Army Corps of Engineers, unpublished

Station	Elev. (ft.)	Temperature, °F Abs. min.	Mean ann.	Abs. max.	Heating degree days (°F-day)	Wind, mph Prevailing Dir.	Mean speed
Arctic Slope Region							
Anaktuvuk Pass	2100	-56	13.3	91	18870		
Barrow WSO AP	31	-56	9.3	78	20265	E	11.9
Barter Island WSO AP	39	-59	10.1	75	19994	E	13.0
Cape Lisburne	45	-47	18.1	74	17119	E	13.0
Galbraith Lake Camp	2700		11.2	78	19637		
Happy Valley Camp	1000	-55	10.8	81	19783		
Point Lay	10	-55	12.5	78	19783		
Prudhoe Bay		-62		76		NE	10.0
Unitat	337	-63	10.3	85	19966	W	7.7
Wainwright (not Ft. Wainwright)	29	-56	10.9	80	19747	E	
Northwest Region							
Candle	15	-60	19.9	85	16462	N	
Cape Thompson	33	-45	18.8	68	168863		
Connell	95	-45	25.9	86	14272		
Gambell	25	-30	24.2	61	14892	N	16.8
Golovin	12	-40	26.8	80	13943	NW	
Kobuk	140	-64	20.8	90	15133		
Kotzebue WSO AP	10	-52	20.9	85	16039	E	13.0
Moses Point FAA	15	-49	24.9	87	14637	NNE	
Nome WSO AP	13	-17	25.6	86	14325	E	11.0
Noorvik	68	-51		87			
Northeast Cape	38	-36	25.5	68	14418	N	12.9
Point Hope	13	-49	18.5	72	16973		
St. Michael	50	-55	25.9	77	14272	N	
Savoonga	35	-55	25.9	77	14272	N	
Shaktoolik	15						
Shishmatef	12	-48	20.3	78	16316	N	
Shungnak	138	-61	22.3	90	15586		
Tellet	15	-45	23.8	82	15038	E	
Tin City	269	-41	21.0	74	16060	N	17.5
Unalakleet WSO	15	-50	26.4	87	14027	E	12.7
Wales	9	-44	21.2	75	15987	NE	
White Mountain	50	-55	27.8	89	13578	N	
Yukon Region							
Akulurak	33	-49	27.3	75	13761		
Allakaket	600	-72	19.5	97	16608	E	
Arctic Village	2020	-68	14.5	80	18433		
Bettles WSO AP	666	-68	21.3	92	15925	NNW	6.7
Big Delta FFA AP (Ft. Grly.)	1268	-63	27.5	92	13698	ESE	8.2
Boundary	2600	-50	22.3	87	15586		
Canyon Village	990	66	17.5	89	17338		
Cathedral Bluffs	1550	-59	23.9	84	15002		
Central #2	960	-66	19.7	92	16535		
Chalkyitsik	560	-69	19.3	94	16681		
Chandalar Lake	1840	-64	16.4	84	17739		
Chena Hot Springs	1195	-59	22.8	87	15403		
Chisana	3170	-59	21.7	85	15805		
Circle Hot Springs	935	-60	22.0	94	15671	SW	
Clear	580	-62	23.0	96	15330		
Clear Water	1100	-71	23.8	93	15038		
Coldfoot Camp	1100	-74	15.5	88	18068		
Colleen River	900		15.5	82	18068		
College Magnetic Observatory	621	-66	26.5	94	14053		
Delta Junction	1190	-58	26.0	86	14235		
Dietrich Camp	1950	-70	12.3	85	19236		
Dot Lake	1100	-62	26.2	88	11162		
Eagle	850	-75	23.9	95	15002		
Eilson	547	-64	25.1	93	11564		
Fairbanks WSO AP	136	-66	25.7	99	14345		
Fort Yukon	413	-75	20.4	100	16279		
Galeno	120	-61	23.6	92	15111		
Gilmore Creek	959	-52	24.9	92	14637		
Healy	1350	-46	30.0	90	12775		
Holy Cross	200	-62	29.2	93	13067	NW	
Hughes	545	-68	23.2	90	15257	N	
Indian Mountain	1220	-65	23.5	89	15148	ENE	5.8
Manley Hot springs	265	-70	24.5	91	14783	N	
McKinley	2070	-54	26.9	89	13878	SE	
Mountain Village	44	-44	27.8	80	13578		
Nenana	356	-69	25.1	98	14539	E	5.3
North Pole	475	-66	22.8	95	15403		
Prospect Creek	1100	-80	13.2	87	18907		
Rampart	375	-68	22.1	97	15659	NE	
Richardson	890	-63	28.0	98	13505	E	
Rock Landing	1268	-65	24.5	94	17783		
Russian Mission	50	-48	27.6	86	13651		
St. Mary's	25	-44	29.2	83	13067		
Tanacross	1500	-75	22.8	90	15403	WNW	
Tanana	232	-76	23.5	92	15116	NE	6.5
The Harris's	2070	-41	23.3	86	15221		
Wiseman	1286	-65	22.0	89	15695	N	
Southwest Region							
Aduk	15	3	40.8	75	8833	W	14.5
Alaknagik	70	-36	33.1	88	11644		
Almak Bay	12	-3	40.0	79	9125		
Amchitka	226	15	38.7	65	9600	None	20.6
Attu	70	2	30.0	77	9190	WSW	12.7
Bethel	125	-52	28.7	86	13203	NNE	12.9
Cape Newhenham	475	-28	32.3	75	11936	SE	9.6
Cape Romanzoff	434	-26	28.8	79	13213	NE	13.7
Cape Sarichef	175	-5	38.7	74	9600		
Chernofski Harbor	25	10	40.2	77	9052		
Chignik	30	-12	37.6	76	10001	SE-W	
Cold Harbor		-12	39.0	80	9490		
Cold Bay WSO AP	96	-13	37.9	78	9865	SSE	17.0
Crooked Creek	125	-59	28.2	94	13432		
Dillingham	50	-41	34.1	92	11279	N	
Driftwood Bay						NW	9.3
Dutch Harbor	13	8	40.5	80	8943	SE	11.0
Egegik	50	-21	31.3	75	12301		
Farewell FAA AP	1499	-61	25.4	86	14454		
Hooper Bay	35						
Iliamna FAA AP	145	-47	33.3	91	11571	ESE	10.4
Intrieare Bay	170	-47	33.6	84	11461		
Kalskag		-48	28.5	79	13323	NE	
Kanatak	85	-20	41.8	75	8468		
King Salmon WSO AP	49	-42	33.2	88	11582	N	11.0
Kitoi Bay	15	-12	38.9	83	9527		
Kodiak NAS	21	-12	40.7	86	8860	NW	10.0
Lake Netka	65	-49	31.2	94	12337		
Larsen Bay	15	-5	39.9	83	9162		
McGrath WSO AP	344	-67	25.2	90	14487	N	4.9
Nikolai	425	-61	23.7	86	15075		
Nikolski	83					NW	15.9
Nunivak	44	-48	29.3	76	13031		
Nyac	450	-49	30.6	87	12556		
Old Harbor	20	0	41.4	76	8614		

Station	Elev. (ft.)	Temperature, °F Abs. min.	Mean ann.	Abs. max.	Heating degree days (°F-day)	Wind, mph Prevailing Dir.	Mean speed
Platinum	20	-34	31.8	82	12118	N	
Port Alsworth	260	-55	33.2	86	11607		
Port Heiden	92	-25	35.7	87	10695	SE	14.6
Port Moller	37		34.3		11206	S	10.0
St. George Island	100	-7	36.3	63	10476		
St. Paul Island WSO AP	22	-26	34.5	64	11119	NW	18.4
Sand Point	32	1	39.6	70	9271		
Scotch Cap	20	9	40.5	74	8943		
Shearwater Bay	10	-1	40.2	86	9052		
Shemva WSO AP	122	7	38.3	63	9735	WSW	18.6
Sitkinak	53	3	39.7	76	9235		
Sleetmute	285	-50	28.2	85	13432		
Sparrevohn	1580	-47	29.4	82	12994	S	5.6
Tatalina	964	-41	28.1	91	13469	ENE	4.6
Ugnik	50	-3	40.8	85	8833		
Umnak	130	12	39.2	73	9417		
Woody Island	101	0	41.9	82	8432		
South Central Region							
Adult Conservation Camp	825	-29	34.1	89	11279		
Alpine Inn	455	-43	33.8	90	11388		
Alyeska	251	-20	34.6	88	11096		
Anchorage 4 ESE	180	-42	32.7	83	11790		
Anchorage Park Strip	85	-50	34.4	87	11169		
Anchorage WSO AP	114	-52	35.0	92	10911	N	6.7
Anderson Lake	475	-44	31.3	85	12301		
Beacon Park	160	-34	31.8	83	12118		
Bear Cove	75	-32	35.1	84	10914		
Ben's Farm Market	100	-45	33.6	90	11461		
Big Lake	220	-44	32.8	89	11753		
Birch Road	460	-28	33.4	85	11534		
Cape Hinchinbrook	185	-15	41.4	81	8614		
Cape St. Elias	58	0	42.4	78	8239		
Caswell	290	-47	31.0	93	12410		
Chickaloon	929	-42	32.7	90	11790		
Chistochina	1857	-55	27.1	93			
Chitina	600	-58	29.0	91	13140		
Chulitna River Lodge	1250	-25	28.8	87	13213		
Cooper Lake Project	445	-25	36.1	84	10549		
Coopers Landing	2147						
Copper Center	1000	-74	25.9	96	14272		
Copper Valley School	1030	-62	27.0	88	13870		
Cordova - KLAM	25	-23	40.2	81	9052		
Cordova FAA AP	41	-33	38.2	84	9765		
Creekside Public School	260	-53	33.0	88	11680		
Curry	544	-42	34.9	86	10987		
Devils Club	360	-17	37.8	79	9928		
Eagle River	750	-26		83			
Eklutna	27	-47	34.9	91	10987		
Eklutna Lake	882	-54	31.2	90	12337		
Eklutna Project	38	-41	33.3	92	11571		
Elmendorf AFB*	192	-43	35.1	86	10905	N	4.6
Ernestine	1836	-48	26.7	85	13980		
Eureka	3326	-44	24.2	85	14892		
Gakona IN	1460	-57	23.8	89	15038		
Girdwood	20	-27	36.3	82	10476		
Glennallen	1456	-60	24.2	90	14892		
Goose Bay Nike Site	100	-42	34.5	93	11133		
Gulkana WSO	1570	-65	26.8	91	13938	SE	6.8
Gunsight	2960	-59	20.4	82	16279		
High Lake Lodge	2398	-44	27.3	77	13761		
Homer WSO	67	-21	36.5	80	10364	NE	6.5
Homer 5 NW	1000	-17	36.0	81	10585		
Iniskin	300	-28	33.9	84	11352		
Kasilof	75	-44	34.1	87	11279	N	
Kasitsna Bay	12	-7	37.5	75	10038		
Kenai FAA Municipal AP	86	-48	33.1	93	11644	N	6.6
Kennecott	2210	-50	30.2	84	12702		
Kenney Lake	1200	-65	26.1	86	14199		

Station	Elev. (ft.)	Temperature, °F Abs. min.	Mean ann.	Abs. max.	Heating degree days (°F-day)	Wind, mph Prevailing Dir.	Mean speed
Latouche	45	-3	41.4	82	8614		
Matanuska Agricultural Exp.	150	-41	35.2	91	10849	NE	
Matanuska Valley #15	350	-42	35.4	84	10804		
May Creek	1500	-64	25.6	88	14381		
McCarthy	1380	-57	32.4	87	11899		
McKinley View	650	-34	34.1	96	11279		
Middleton Island FAA	39	6	42.3	72	8286	ESE	13.8
Moose Pass	485	-48	34.0	90	11315		
Moose Run-Ft. Richardson GC	395	-23	35.4	84	10804		
Nikiski Terminal	110	-35	34.7	86	11060		
Ninilchik 5 NE	205	-20	33.9	74	11352		
North Dutch Island FAA	33	0	40.8	79	8833		
Old Well Road EP	370	-27	33.8	88	11388		
Old Edgerton	1320	-58	24.4	92	114819		
Palmer AAES	225	-38	34.2	87	11242		
Palmer 1 N	220	-35	35.7	90	10667		
Palmer 2 ESE	125	-41	32.1	83	10667		
Palmer 4 SSE	175	-44	34.6	84	11096		
Palmer 5 NW	630	-42	34.7	87	11060		
Paxson Lake	2750	-59	23.1	85	15294		
Portage	35	-37	36.8	85	10293		
Puntilla	1832	-47	25.8	86	14308		
Seldovia Dock	31	-10	37.5	73	10038		
Seward	70	-20	39.6	88	9242	N-S	
Sheep Mountain	2280	-36	28.4	85	13359		
Skwentna	153	-51	32.0	90	12045		
Slana	2200	-51	27.9	93	13542		
Slide Mountain	2450	-53	23.5	87	15148		
Snowshoe Lake	2410	-63	22.1	85	15659		
Soldotna	113	-39	32.5	89	11863		
South Fork	1100	-23	34.0	88	11315		
Sterling	180	-52	31.8	90	12118		
Summit Lake	3230	-53	22.7	79	15440		
Summit Nike Site	3980	-62	28.4	75	13359		
Summit WSO	2401	-45	25.5	89	14368	NE	9.7
Susitna		-48	35.6	87	10731		
Susitna Meadows	750	-56	28.6	96	13286		
Talkeetna WSO	345	-48	32.8	91	11708		
Thompson Pass	2500	-39	28.5	75	13323		
Tolovankorga	470	-44	31.9	85	12082		
Tonsina Lodge	1500	-61	25.7	90	14345		
Trappers Creek Camp	500	-36	32.5	92	11863		
Tri-Nal Acres	325	-40	30.3	85	12666		
Tsaina Lodge	1650	-46	25.8	83	14308		
Tyonek	50	-27	36.3	91	10476		
Valdez	49	-28	36.0	87	10545		
Venta	150	-20	37.1	76	10184		
Wasilla 2 NE	500	-39	34.2	87	11242		
Wasilla 3 S	50	-50	35.1	90	10914		
White's Crossing	251	-46	28.3	89	13396		
Whittier	15	-29	38.7	88	9600		
Willow Lake	1400	-56	24.6	90	14746		
Willow Trading Post	600	-48	41.2	90	8687		
Yakataga FAA	27	-11	34.1	78	11279	ESE	7.1
Southeast Region							
Angoon	15	-10	41.6	83	8511	SE	
Annette WSO AP	110	-4	45.7	90	7053	SSE	10.8
Annex Creek	24	-18	39.8	84	9187	SE-N	
Auke Bay	42	-15	40.6	87	8906		
Baranof	20	-10	41.3	78	8651		
Beaver Falls	1		44.2	88	7592		
Bell Island	10	-10	43.6	90	7811		
Calder	20	-9	43.1	85	7994		
Canyon Island	175	-21	39.2	86	9417		
Cape Decision	39	0	43.6	81	7816	W	
Cape Spencer	81	-1	42.0	79	8391		
Chichagof	10	-10	41.9	86	8432		
Coffman Cove	10						
Craig	13	-2	44.9	86	7337	SE	

Station	Elev. (ft.)	Temperature, °F Abs. min.	Mean ann.	Abs. max.	Heating degree days (°F-day)	Wind, mph Prevailing Dir.	Mean speed
Eldred Rock	55	-20	41.3	86	8651	SW	
Five Finger Light	30	1	42.9	77	8067	SSE	
Fortmann Hatchery	132	-23	43.3	93	7921		
Glacier Bay	50	-4	39.6	76	9271		
Guard Island	20	0	45.9	81	6972	SE	
Gull Cove	18	-2	41.2	80	8687		
Gustavus	17	-25	40.9	87	8797		
Haines Terminal	175	-16	40.4	90	8979	SE	
Hollis	15	9	45.1	87	7264		
Hydaburg	25	-3	45.8	88	7008		
Hyder	9	-8	41.3	89	8651		
Juneau #2	25	-10	42.8	87	8106		
Juneau WSO AP	12	-22	40.3	86	9007	ESE	8.6
Juneau 9 NW	120	-22	37.7	73	9964		
Kake	30	-4	42.1	88	8359		
Kasaan	28						
Ketchikan	15	-8	46.2	96	6885	SE	
Klukwan		-36	36.3	94	10476		
Lincoln Rock Light	25	-5	44.8	85	7373		
Linger Longer	700	-29	36.3	94	10476		
Little Port Walter	14	0	42.8	81	8069	N	
Mendenhall	85	14	40.0	78	9125		
Moose Valley	400	-40	35.8	93	10658		
Pehean	75	-3	40.8	84	8833		
Petersburg	50	-19	41.9	84	8409	SW	
Point Retreat Light	20	-15	41.9	86	8432		
Porcupine Creek	1600	-42	34.5	95	11133		
Port Alexander	18	4	43.9	80	7702		
Radioville	15	-3	45.0	89	7300		
Seclusion Harbor	20	-2	43.2	92	7957		
Sitka FAA AP	15	-1	44.1	85	7629		
Sitka Magnetic	67	-8	42.7	87	8132	E	
Skagway #2	10	-15	40.8	92	8833		
Snettisham Project	42	-16	36.6	83	10366		
Speel River	15						
Tenakee Springs	20	-9	42.1	93	8359		
Tree Point Light	36	-11	45.7	96	7045		
View Cove	13	5	46.3	88	6826		
Wrangell	37	-10	43.0	92	8010	SE	
Yakatat WSO AP	28	-24	38.8	86	9533	E	

APPENDIX C

R-Values of Building Materials

Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a]

(For Industrial Insulation Design Values, see Table 3B). These constants are expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature difference). Conductivities *(k)* are per inch thickness, and conductances *(C)* are for thickness or construction stated, not per inch thickness. **All values are for a mean temperature of 75 F, except as noted by an asterisk (*) which have been reported at 45 F.** The SI units for Resistance (last two columns) were calculated by taking the values from the two Resistance columns under Customary Unit, and multiplying by the factor 1/k (r/in.) and 1/C (R) for the appropriate conversion factor in Table 18.

Description	Customary Unit						SI Unit	
	Density (lb/ft³)	Conductivity (*k*)	Conductance (*C*)	Resistance[b] (*R*) Per inch thickness (1/*k*)	Resistance[b] (*R*) For thickness listed (1/*C*)	Specific Heat, Btu/(lb) (deg F)	Resistance[b] (*R*) (m·K)/W	Resistance[b] (*R*) (m²·K)/W
BUILDING BOARD								
Boards, Panels, Subflooring, Sheathing								
Woodboard Panel Products								
Asbestos-cement board	120	4.0	—	*0.25*	—	0.24	1.73	
Asbestos-cement board 0.125 in.	120	—	33.00	—	*0.03*			*0.005*
Asbestos-cement board 0.25 in.	120	—	16.50	—	*0.06*			*0.01*
Gypsum or plaster board 0.375 in.	50	—	3.10	—	*0.32*	0.26		*0.06*
Gypsum or plaster board 0.5 in.	50	—	2.22	—	*0.45*			*0.08*
Gypsum or plaster board 0.625 in.	50	—	1.78	—	*0.56*			*0.10*
Plywood (Douglas Fir)[o]	34	0.80	—	*1.25*	—	0.29	8.66	
Plywood (Douglas Fir) 0.25 in.	34	—	3.20	—	*0.31*			*0.05*
Plywood (Douglas Fir) 0.375 in.	34	—	2.13	—	*0.47*			*0.08*
Plywood (Douglas Fir) 0.5 in.	34	—	1.60	—	*0.62*			*0.11*
Plywood (Douglas Fir) 0.625 in.	34	—	1.29	—	*0.77*			*0.19*
Plywood or wood panels 0.75 in.	34	—	1.07	—	*0.93*	0.29		*0.16*
Vegetable Fiber Board								
Sheathing, regular density 0.5 in.	18	—	0.76	—	*1.32*	0.31		*0.23*
0.78125 in.	18	—	0.49	—	*2.06*			*0.36*
Sheathing intermediate density 0.5 in.	22	—	0.82	—	*1.22*	0.31		*0.21*
Nail-base sheathing 0.5 in.	25	—	0.88	—	*1.14*	0.31		*0.20*
Shingle backer 0.375 in.	18	—	1.06	—	*0.94*	0.31		*0.17*
Shingle backer 0.3125 in.	18	—	1.28	—	*0.78*			*0.14*
Sound deadening board 0.5 in.	15	—	0.74	—	*1.35*	0.30		*0.24*
Tile and lay-in panels, plain or acoustic	18	0.40	—	*2.50*	—	0.14	17.33	
0.5 in.	18	—	0.80	—	*1.25*			*0.22*
0.75 in.	18	—	0.53	—	*1.89*			*0.33*
Laminated paperboard	30	0.50	—	*2.00*	—	0.33	13.86	
Homogeneous board from repulped paper	30	0.50	—	*2.00*	—	0.28	13.86	
Hardboard								
Medium density	50	0.73	—	*1.37*	—	0.31	9.49	
High density, service temp. service underlay	55	0.82	—	*1.22*	—	0.32	8.46	
High density, std. tempered	63	1.00	—	*1.00*	—	0.32	6.93	
Particleboard								
Low density	37	0.54	—	*1.85*	—	0.31	12.82	
Medium density	50	0.94	—	*1.06*	—	0.31	7.35	
High density	62.5	1.18	—	*0.85*	—	0.31	5.89	
Underlayment 0.625 in.	40	—	1.22	—	*0.82*	0.29		*0.14*
Wood subfloor 0.75 in.		—	1.06	—	*0.94*	0.33		*0.17*
BUILDING MEMBRANE								
Vapor—permeable felt	—	—	16.70	—	*0.06*			*0.01*
Vapor—seal, 2 layers of mopped 15-lb felt	—	—	8.35	—	*0.12*			*0.02*
Vapor—seal, plastic film	—	—	—	—	Negl.			
FINISH FLOORING MATERIALS								
Carpet and fibrous pad	—	—	0.48	—	*2.08*	0.34		*0.37*
Carpet and rubber pad	—	—	0.81	—	*1.23*	0.33		*0.22*
Cork tile 0.125 in.	—	—	3.60	—	*0.28*	0.48		*0.05*
Terrazzo 1 in.	—	—	12.50	—	*0.08*	0.19		*0.01*
Tile—asphalt, linoleum, vinyl, rubber	—	—	20.00	—	*0.05*	0.30		*0.01*
vinyl asbestos						0.24		
ceramic						0.19		
Wood, hardwood finish 0.75 in.			1.47		*0.68*			0.12
INSULATING MATERIALS								
Blanket and Batt[d]								
Mineral Fiber, fibrous form processed from rock, slag, or glass								
approx.[e] 3-3.5 in.	0.3-2.0	—	0.091	—	*11[d]*			*1.94*
approx.[e] 5.50-6.5	0.3-2.0	—	0.053	—	*19[d]*			*3.35*
approx.[e] 6-7 in.	0.3-2.0		0.045		*22[d]*			*3.87*
approx.[e] 8.5-9 in.	0.3-2.0		0.033		*30[d]*			*5.28*
approx. 12 in.	0.3-2.0	—	0.026		*38[d]*			*6.69*

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a]

Description	Density (lb/ft³)	Conductivity (k)	Conductance (C)	Customary Unit Resistance[b] (R) Per inch thickness (1/k)	Customary Unit Resistance[b] (R) For thickness listed (1/C)	Specific Heat, Btu/(lb) (deg F)	SI Unit Resistance[b] (R) (m·K)/W	SI Unit Resistance[b] (R) (m²·K)/W
BOARD AND SLABS								
Cellular glass	8.5	0.35	—	*2.86*	—	0.18	*19.81*	
Glass fiber, organic bonded	4–9	0.25	—	*4.00*	—	0.23	*27.72*	
Expanded perlite, organic bonded	1.0	0.36	—	*2.78*	—	0.30	*19.26*	
Expanded rubber (rigid)	4.5	0.22	—	*4.55*	—	0.40	*31.53*	
Expanded polystyrene extruded								
Cut cell surface	1.8	0.25	—	*4.00*	—	0.29	*27.72*	
Smooth skin surface	1.8–3.5	0.20	—	*5.00*	—	0.29	*34.65*	
Expanded polystyrene, molded beads	1.0	0.20	—	—	—	—	*26.3*	*3.8*
	1.25	0.25	—	—	—	—	*27.8*	*4.0*
	1.5	0.24	—	—	—	—	*29.1*	*4.2*
	1.75	0.24	—	—	—	—	*29.1*	*4.2*
	2.0	0.23	—	—	—	—	*29.8*	*4.3*
Cellular polyurethane[f] (R-11 exp.)(unfaced)	1.5	0.16	—	*6.25*	—	0.38	*43.82*	
(Thickness 1 in. or greater)	2.5							
(Thickness 1 in. or greater—high resistance to gas permeation facing)	1.5	0.14						
Foil-faced, glass fiber-reinforced cellular								
Polyisocyanurate (R-11 exp.)[n]	2	0.14	—	*7.04*	—	0.22	*48.79*	
Nominal 0.5 in.		—	0.278	—	*3.6*			*0.63*
Nominal 1.0 in.		—	0.139	—	*7.2*			*1.27*
Nominal 2.0 in.		—	0.069	—	*14.4*			*2.53*
Mineral fiber with resin binder	15	0.29	—	*3.45*	—	0.17	23.91	
Mineral fiberboard, wet felted								
Core or roof insulation	16–17	0.34	—	*2.94*	—		20.38	
Acoustical tile	18	0.35	—	*2.86*	—	0.19	19.82	
Acoustical tile	21	0.37	—	*2.70*	—		18.71	
Mineral fiberboard, wet molded								
Acoustical tile[g]	23	0.42	—	*2.38*	—	0.14	16.49	
Wood or cane fiberboard								
Acoustical tile[g] 0.5 in.	—	—	0.80	—	*1.25*	0.31		0.22
Acoustical tile[g] 0.75 in.	—	—	0.53	—	*1.89*			0.33
Interior finish (plank, tile)	15	0.35	—	*2.86*	—	0.32	19.82	
Cement fiber slabs (shredded wood with Portland cement binder	25–27	0.50–0.53	—	*2.0–1.89*	—	—	*13.87*	
Cement fiber slabs (shredded wood with magnesia oxysulfide binder)	22	0.57	—	*1.75*	—	0.31	*12.16*	
LOOSE FILL								
Cellulosic insulation (milled paper or wood pulp)	2.3–3.2	0.27–0.32	—	*3.13–3.70*	—	0.33	*21.69–25.64*	
Sawdust or shavings	8.0–15.0	0.45	—	*2.22*	—	0.33	*15.39*	
Wood fiber, softwoods	2.0–3.5	0.30	—	*3.33*	—	0.33	*23.08*	
Perlite, expanded	5.0–8.0	0.37	—	*2.70*	—	0.26	*18.71*	
	2.0–4.1	0.27–0.31	3.7–3.3					
	4.1–7.4	0.31–0.36	3.3–2.8					
	7.4–11.0	0.36–0.42	2.8–2.4					
Mineral fiber (rock, slag or glass)								
approx.[e] 3.75–5 in.	0.6–2.0	—	—		11	0.17		*1.94*
approx.[e] 6.5–8.75 in.	0.6–2.0	—	—		19			*3.35*
approx.[e] 7.5–10 in.	0.6–2.0	—	—		22			*3.87*
approx.[e] 10.25–13.75 in.	0.6–2.0	—	—		30			*5.28*
Vermiculite, exfoliated	7.0–8.2	0.47	—	*2.13*	—	3.20	*14.76*	
	4.0–6.0	0.44	—	*2.27*	—		*15.73*	
ROOF INSULATION[h]								
Preformed, for use above deck								
Different roof insulations are available in different thicknesses to provide the design C values listed.[h] Consult individual manufacturers for actual thickness of their material			0.36 to 0.05		2.7 *to* 20		— —	*0.49 to 3.52*
MASONRY MATERIALS								
CONCRETES								
Cement mortar	116	5.0	—	*0.20*	—		*1.39*	
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	51	1.66	—	*0.60*	—	0.21	*4.16*	

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a]

Description	Density (lb/ft³)	Conductivity (k)	Conductance (C)	Customary Unit Resistance[b] (R) Per inch thickness (1/k)	Customary Unit Resistance[b] (R) For thickness listed (1/C)	Specific Heat, Btu/(lb) (deg F)	SI Unit Resistance[b] (R) (m·K)/W	SI Unit Resistance[b] (R) (m²·K)/W
Lightweight aggregates including expanded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes	120	5.2	—	*0.19*	—		*1.32*	
	100	3.6	—	*0.28*	—		*1.94*	
	80	2.5	—	*0.40*	—		*2.77*	
	60	1.7	—	*0.59*	—		4.09	
	40	1.15	—	*0.86*	—		*5.96*	
	30	0.90	—	*1.11*	—		*7.69*	
	20	0.70		*1.43*			*9.91*	
Perlite, expanded	40	0.93		*1.08*			*7.48*	
	30	0.71		*1.41*			*9.77*	
	20	0.50		*2.00*		0.32	*13.86*	
Sand and gravel or stone aggregate (oven dried)	140	9.0	—	*0.11*		0.22	*0.76*	
Sand and gravel or stone aggregate (not dried)	140	12.0	—	*0.08*			*0.55*	
Stucco	116	5.0	—	*0.20*			*1.39*	
MASONRY UNITS								
Brick, common[i]	120	5.0	—	*0.20*	—	0.19	*1.39*	
Brick, face[i]	130	9.0	—	*0.11*	—		*0.76*	
Clay tile, hollow:								
1 cell deep ... 3 in.	—	—	1.25	—	*0.80*	0.21		*0.14*
1 cell deep ... 4 in.	—	—	0.90	—	*1.11*			*0.20*
2 cells deep ... 6 in.	—	—	0.66	—	*1.52*			*0.27*
2 cells deep ... 8 in.	—	—	0.54	—	*1.85*			*0.33*
2 cells deep ... 10 in.	—	—	0.45	—	*2.22*			*0.39*
3 cells deep ... 12 in.	—	—	0.40	—	*2.50*			*0.44*
Concrete blocks, three oval core:								
Sand and gravel aggregate ... 4 in.	—	—	1.40	—	*0.71*	0.22		*0.13*
... 8 in.	—	—	0.90	—	*1.11*			*0.20*
... 12 in.	—	—	0.78	—	*1.28*			*0.23*
Cinder aggregate ... 3 in.	—	—	1.16	—	*0.86*	0.21		*0.15*
... 4 in.	—	—	0.90	—	*1.11*			*0.20*
... 8 in.	—	—	0.58	—	*1.72*			*0.30*
... 12 in.	—	—	0.53	—	*1.89*			*0.33*
Lightweight aggregate ... 3 in.	—	—	0.79	—	*1.27*	0.21		*0.22*
(expanded shale, clay, slate ... 4 in.	—	—	0.67	—	*1.50*			*0.26*
or slag; pumice) ... 8 in.	—	—	0.50	—	*2.00*			*0.35*
... 12 in.	—	—	0.44	—	*2.27*			*0.40*
Concrete blocks, rectangular core.*[j]								
Sand and gravel aggregate								
2 core, 8 in. 36 lb.[k]*	—	—	0.96	—	*1.04*	0.22		*0.18*
Same with filled cores[j]*	—	—	0.52	—	*1.93*	0.22		*0.34*
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):								
3 core, 6 in. 19 lb.[k]*	—	—	0.61	—	*1.65*	0.21		*0.29*
Same with filled cores[l]*	—	—	0.33	—	*2.99*			*0.53*
2 core, 8 in. 24 lb.[k]*	—	—	0.46	—	*2.18*			*0.38*
Same with filled cores[l]*	—	—	0.20	—	*5.03*			*0.89*
3 core, 12 in. 38 lb.[k]*	—	—	0.40	—	*2.48*			*0.44*
Same with filled cores[l]*	—	—	0.17	—	*5.82*			*1.02*
Stone, lime or sand	—	12.50	—	*0.08*	—	0.19	*0.55*	
Gypsum partition tile:								
3 × 12 × 30 in. solid	—	—	0.79	—	*1.26*	*0.19*		*0.22*
3 × 12 × 30 in. 4-cell	—	—	0.74	—	*1.35*			*0.24*
4 × 12 × 30 in. 3-cell	—	—	0.60	—	*1.67*			*0.29*
METALS								
PLASTERING MATERIALS								
Cement plaster, sand aggregate	116	5.0	—	*0.20*	—	0.20	*1.39*	
Sand aggregate ... 0.375 in.	—	—	13.3	—	*0.08*	0.20		*0.01*
Sand aggregate ... 0.75 in.	—	—	6.66	—	*0.15*	0.20		*0.03*
Gypsum plaster:								
Lightweight aggregate ... 0.5 in.	45	—	3.12	—	*0.32*			*0.06*
Lightweight aggregate ... 0.625 in.	45	—	2.67	—	*0.39*			*0.07*
Lightweight agg. on metal lath ... 0.75 in.	—	—	2.13	—	*0.47*			*0.08*
Perlite aggregate	45	1.5	—	*0.67*	—	0.32	*4.64*	
Sand aggregate	105	5.6	—	*0.18*	—	0.20	*1.25*	
Sand aggregate ... 0.5 in.	105	—	11.10	—	*0.09*			*0.02*
Sand aggregate ... 0.625 in.	105	—	9.10	—	*0.11*			*0.02*
Sand aggregate on metal lath ... 0.75 in.	—	—	7.70	—	*0.13*			*0.02*
Vermiculite aggregate	45	1.7	—	*0.59*	—		*4.09*	

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Thermal Properties of Typical Building and Insulating Materials—(Design Values)[a]

Description	Density (lb/ft³)	Conductivity (k)	Conductance (C)	Resistance[b] (R) Per inch thickness (1/k)	Resistance[b] (R) For thickness listed (1/C)	Specific Heat, Btu/(lb) (deg F)	Resistance[b] (R) (m·K)/W	Resistance[b] (R) (m²·K)/W
	Customary Unit						SI Unit	
ROOFING								
Asbestos-cement shingles	120	—	4.76	—	*0.21*	0.24		*0.04*
Asphalt roll roofing	70	—	6.50	—	*0.15*	0.36		*0.03*
Asphalt shingles	70	—	2.27	—	*0.44*	0.30		0.08
Built-up roofing 0.375 in.	70	—	3.00	—	*0.33*	0.35		*0.06*
Slate 0.5 in.	—	—	20.00	—	*0.05*	0.30		*0.01*
Wood shingles, plain and plastic film faced	—	—	1.06	—	*0.94*	0.31		*0.17*
SIDING MATERIALS (ON FLAT SURFACE)								
Shingles								
Asbestos-cement	120	—	4.75	—	*0.21*			*0.04*
Wood, 16 in., 7.5 exposure	—	—	1.15	—	*0.87*	0.31		*0.15*
Wood, double, 16-in., 12-in. exposure	—	—	0.84	—	*1.19*	0.28		*0.21*
Wood, plus insul. backer board, 0.3125 in.	—	—	0.71	—	*1.40*	0.31		*0.25*
Siding								
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	*0.21*	0.24		*0.04*
Asphalt roll siding	—	—	6.50	—	*0.15*	0.35		*0.03*
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	*1.46*	0.35		*0.26*
Hardboard siding, 0.4375 in.	40	1.49	—	*0.67*		0.28	*4.65*	
Wood, drop, 1 × 8 in.	—	—	1.27	—	*0.79*	0.28		*0.14*
Wood, bevel, 0.5 × 8 in., lapped	—	—	1.23	—	*0.81*	0.28		*0.14*
Wood, bevel, 0.75 × 10 in., lapped	—	—	0.95	—	*1.05*	0.28		*0.18*
Wood, plywood, 0.375 in., lapped	—	—	1.59	—	*0.59*	0.29		*0.10*
Aluminum or Steel[m], over sheathing								
Hollow-backed	—	—	1.61	—	*0.61*	0.29		*0.11*
Insulating-board backed nominal 0.375 in.	—	—	0.55	—	*1.82*	0.32		*0.32*
Insulating-board backed nominal 0.375 in., foil backed			0.34		*2.96*			*0.52*
Architectural glass	—	—	10.00	—	*0.10*	0.20		*0.02*
WOODS[o,p]								
Maple, oak, and similar hardwoods	45	1.10	—	*0.91*	—	0.30	*6.31*	—
Fir, pine, etc.	32	0.80	—	*1.25*	—	0.33	*8.66*	—
0.75 in.	32	—	1.06	—	*0.94*		—	*0.17*
1.5 in.		—	0.53	—	*1.88*		—	*0.33*
2.5 in.		—	0.32	—	*3.12*		—	*0.55*
3.5 in.		—	0.23	—	*4.38*		—	*0.77*
5.5 in.		—	0.14	—	*7.14*		—	*1.26*
7.25 in.		—	-.11	—	*9.09*		—	*1.60*
9.25 in.		—	0.09	—	*11.11*		—	*1.96*
11.25 in.		—	0.07	—	*14.28*		—	*2.15*

Notes for Table 3A

[a] Representative values for dry materials were selected by ASHRAE TC 4.4, Thermal Insulation and Moisture Retarders (Total Thermal Performance Design Criteria). They are intended as design (not specification) values for materials in normal use. Insulation materials in actual service may have thermal values which vary from design values depending on their in-situ properties such as density and moisture content. For properties of a particular product, use the value supplied by the manufacturer or by unbiased tests.

[b] Resistance values are the reciprocals of *C* before rounding off *C* to two decimal places.

[c] Also see Insulating Materials, Board.

[d] Does not include paper backing and facing, if any. Where insulation forms a boundary (reflective or otherwise) of an air space, see Tables 1 and 2 for the insulating value of air space for the appropriate effective emittance and temperature conditions of the space.

[e] Conductivity varies with fiber diameter. (See Chapter 21, Thermal Conductivity section, and Fig. 1) Insulation is produced by different densities; therefore, there is a wide variation in thickness for the same *R*-value among manufacturers. No effort should be made to relate any specific *R*-value to any specific thickness. Commercial thicknesses generally available range from 2 to 8.5.

[f] Values are for aged, unfaced, board stock. For change in conductivity with age of expanded urethane, see Chapter 20, Factors Affecting Thermal Conductivity.

[g] Insulating values of acoustical tile vary, depending on density of the board and on type, size, and depth of perforations.

[h] ASTM C-855-77 recognizes the specification of roof insulation on the basis of the *C*-values shown. Roof insulation is made in thicknesses to meet these values.

[i] Face brick and common brick do not always have these specific densities. When density is different from that shown, there will be a change in thermal conductivity.

[j] Data on rectangular core concrete blocks differ from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.

[k] Weights of units approximately 7.625 in. high and 15.75 in. long. These weights are given as a means of describing the blocks tested, but conductance values are all for 1 ft² of area.

[l] Vermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barriers or other precautions must be considered to keep insulation dry.

[m] Values for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air space is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values given are averages for use as design guides, and were obtained from several guarded hotbox tests (ASTM C236) or calibrated hotbox (BSS 77) on hollow-backed types and types made using backing-boards of wood fiber, foamed plastic, and glass fiber. Departures of ±50% or more from the values given may occur.

[n] Time-aged values for board stock with gas-barrier quality (0.001 in. thickness or greater) aluminum foil facers on two major surfaces.

[o] Forest Products Laboratory Wood Handbook, U.S. Dept. of Agriculture #72, 1974, Tables 3 and 4.

[p] L. Adams: Supporting cryogenic equipment with wood (*Chemical Engineering*, May 17, 1971).

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Thermal Conductivity (k) of Industrial Insulation (Design Values)[a] (For Mean Temperatures Indicated)

Expressed in Btu per (hour)(square foot)(degree Fahrenheit temperature difference per in.)

Form	Material Composition	Accepted Max Temp for Use, F*	Typical Density (lb/ft^3)	Typical Conductivity k at Mean Temp F													
				−100	−75	−50	−25	0	25	50	75	100	200	300	500	700	900
BLANKETS & FELTS																	
MINERAL FIBER																	
(Rock, slag or glass)																	
Blanket, metal reinforced		1200	6–12									0.26	0.32	0.39	0.54		
		1000	2.5–6									0.24	0.31	0.40	0.61		
Mineral fiber, glass		350	less														
Blanket, flexible, fine-fiber			than				0.25	0.26	0.28	0.30	0.33	0.36	0.53				
organic bonded			0.75				0.24	0.25	0.27	0.29	0.32	0.34	0.48				
			1.0				0.23	0.24	0.25	0.27	0.29	0.32	0.43				
			1.5				0.21	0.22	0.23	0.25	0.27	0.28	0.37				
			2.0				0.20	0.21	0.22	0.23	0.25	0.26	0.33				
			3.0				0.19	0.20	0.21	0.22	0.23	0.24	0.31				
Blanket, flexible, textile-fiber		350	0.65				0.27	0.28	0.29	0.30	0.31	0.32	0.50	0.68			
organic bonded			0.75				0.26	0.27	0.28	0.29	0.31	0.32	0.48	0.66			
			1.0				0.24	0.25	0.26	0.27	0.29	0.31	0.45	0.60			
			1.5				0.22	0.23	0.24	0.25	0.27	0.29	0.39	0.51			
			3.0				0.20	0.21	0.22	0.23	0.24	0.25	0.32	0.41			
Felt, semirigid organic bonded		400	3–8						0.24	0.25	0.26	0.27	0.35	0.44			
		850	3	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.35	0.55			
Laminated & felted		1200	7.5											0.35	0.45	0.60	
Without binder																	
VEGETABLE & ANIMAL FIBER																	
Hair Felt or Hair Felt plus Jute		180	10						0.26	0.28	0.29	0.30					
BLOCKS, BOARDS & PIPE INSULATION																	
ASBESTOS																	
Laminated asbestos paper		700	30									0.40	0.45	0.50	0.60		
Corrugated & laminated asbestos																	
Paper																	
4-ply		300	11–13								0.54	0.57	0.68				
6-ply		300	15–17								0.49	0.51	0.59				
8-ply		300	18–20								0.47	0.49	0.57				
MOLDED AMOSITE & BINDER		1500	15–18									0.32	0.37	0.42	0.52	0.62	0.72
85% MAGNESIA		600	11–12									0.35	0.38	0.42			
CALCIUM SILICATE		1200	11–15									0.38	0.41	0.44	0.52	0.62	0.72
		1800	12–15												0.63	0.74	0.95
CELLULAR GLASS		900	8.5	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.35	0.36	0.42	0.49	0.70	1.03	
DIATOMACEOUS SILICA		1600	21–22												0.64	0.68	0.72
		1900	23–25												0.70	0.75	0.80
MINERAL FIBER																	
Glass,																	
Organic bonded, block and boards		400	3–10	0.16	0.17	0.18	0.19	0.20	0.22	0.24	0.25	0.26	0.33	0.40			
Nonpunking binder		1000	3–10									0.26	0.31	0.38	0.52		
Pipe insulation, slag or glass		350	3–4					0.20	0.21	0.22	0.23	0.24	0.29				
		500	3–10					0.20	0.22	0.24	0.25	0.26	0.33	0.40			
Inorganic bonded-block		1000	10–15									0.33	0.38	0.45	0.55		
		1800	15–24									0.32	0.37	0.42	0.52	0.62	0.74
Pipe insulation slag or glass		1000	10–15									0.33	0.38	0.45	0.55		
MINERAL FIBER																	
Resin binder			15			0.23	0.24	0.25	0.26	0.28	0.29						
RIGID POLYSTYRENE																	
Extruded, Refrigerant 12 exp, smooth																	
skin surface		170	2.2	0.16	0.16	0.17	0.16	0.17	0.18	0.19	0.20						
Extruded cut cell surface		170	1.8	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27					
Molded beads		170	1	0.17	0.19	0.20	0.21	0.22	0.24	0.25	0.26	0.28					
			1.25	0.17	0.18	0.19	0.20	0.22	0.23	0.24	0.25	0.27					
			1.5	0.16	0.17	0.19	0.20	0.21	0.22	0.23	0.24	0.26					
			1.75	0.16	0.17	0.18	0.19	0.20	0.22	0.23	0.24	0.25					
			2.0	0.15	0.16	0.18	0.19	0.20	0.21	0.22	0.23	0.24					
RIGID POLYISOCYANDRATE**																	
Cellular, foil-faced glass fiber																	
reinforced, Refrigerant 11 exp		250	2						0.12	0.13	0.14	0.15					
POLYURETHANE***																	
Refrigerant 11 exp (unfaced)		210	1.5–2.5	0.16	0.17	0.18	0.18	0.18	0.17	0.16	0.16	0.17					
RUBBER, Rigid Foamed		150	4.5						0.20	0.21	0.22	0.23					
VEGETABLE & ANIMAL FIBER																	
Wool felt (pipe insulation)		180	20						0.28	0.30	0.31	0.33					
INSULATING CEMENTS																	
MINERAL FIBER																	
(Rock, slag, or glass)																	
With colloidal clay binder		1800	24–30									0.49	0.55	0.61	0.73	0.85	
With hydraulic setting binder		1200	30–40									0.75	0.80	0.85	0.95		

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

LOOSE FILL																
Cellulose insulation (milled pulverized paper or wood pulp)	2.5–3									0.26	0.27	0.29				
Mineral fiber, slag, rock or glass	2–5			0.19	0.21	0.23	0.25	0.26	0.28	0.31						
Perlite (expanded)	3–5	0.22	0.24	0.25	0.27	0.28	0.30	0.31	0.33	0.35						
Silica aerogel	7.6			0.13	0.14	0.15	0.15	0.16	0.17	0.18						
Vermiculite (expanded)	7–8.2			0.39	0.40	0.42	0.44	0.45	0.47	0.49						
	4–6			0.34	0.35	0.38	0.40	0.42	0.44	0.46						

[a]Representative values for dry materials as selected by ASHRAE TC 4.4, *Thermal Insulation and Moisture Retarders (Total Thermal Performance Design Criteria)*. They are intended as design (not specification) values for materials of building construction for normal use. Insulation materials in actual service may have thermal values which vary from design values depending on their in-situ properties such as density and moisture content. For thermal resistance of a particular product, use the value supplied by the manufacturer or by unbiased tests.

*These temperatures are generally accepted as maximum. When operating temperature approaches these limits follow the manufacturer's recommendations.

**Time-aged values for board stock with gas-barrier quality (0.001 in. or greater) aluminum foil facers on two major surfaces.

***Values are for aged, unfaced, board stock. For change in conductivity with age of refrigerant-blown expanded urethane see section on Thermal Conductivity, Chapter 20.

Note: Some polyurethane foams are formed by means which produce a stable product (with respect to *k*), but most are blown with refrigerant and will change with time.

Table 3C Insulation Materials Manufactured In-situ

Expressed in Btu per (hour) (square foot) (degree Fahrenheit temperature per in.)

Form	Material Composition	Accepted Max Temp for Use, *F**	Typical Density (lb/ft³)	Typical Conductivity *k* at Mean Temp *F*														
				−100	−75	−50	−25	0	25	50	75	100	200	300	500	700	900
FOAMED IN PLACE																		
Polyurethane		110	1.5-2.5								(0.16–0.18							
Ureaformaldehyde		100	0.7-1.6								(0.22–0.28							
Phenol formaldehyde																		
SPRAYED ON SUBSTRATE																		
Cellulosic fiber base		120	2-6								(0.24–0.30							
Cementitious/fiber and perlite or vermiculite base		1000	24-36								0.52–0.77							
Mineral fiber base		2000	12-14								0.30							

*These temperatures are generally accepted as maximum. When operating temperature approaches these limits follow the manufacturer's recommendations.

Notes for Table 3C

The material listed above are fabricated in-situ and are especially sensitive to installation and fabrication technique. They are subject to variations in density, dimensional stability, and moisture content. Thermal data listed are not to be used as absolute values and are for guidance only. Degradations for installed performance of up to 50% of listed values are possible. CAUTION: For all materials manufactured in the field, follow the manufacturer's precautions and recommendations.

Table 3D Abbreviated Reference of Previously Listed Insulating Materials

This table is included as a guide for determining the thermal performance of existing constructions. Most of the materials below are no longer commercially available. The table was abstracted from Heating, Ventilating, Air Conditioning Guide, 1939, pp. 95, 97, 98.

Expressed in Btu per (hour)(square foot)(degree Fahrenheit temperature difference per in.)

Material	Description	Density, lb/ft³	Mean temp, F	*k* or *C*	1/*k* or 1/*C*	Ref (see below)
INSULATION—BLANKET OR FLEXIBLE TYPES						
Fiber	Typical	—	—	0.27*	3.70	—
	Chemically treated wood fibers held between layers of strong paper**	3.62	70	0.25	4.00	3
	Eel grass between strong paper**	4.60	90	0.26	3.85	1
	" " " " "	3.40	90	0.25	4.00	1
	Flax fibers between strong paper**	4.90	90	0.28	3.57	1
	Chemically treated hog hair between kraft paper	5.76	71	0.26	3.85	3
	Chemically treated hog hair between kraft paper and asbestos paper**	7.70	71	0.28	3.57	3
	Hair felt between layers of paper**	11.00	75	0.25	4.00	3
	Kapok between burlap or paper**	1.00	90	0.24	4.17	1
	Jute fiber**	6.70	75	0.25	4.00	3
	Ground paper between two layers, each 3/8-in. thick made up of two layers of kraft paper (sample 3/4-in. thick)	12.1	75	0.40†	2.50	4
INSULATION—SEMI-RIGID TYPE						
Fiber	Felted cattle hair**	13.00	90	0.26	3.84	1
	" " "	11.00	90	0.26	3.84	1
	Flax**	12.10	70	0.30	3.33	3
	Flax and rye**	13.60	90	0.32	3.12	1
	Felted hair and asbestos**	7.80	90	0.28	3.57	1

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Abbreviated Reference of Previously Listed Insulating Materials (Concluded)

	75% hair and 25% jute**	6.30	90	0.27	3.70	1
	50% hair and 50% jute**	6.10	90	0.26	3.85	1
	Jute**	6.70	75	0.25	4.00	3
	Felted jute and asbestos**	10.00	90	0.37	2.70	1
	Compressed peat moss	11.00	70	0.26	3.84	3
INSULATION—LOOSE FILL OR BAT TYPE						
Fiber	Made from ceiba fibers**	1.90	75	0.23	4.35	3
	" " " "	1.60	75	0.24	4.17	3
	Fibrous material made from dolomite and silica	1.50	75	0.27	3.70	3
	Fibrous material made from slag	9.40	103	0.27	3.70	1
Glass wool	Fibrous material 25 to 30 microns in diameter, made from virgin bottle glass	1.50	75	0.27	3.70	3
Granular	Made from combined silicate of lime and alumina	4.20	72	0.24	4.17	3
	Made from expanded aluminum-magnesium silicate	6.32	86	0.29	3.45	3
Gypsum	Cellular dry	30.00	90	1.00	1.00	1
	" "	24.00	90	0.77	1.30	1
	" "	18.00	90	0.59	1.69	1
	" "	12.00	90	0.44	2.27	1
	Flaked, dry and fluffy**	34.00	90	0.60	1.67	1
	" " " "	26.00	90	0.52	1.92	1
	" " " "	24.00	75	0.48*	2.08	3
	" " " "	19.80	90	0.35	2.86	1
	" " " "	18.00	75	0.34	2.94	3
Mineral wool	All forms typical	—	—	0.27*	3.70	—
Regranulated cork	About 3/16-in. particles	8.10	90	0.31	3.22	1
Rock wool	Fibrous material made from rock	21.00	90	0.30	3.33	1
	" " " " "	18.00	90	0.29	3.45	1
	" " " " "	14.00	90	0.28	3.57	1
	" " " " "	10.00	90	0.27*	3.70	1
	Rock wool with a binding agent	14.50	77	0.33	3.03	1
	Rock wool with flax. straw pulp, and binder	14.50	75	0.38	2.63	3
	Rock wool with vegetable fibers	11.50	72	0.31	3.22	3
Sawdust	Various	12.00	90	0.41	2.44	1
Shavings	Various from planer	8.80	90	0.41	2.44	1
	From maple, beech and birch (coarse)	13.20	90	0.36	2.78	1
	Redwood bark	3.00	90	0.31	3.22	1
	Redwood bark	5.00	75	0.26	3.84	3
INSULATION—RIGID						
Corkboard	Typical	—	—	0.30*	3.33	—
	No added binder	14.00	90	0.34	2.94	1
	" " "	10.60	90	0.30	3.33	1
	" " "	7.00	90	0.27	3.70	1
	" " "	5.40	90	0.25	4.00	1
	Asphaltic binder	14.50	90	0.32	3.12	1
Fiber	Typical	—	—	0.33*	3.03	—
	Chemically treated hog hair covered with film of asphalt	10.00	75	0.28	3.57	3
	Made from corn stalks	15.00	71	0.33	3.03	3
	" " exploded wood fibers	17.90	78	0.32	3.12	4
	" " hard wood fibers	15.20	70	0.32	3.12	3
	Insulating plaster 9/10-in. thick applied to 3/8-in. plaster board base	54.00	75	1.07†	0.93	3
	Made from licorice roots	16.10	81	0.34	2.94	3
	" " 85% magnesia and 15% asbestos	19.30	86	0.51	1.96	1
	" " shredded wood and cement	24.20	72	0.46	2.17	3
	" " sugar cane fiber	13.50	70	0.33	3.03	3
	Sugar cane fiber insulation blocks encased in asphalt membrane	13.80	70	0.30	3.33	3
	Made from wheat straw	17.00	68	0.33	3.03	3
	" " wood fiber	15.90	72	0.33	3.03	3
	" " " "	15.00	70	0.33	3.03	3
	" " " "	—	52	0.33	3.03	—
	" " " "	8.50	72	0.29	3.45	3
	" " " "	15.20	—	0.33	3.03	3
	" " " "	16.90	90	0.34	2.94	1
BUILDING BOARDS						
Asbestos	Compressed cement and asbestos sheets	123.00	86	2.70	0.37	1
	Corrugated asbestos board	20.40	110	0.48	2.08	2

[1]U.S. Bureau of Standards, tests based on samples submitted by manufacturers.
[2]A.C. Willard, L.C. Lichty, and L.A. Harding, tests conducted at the University of Illinois.
[3]J.C. Peebles, tests conducted at Armour Institute of Technology, based on samples submitted by manufacturers.
[4]F.B. Rowley, tests conducted at the University of Minnesota.
*Recommended conductivities and conductances for computing heat transmission coefficients.
**Not compressed.
†For thickness stated or used on construction, not per 1-in. thickness.

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Surface Conductances and Resistances for Air[a,b,c]

All conductance values expressed in Btu/h · ft² · F.

A surface cannot take credit for both an air space resistance value and a surface resistance value. No credit for an air space value can be taken for any surface facing an air space of less than 0.5 in.

Position of Surface	Direction of Heat Flow	Surface *Emittance* Non-reflective ε = 0.90		Reflective ε = 0.20		Reflective ε = 0.05	
		h_i	R	h_i	R	h_i	R
STILL AIR							
Horizontal	Upward	1.63	*0.61*	0.91	*1.10*	0.76	*1.32*
Sloping—45 deg	Upward	1.60	*0.62*	0.88	*1.14*	0.73	*1.37*
Vertical	Horizontal	1.46	*0.68*	0.74	*1.35*	0.59	*1.70*
Sloping—45 deg	Downward	1.32	*0.76*	0.60	*1.67*	0.45	*2.22*
Horizontal	Downward	1.08	*0.92*	0.37	*2.70*	0.22	*4.55*
MOVING AIR		h_o	R	h_o	R	h_o	R
(Any Position)							
15-mph Wind (for winter)	Any	6.00	0.17				
7.5-mph Wind (for summer)	Any	4.00	0.25				

[a]For ventilated attics or spaces above ceilings under summer conditions (heat flow down) see Table 6.

[b]Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10 deg F and for surface temperature of 70 F.

[c]See Fig. 1 for additional data.

Thermal Resistances of Plane[a] Air Spaces[d,e*]

SECTION A

All resistance values expressed in ft² · F · h/Btu

Values apply only to air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no leakage of air to or from the space. These conditions are not normally present in standard building construction. When accurate values are required, use overall *U*-factors determined for your particular construction through calibrated hot box (BSS-77) or guarded hot box (ASTM-C-236) testing.

Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

See the Caution section, under Overall Coefficients and Their Practical Use.

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp,[b] (F)	Air Space Temp Diff,[b] (deg F)	0.5-in. Air Space[d] Value of $E^{b,c}$ 0.03	0.05	0.2	0.5	0.82	0.75-in. Air Space[d] Value of $E^{b,c}$ 0.03	0.05	0.2	0.5	0.82
Horiz.	Up ↑	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		−50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		−50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
45° Slope	Up ↗	90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		50	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
		−50	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		−50	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30
Vertical	Horiz. →	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		−50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		−50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
45° Slope	Down ↘	90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84
		50	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99
		50	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02
		0	20	2.91	2.80	2.19	1.52	1.15	3.75	3.57	2.63	1.72	1.26
		0	10	2.94	2.83	2.21	1.53	1.15	4.12	3.91	2.81	1.80	1.30
		−50	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57
		−50	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66
Horiz.	Down ↓	90	10	2.48	2.34	1.67	1.06	0.77	3.55	3.29	2.10	1.22	0.85
		50	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02
		50	10	2.67	2.55	1.89	1.25	0.92	3.84	3.59	2.41	1.45	1.02
		0	20	2.94	2.83	2.20	1.53	1.15	4.18	3.96	2.83	1.81	1.30
		0	10	2.96	2.85	2.22	1.53	1.16	4.25	4.02	2.87	1.82	1.31
		−50	20	3.25	3.15	2.58	1.89	1.47	4.60	4.41	3.36	2.28	1.69
		−50	10	3.28	3.18	2.60	1.90	1.47	4.71	4.51	3.42	2.30	1.71

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

Coefficients of Transmission (U) for Wood Doors,[a] Btu/h · ft^2 · F

Door Thickness, in.[d]	Description	Winter[b] No Storm Door	Winter[b] Wood Storm Door[e]	Winter[b] Metal Storm Door[f]	Summer[c] No Storm Door
1-3/8	Hollow core flush door	0.47	0.30	0.32	0.45
1-3/8	Solid core flush door	0.39	0.26	0.28	0.38
1-3/8	Panel door with 7/16-in. panels	0.57	0.33	0.37	0.54
1-3/4	Hollow core flush door	0.46	0.29	0.32	0.44
	with single glazing[g]	0.56	0.33	0.36	0.54
1-3/4	Solid core flush door	0.33	0.28	0.25	0.32
	With single glazing[g]	0.46	0.29	0.32	0.44
	With insulating glass[g]	0.37	0.25	0.27	0.36
1-3/4	Panel door with 7/16-in. panels[h]	0.54	0.32	0.36	0.52
	With single glazing[i]	0.67	0.36	0.41	0.63
	With insulating glass[i]	0.50	0.31	0.34	0.48
1-3/4	Panel door with 1-1/8-in. panels[h]	0.39	0.26	0.28	0.38
	With single glazing[i]	0.61	0.34	0.38	0.58
	With insulating glass[i]	0.44	0.28	0.31	0.42
2-1/4	Solid core flush door	0.27	0.20	0.21	0.26
	With single glazing[g]	0.41	0.27	0.29	0.40
	With insulating glass[g]	0.33	0.23	0.25	0.32

[a] Values for doors are based on nominal 3'8" × 6'8" door size. Interpolation and moderate extrapolation are permitted for glazing areas and door thicknesses other than those specified.
[b] 15 mph outdoor air velocity; 0 F outdoor air; 70 F inside air temp natural convection.
[c] 7.5 mph outdoor air velocity; 89 F outdoor air; 75 F inside air natural convection.
[d] Nominal thickness.
[e] Values for wood storm door are approximately 50% glass area.
[f] Values for metal storm door are for any percent of glass area.
[g] 17% exposed glass area; insulating glass contains 0.25 inch air space.
[h] 55% panel area.
[i] 33% glass area; 22% panel area; insulating glass contains 0.25 inch air space.

Coefficients of Transmission (U) for Steel Doors

Btu/h · ft^2 · F

Thickness	Steel Door[14]			No Storm Door
1.75 in.				
A[a]	0.59	—	—	0.58
B[b]	0.40	—	—	0.39
C[c]	0.47	—	—	0.46

[a] A = Mineral fiber core (2 lb/ft^3).
[b] B = Solid urethane foam core with thermal break.
[c] C = Solid Polystyrene core with thermal break.

SOURCE: ASHRAE, Handbook of Fundamentals, 1981: Reprinted by permission

APPENDIX D

Conversion Units

Appendix D

UNIT CONVERSIONS

Energy

1 BTU	=	1.05506 kJ
1 Therm	=	105.506 MJ
1 cal	=	4.1868 J
1 kW-hr	=	41.86 kJ/m²

Power

1 BTU/hr	=	0.29307 W
1 ton (refg)	=	3.51685 kW
1 kcal/hr	=	1.163 W
1 hp	=	0.74570 kW

Energy Flux

1 BTU/hr-ft²	=	3.15469 W/m²
1 langley/hr	=	11.6277 W/m²
1 cal/cm²-min	=	697.4 W/m²
1 BTU/hr-ft²-F	=	5.67826 W/m²-C
1 BTU/hr-ft-F	=	1.70307 W/m-C

NUMERICAL VALUES OF SOME PROPERTIES

	Density	Specific Heat
Air	1.204 kg/m 0.07516 lb/ft³	1012 J/kg-C 0.241 BTU/lb-F
Water	1000 kg/m³ 62.42 lb/ft³ 8.34 lb/gal	4190 J/kg-C 1.00 BTU/lb-F
Rock	2400 kg/m³ 150 lb/ft³	838 J/kg-C 0.2 BTU/lb-F
Antifreeze (50-50 ethylene glycol/water)	1065 kg/m³ 66.50 lb/ft³	3350 j/kg-C 0.80 BTU/lb-F

APPENDIX E

Greenhouse Drawings and Materials List

APPENDIX E

CONSTRUCTION, DRAWINGS AND MATERIALS LISTS

The following documents are designed for concrete foundations. In areas of permafrost, ask a local builder or supplier for advice on floor and foundation systems. The drawings and materials lists will be the same for the walls, roof and glazing, regardless of the type of floor system used.

The drawings have been reduced from full size blueprints and are not to the scales noted.

Provided by AREA

MATERIALS LIST FOR A 10' x 40' FREESTANDING GREENHOUSE

Description	Dimension	Quantity
Roof		
-TJI Roof Rafters	9½" x 12'	(21)
-TJI for Blocking	9½" x 20'	(4)
-CDX Plywood Sheathing	½" x 4' x 8'	(17)
-15 lb. Felt Paper	600 square feet	
-3 tab, Square Butt Asphalt Shingles	525 square feet	
-Roof Sub-Fascia	1" x 10" x 12'	(10)
-Roof Fascia	1" x 12" x 12'	(10)
-Soffit Nailer	2" x 4" x 12'	(6)
-Soffit Plywood	3/8" x 4' x 8'	(3)
Walls		
-Hem-Fir Studs	2" x 6" x 8'	(40)
-Hem-Fir Plates	2" x 6" x 10'	(20)
-Cedar or AWWF Bottom Plates	2" x 6" x 10'	(4)
-Filon Fiberglass Clear Glazing	300 square feet	
-Glazing Spacers	1" x 2" x 8'	(28)
-Glazing Trim	1" x 2" x 8'	(18)
-Glazing Trim	1" x 2" x 16'	(5)
-Plywood Siding	5/8" x 4' x 8'	(23)
-Hem-Fir Studs	2" x 8" x 8'	(38)
-Hem-Fir Plate	2" x 8" x 16'	(11)
-Cedar or AWWF Bottom Plate	2" x 8" x 16'	(4)
-"Z" Metal Flashing	60 lineal feet	
-Interior Furring	2" x 2" x 10'	(30)
-Interior Plywood (other finish may be used)	½" x 4' x 8'	(17)
-Fiberglass Insulation	6" thick	160 sq. ft.
-Fiberglass Insulation	9" thick	400 sq. ft.
-Fiberglass Insulation	4" thick	1100 sq. ft.
-"Thermax" Insul-Sheathing	3/4" to 1' x 4' x 9'	(17)
-6-Mil Polyethelene Vapor Barrier		1000 sq. ft.

Materials List provided by AREA

MATERIALS LIST FOR A 10' x 40' FREESTANDING GREENHOUSE cont.

Description	Dimension	Quantity
-Polyethelene Tape	as needed	
-Insulated Metal Door	3' x 7'	(1)
-Roofing Nails	as needed	
-8d Galvanized	as needed	
-16d Galvanized	as needed	
-Brass Glazing Screws	as needed	
-Butyl Rubber or Silicone Caulking Compound	as needed	
-Panel Adhesive (for Rigid Insulation)	as needed	
-Damproofing for Foundation*		400 sq. ft.
-Custom Galvanized Flashing at Wall/Foundation*		100 lineal ft.
-Sill Sealer*		100 lineal ft.
-Rigid Styrene (below grade)	2" x 2' x 8'	(50)

NOTE: Material for bends are not included here, nor for the actual concrete and concrete block required for foundation work in non-permafrost areas. Contact your local mason for material and price quotes.

*For concrete foundation only (not permafrost).

Materials List provided by AREA

MATERIALS LIST FOR AN 8' x 20' ATTACHED GREENHOUSE

Description	Dimension	Quantity
Roof		
-TJI Roof Rafters	9½" x 10'	(11)
-TJI for Blocking	9½" x 24'	(1)
-CDX Plywood Sheathing	½" x 4' x 8'	(7)
-15 lb. Felt Paper	250 square feet	
-3 tab, Square Butt Asphalt Shingles	225 square feet	2 squares
-Roof Rafter Ledger	2" x 10" x 20'	(1)
-TJI Joist Hangers		(9)
-Galvanized "L" Flashing	3" x 3" 22'	(1)
-Roof Sub-Fascia	1" x 10" x 12'	(4)
-Soffit Nailer	2" x 4" x 12'	(6)
-Soffit Plywood	3/8" x 4' x 8'	(2)
-Bevel Plate	2" x 4" x 20'	(1)
-Roof Fascia	1" x 12" x 12'	(4)
Walls		
-Hem-Fir Studs	2" x 6" x 8'	(13)
-Hem-Fir Plates	2" x 6" x 10'	(4)
-Cedar or AWWF Bottom Plates	2" x 6" x 10'	(2)
-Filon Fiberglass Clear Glazing	48" w. x 50' (Roll)	1 Roll and 16'
-Glazing Spacers	1" x 2" x 8'	(13)
-Glazing Trim	1" x 2" x 8'	(9)
-Glazing Trim	1" x 2" x 16'	(2)
-Plywood Siding	5/8" x 4' x 8'	(1)
-Hem-Fir Studs	2" x 8" x 8'	(14)
-Hem-Fir Plate	2" x 8" x 16'	(2)
-Cedar or AWWF Bottom Plate	2" x 8" x 16'	(1)
-Hem-Fir Plates	2" x 8" x 10'	(4)
-Plywood Siding	5/8" x 4' x 8'	(7)
-"Z" Metal Flashing	16 lineal feet	
-Interior Furring	2" x 2" x 8'	(10)
-Interior Plywood Finish (other finish may be used)	5/8" x 4' x 8'	(12)
-Fiberglass Insulation	9" thick	210 sq. ft.
-Fiberglass Insulation	4" thick	500 sq . ft.
-"Thermax" Insul-Sheathing	3/4" to 1" x 4' x 8'	(7)
-Exterior Lap Siding	3/4" x 10"	300 L.F.
-6-Mil Polyethelene Vapor Barrier		500 sq. ft.

Materials List provided by AREA

MATERIALS LIST FOR AN 8' x 20' ATTACHED GREENHOUSE cont.

Description	Dimension	Quantity
-Polyethelene Tape	as needed	
-Insulated Metal Door	3' x 7'	(1)
-Roofing Nails	as needed	
-8d Galvanized	as needed	
-16d Galvanized	as needed	
-Brass Glazing Screws	as needed	
-Butyl Rubber or Silicone Caulking Compound	as needed	
-Panel Adhesive (for Rigid Insulation)	as needed	
-Damproofing for Foundation*		144 sq. ft.
-Custom Galvanized Flashing at Wall/Foundation*		36 lineal ft.
-Sill Sealer*		36 lineal ft.
-Rigid Styrene (below grade)	2" x 2' x 8'	(18)

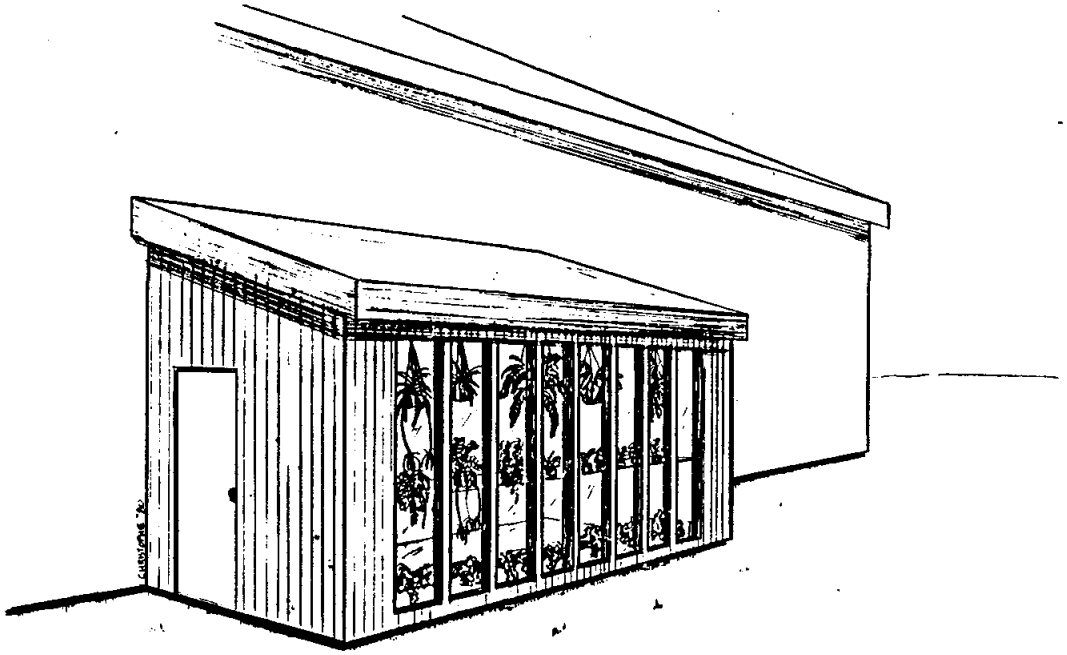
NOTE: Material for bends are not included here, nor for the actual concrete and concrete block required for foundation and slab work in non-permafrost areas. Contact your local mason for material and price quotes.

Material for electric wiring is not included here.

Materials for heat storage systems and interior furnishings are not included here.

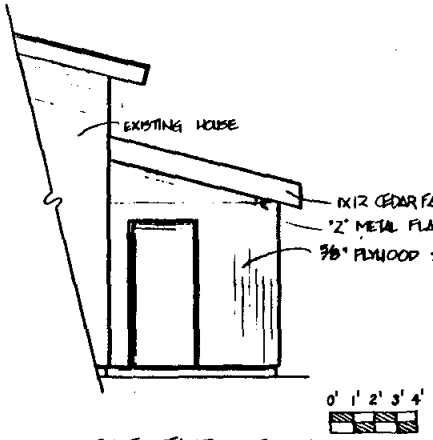
*For concrete foundation only (not permafrost).

Materials List provided by AREA

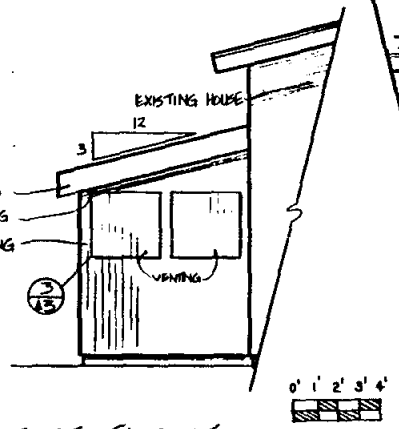


ALASKA ENERGY EFFICIENT GREENHOUSE

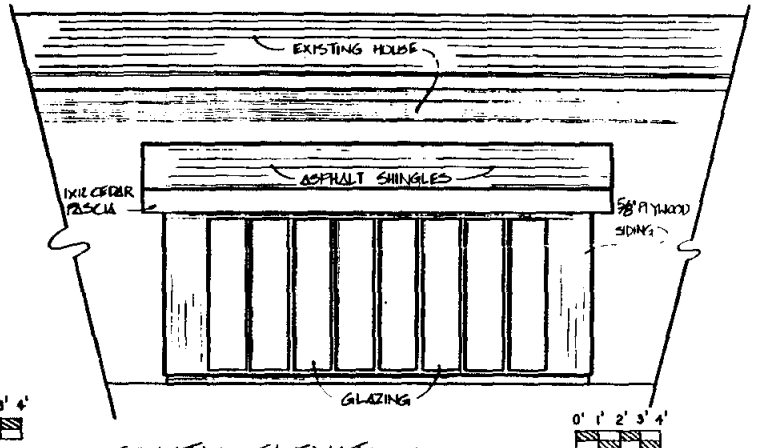
ALASKA RENEWABLE ENERGY ASSOCIATES



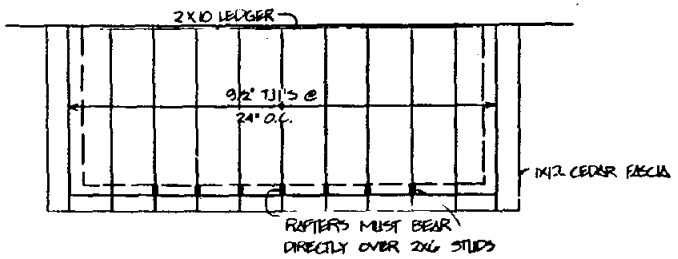
WEST ELEVATION 1/4"=1'-0"

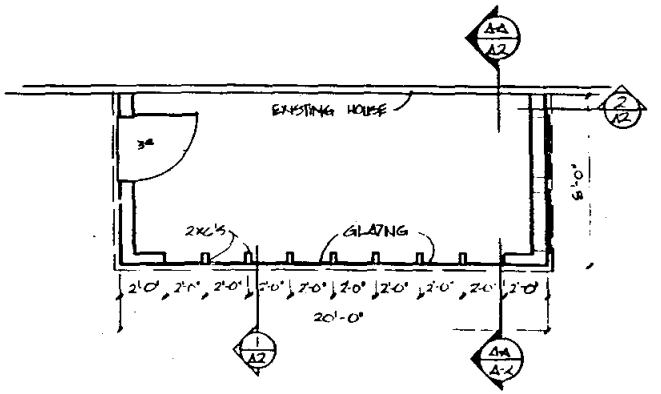


EAST ELEVATION 1/4"=1'-0"



SOUTH ELEVATION 1/4"=1'-0"





ROOF FRAMING PLAN

FLOOR PLAN

ALASKA RENEWABLE ENERGY ASSOCIATES

PLANS, ELEVATIONS

ATTACHED MODEL

DRAWN: CB

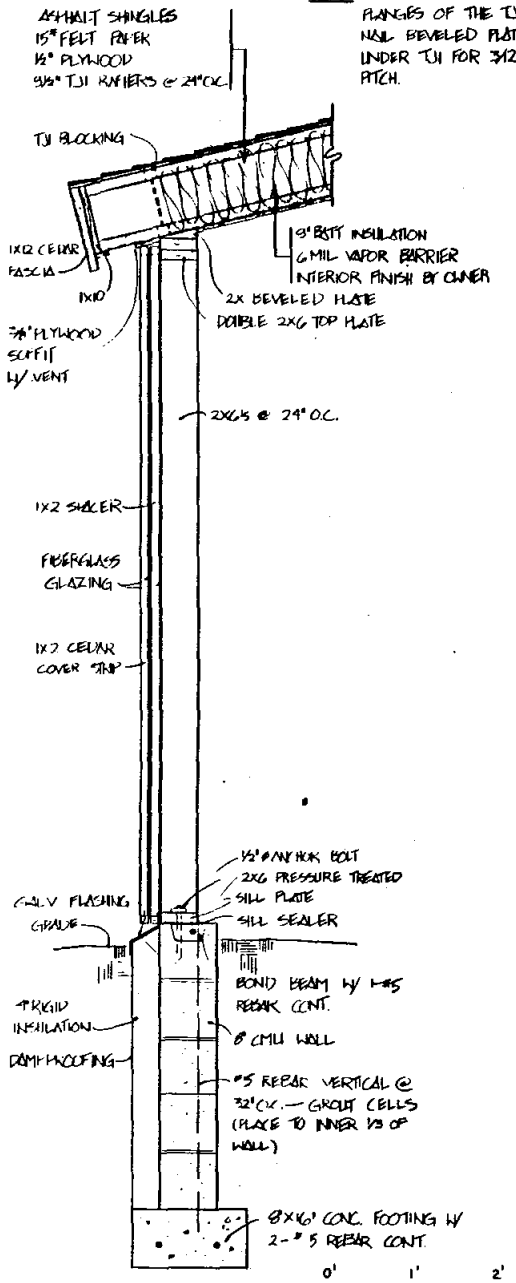
CHECKED: JB

JOB NO.:

DATE: 6/80

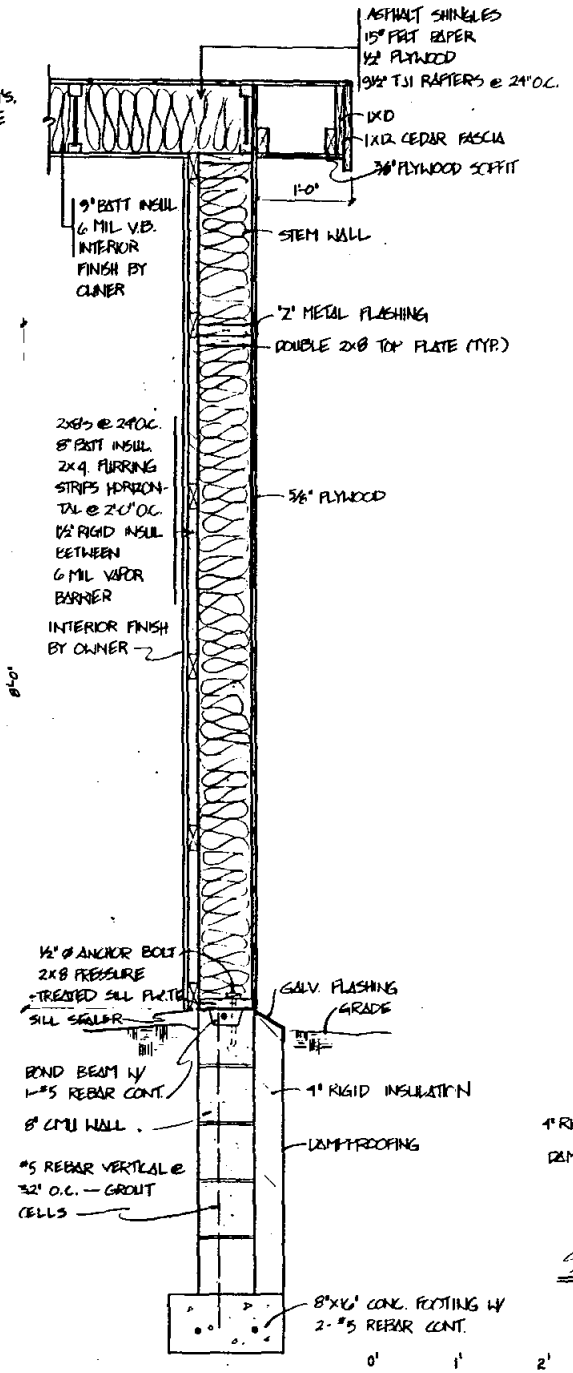
SHEET

A1



1 FRONT WALL SECTION 1"=1'-0"

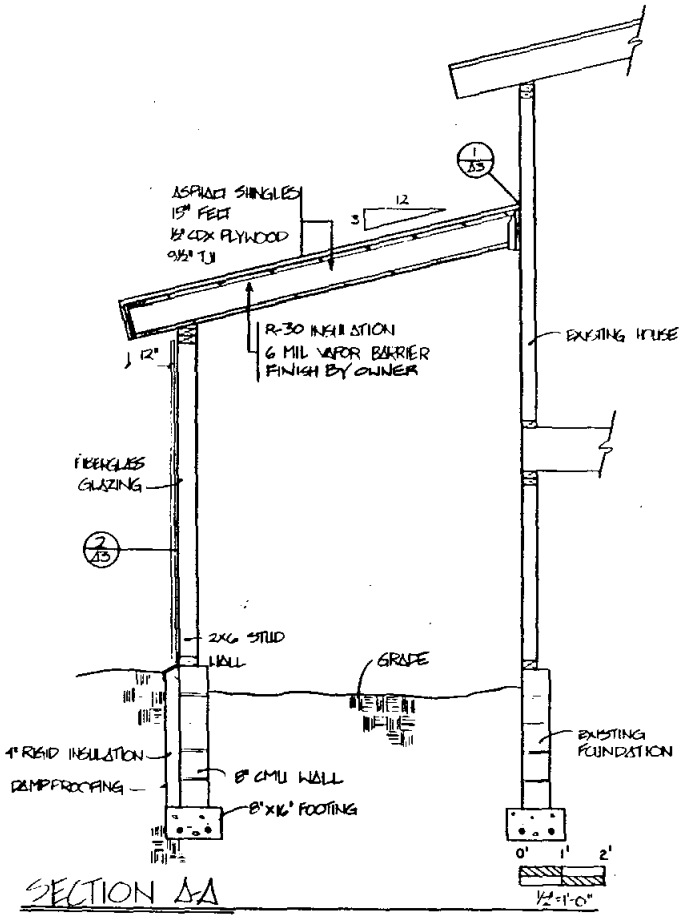
NOTE: DO NOT CUT INTO FLANGES OF THE TJI'S. NAIL BEVELED PLATE UNDER TJI FOR 3/12 PITCH.



2 SIDE WALL SECTION 1"=1'-0"

SUGGESTED INTERIOR FINISHES:

1. 5/8" WATERPROOF GYPSUM BOARD
2. 3/8" PLYWOOD (VARIOUS FINISHES AVAILABLE)
3. WOOD BOARD (CEDAR, REDWOOD, ETC.)



SECTION A-A ½"=1'-0"

ALASKA RENEWABLE ENERGY ASSOCIATES

BUILDING & WALL SECTIONS

ATTACHED MODEL

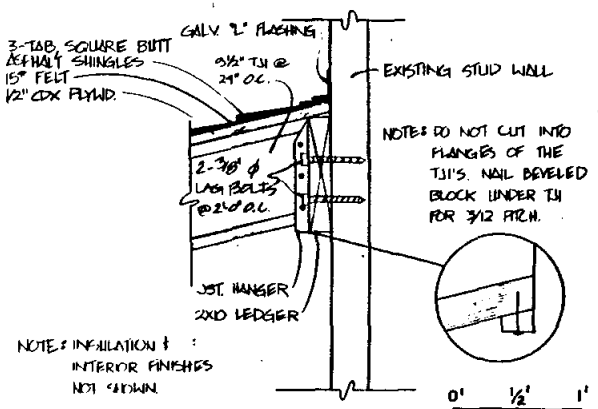
DRAWN: CB

CHECKED: JB

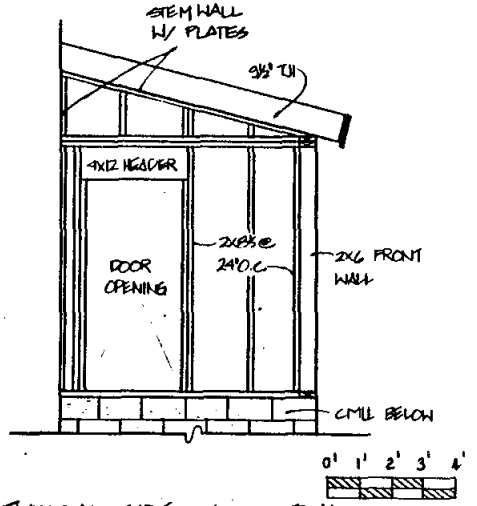
JOB NO.:

DATE: 6/80

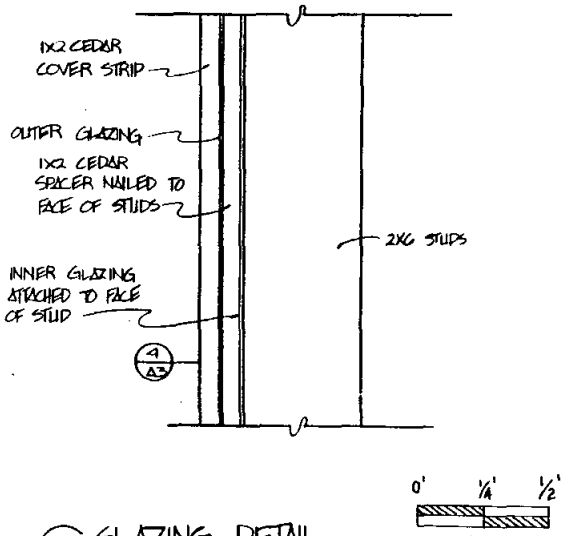
SHEET A2



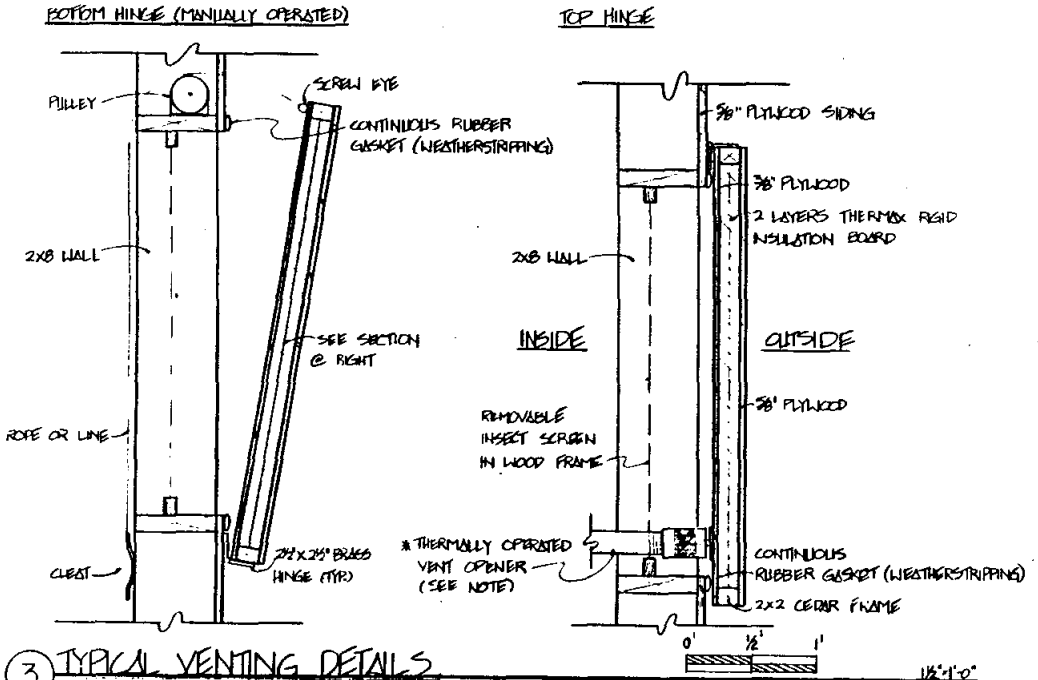
1 NORTH WALL CONNECTION 1½"=1'-0"



TYPICAL SIDE WALL FRAMING 3/8"=1'-0"

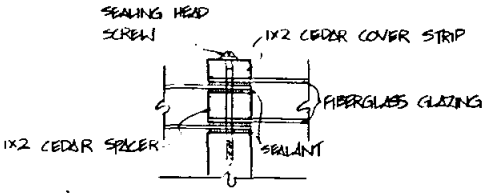


2 GLAZING DETAIL 3"=1'-0"



3 TYPICAL VENTING DETAILS

* NOTE: AUTOMATIC VENTS TO BE CONTROLLED BY THERMAL SENSOR - "THERMOFOR" OR "HEAT MOTOR" BY CALIFORNIA



4 GLAZING DETAIL (PLAN VIEW) NO SCALE

NOTES:
1. BRASS SEALING HEAD SCREWS ARE RECOMMENDED, 2½" TO 3" IN LENGTH.
2. SEALANT TO BE GE "R001 SILICONE SEALANT, GE SILGLAZE SEALANT, OR EQUAL.
3. FIBERGLASS GLAZING SUGGESTED: KOL-WALL SUNLITE PREMIUM II (.040") - 49½" WIDTH TO PROVIDE FOR OVERLAP OVER STUDS.

ALASKA RENEWABLE ENERGY ASSOCIATES

SECTIONS & DETAILS

BOTH MODELS

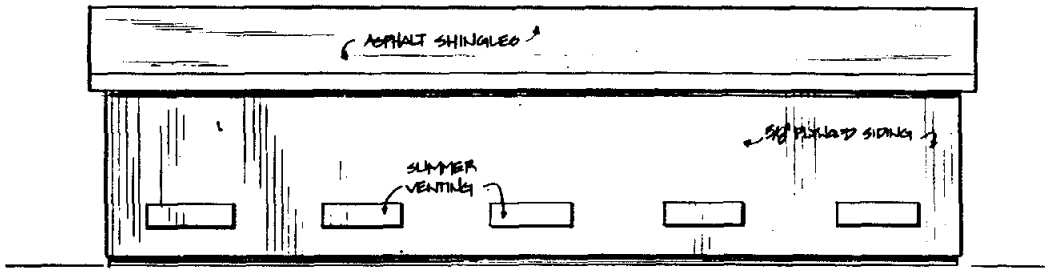
DRAWN: CB

CHECKED: JAB

JOB NO.:

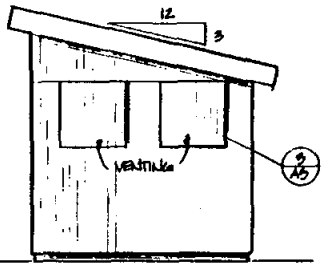
DATE: 6/80

SHEET A3 OF 5



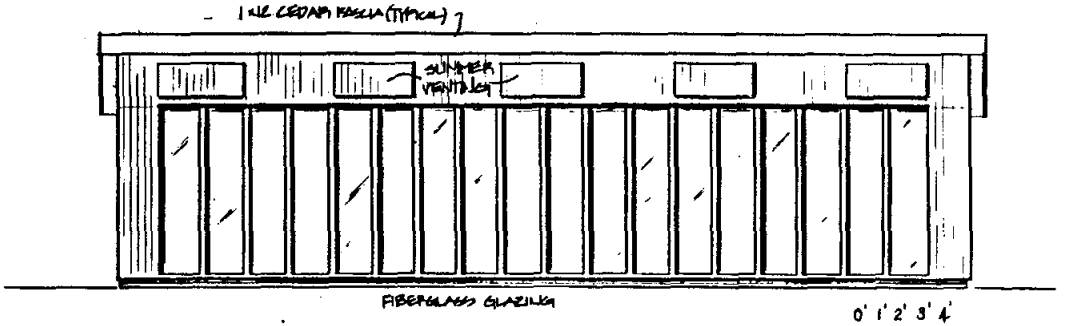
0' 1' 2' 3' 4'

NORTH ELEVATION 1/4"=1'-0"



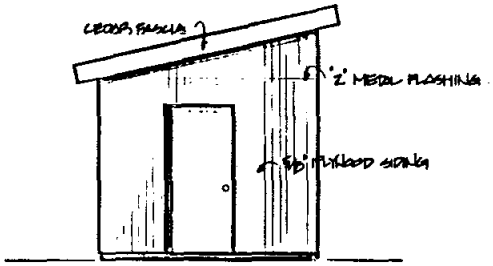
0' 1' 2' 3' 4'

EAST ELEVATION 1/4"=1'-0"



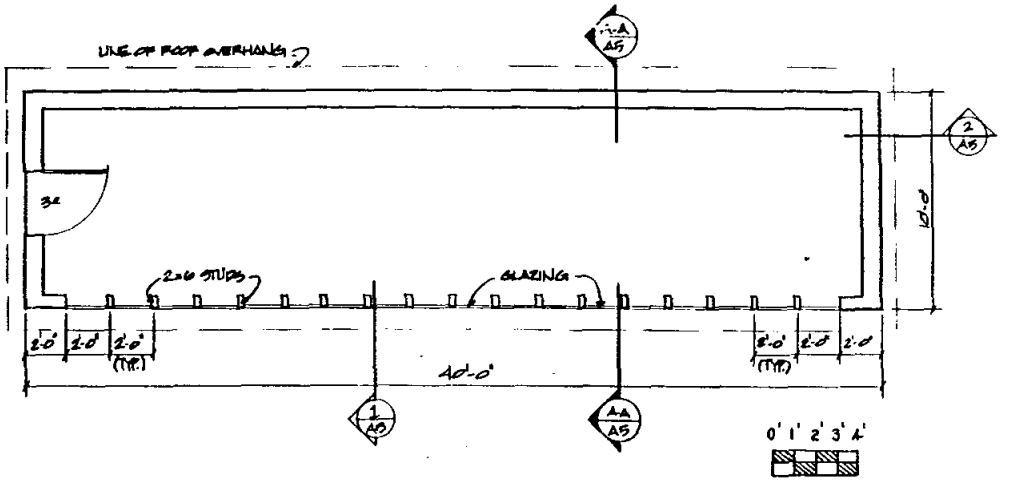
0' 1' 2' 3' 4'

SOUTH ELEVATION 1/4"=1'-0"



0' 1' 2' 3' 4'

WEST ELEVATION 1/4"=1'-0"



0' 1' 2' 3' 4'

FLOOR PLAN

ALASKA RENEWABLE ENERGY ASSOCIATES

PLAN, ELEVATIONS

FREESTANDING MODEL

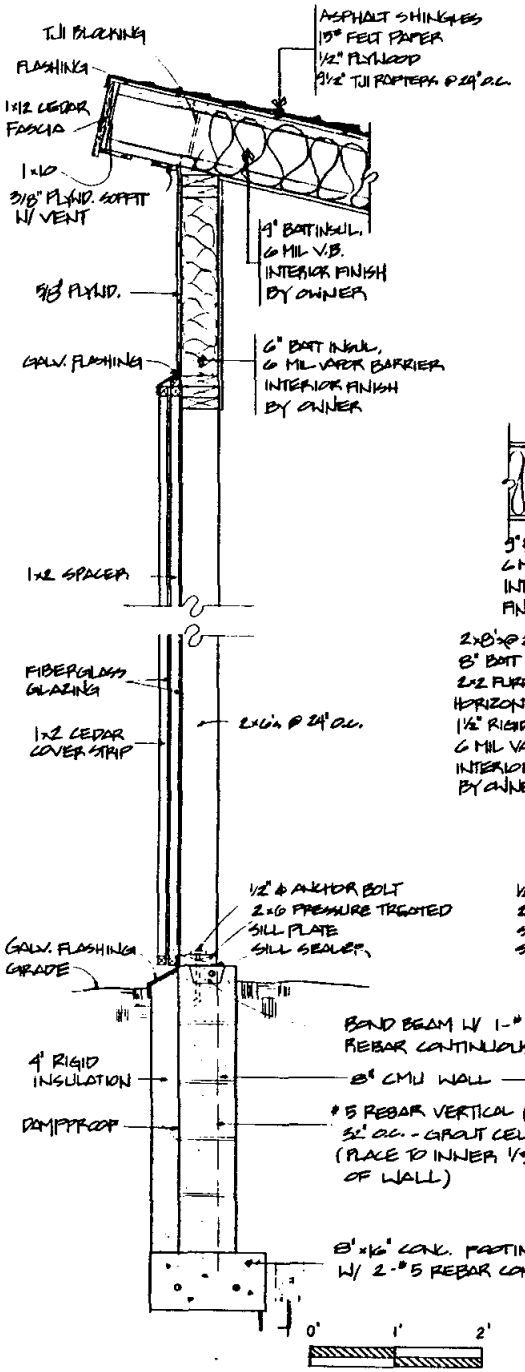
DRAWN: JB

CHECKED: JB

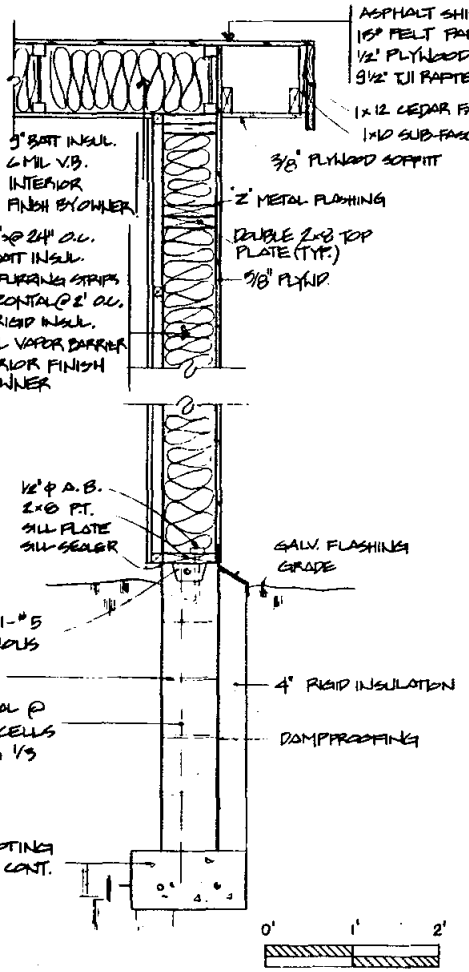
JOB NO.:

DATE: 12/80

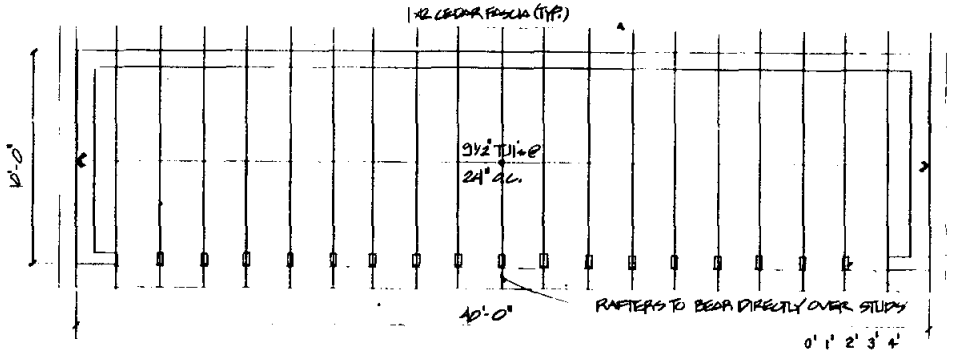
SHEET A4



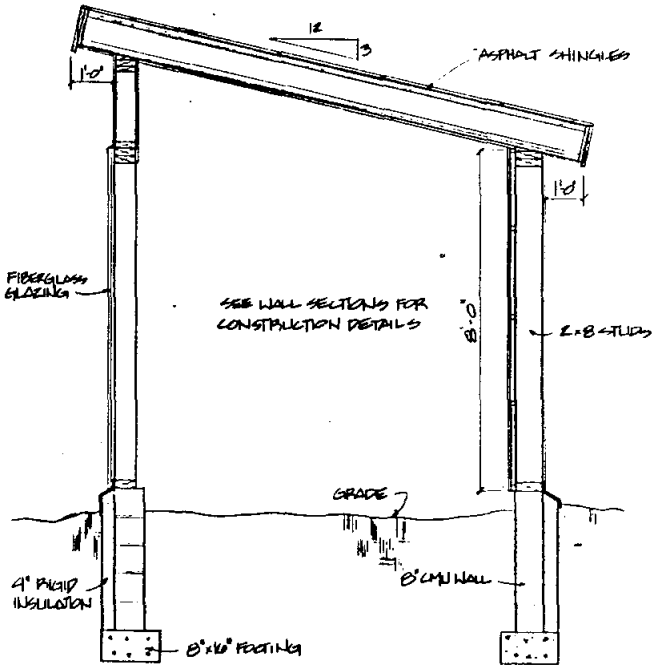
1 FRONT WALL SECTION 1/2"=1'-0"



2 SIDE WALL SECTION 1/2"=1'-0"



ROOF FRAMING PLAN



SECTION A-A

(INSULATION NOT SHOWN FOR CLARITY)

ALASKA RENEWABLE ENERGY ASSOCIATES

SECTIONS, FRAMING PLAN

FREESTANDING MODEL

DRAWN: JB

CHECKED: JB

JOB NO.:

DATE: 12/80

SHEET

A5

APPENDIX F

Absorption and Reflectance of Building Materials

Appendix F

Percentage of Solar Radiation Absorbed by Various Surfaces

Reflective surfaces	20%
White, smooth surfaces	25 to 40%
Grey to dark grey	40 to 50%
Green, red and brown	50 to 70%
Dark brown to blue	70 to 80%
Dark blue to black	80 to 90%

Most building materials have an Emissivity of 0.90, meaning they radiate 90% of the thermal energy possible at a given temperature. Polished metals have low Emissivity (e.g., galvanized steel, 0.13; aluminum foil, 0.05).

Reflectance of Commonly Used Building Materials**

Material	Reflectance
White plaster	90 to 92%
Mirrored glass	80 to 90%
Matte white paint	75 to 90%
Porcelain enamel	60 to 90%
Polished aluminum	60 to 70%
Aluminum paint	60 to 70%
Stainless steel	55 to 65%

*Mazria.
**Yanda and Fisher.

APPENDIX G

Sun Path Charts

SUN PATH CHARTS

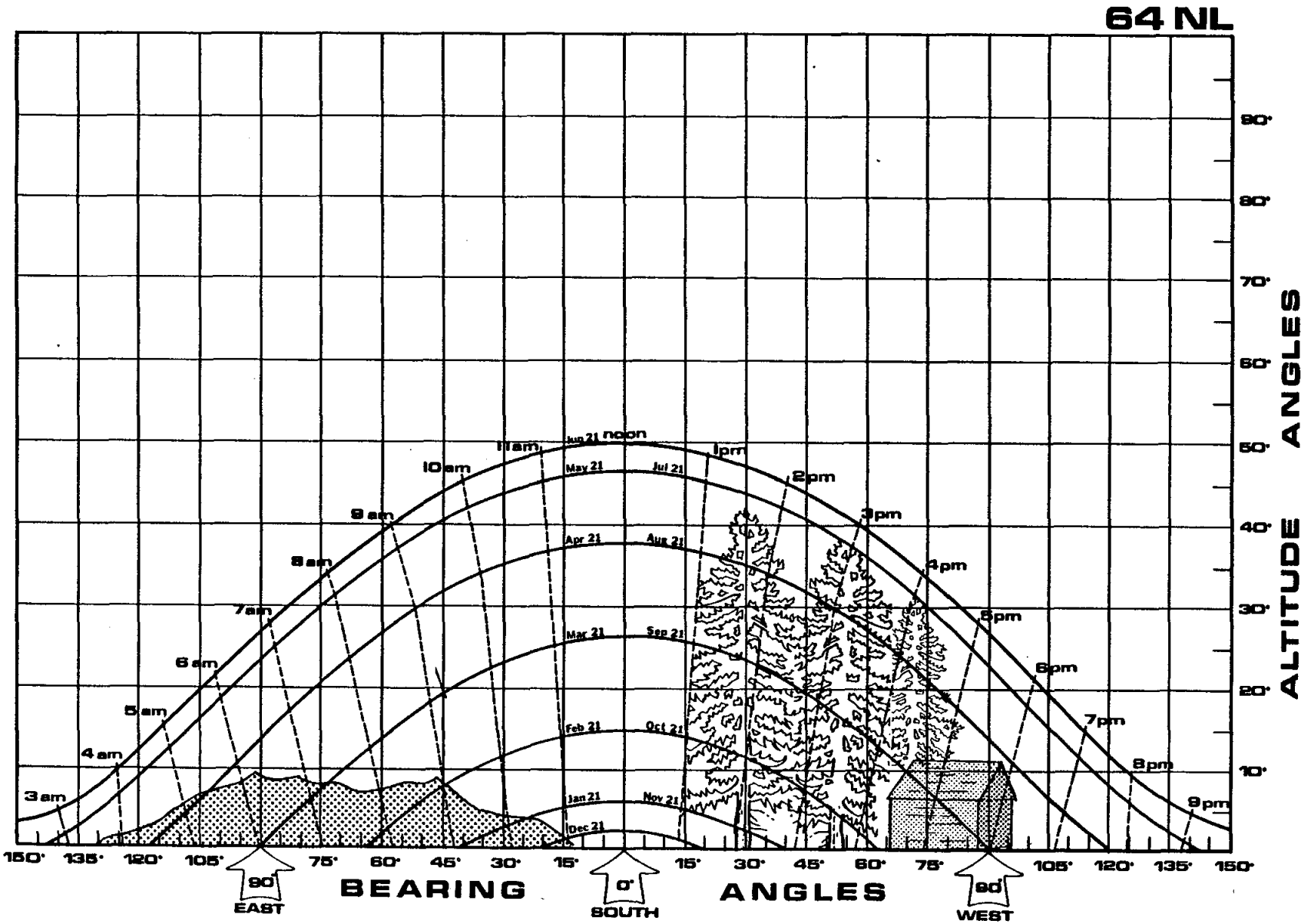
It is possible to predict the position of the sun at any time (Figures G-3 thru G-11). The path and the position are both a result of the latitude of the site. A sun path diagram is a graphic representation of the path of the sun in the sky for virtually any time of the year. This type of sun path diagram is useful for architectural insights, since a horizon can be sketched onto it to indicate solar obstructions. This is accomplished by sketching in obstacles on the horizon in their true angular elevations of obstacles. Page G-2 shows an example of a horizon sketched onto a sun path diagram.

Sketching the horizon onto the chart enables the prospective solar user to identify the major obstructions that will shade the collector from the sun. In the example (Page G-2), the trees are the major obstruction. Identifying such obstructions by location can also indicate how much sun is actually blocked by the obstruction. Let us examine the situation in March. Using the March 21 sun path we can see what happens during the day. Beyond 74°east of south, the sun is blocked by the hills to the southeast of the site, so sunrise is delayed until the sun clears the hills. This delay is 1 hour 20 minutes on March 21. From 7:20 a.m. until 1:20 p.m., the sun is unobstructed. The trees to the southwest of the site obstruct the sun during the entire afternoon; the site gets virtually no direct afternoon sun after 1:20 p.m.

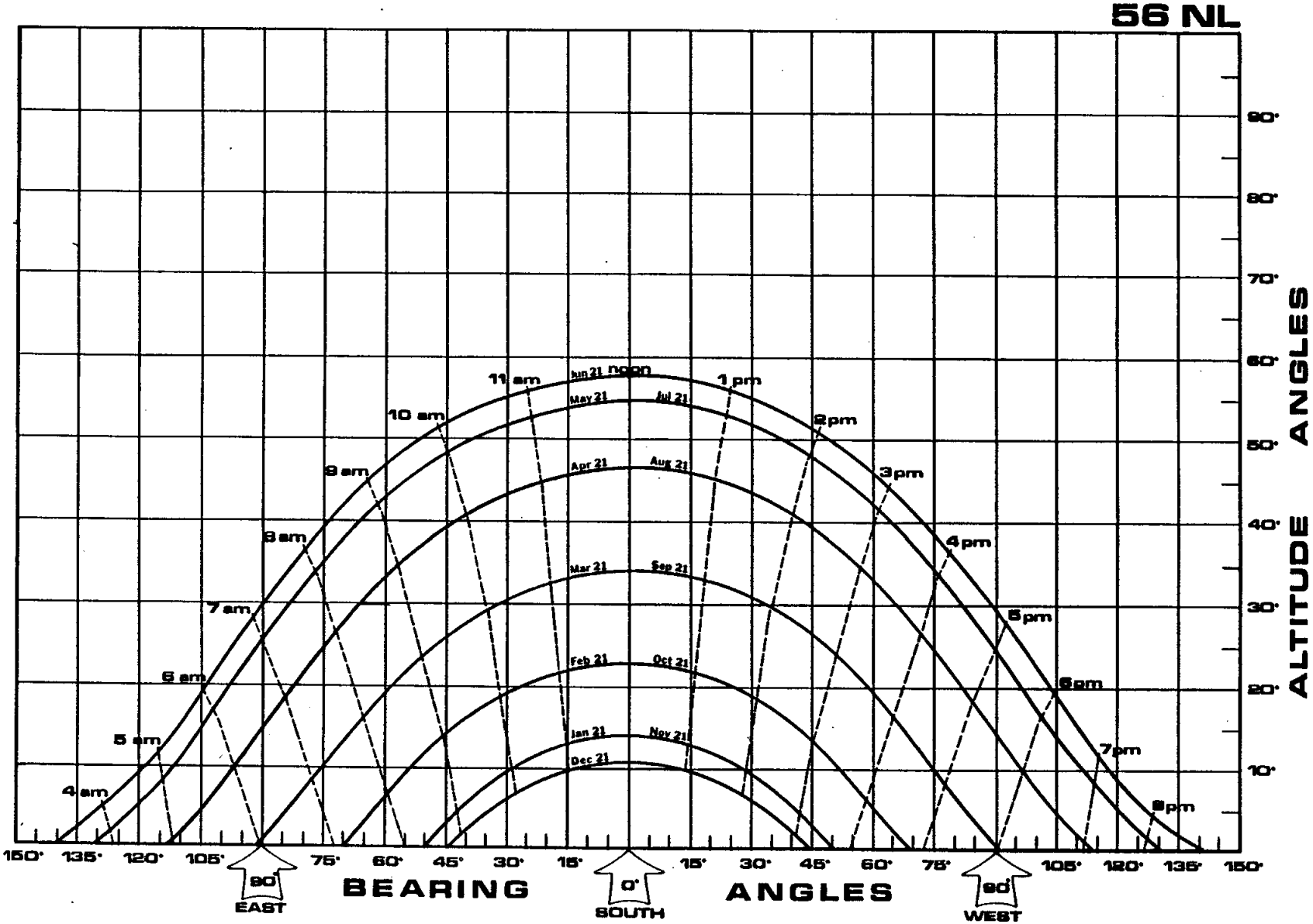
This can be quantified by checking the solar position and hourly radiation chart in Appendix A, p. A-2. Using the chart for 64°N, the amount of solar radiation vertical surface for March 21 can be determined for each hour. The hours of 2, 3, 4, and 5 p.m. receive 194, 143, 78, and 17 BTU/ft^2, respectively. This is a total of 432 BTU/ft^2. Since the hourly radiation chart also gives us the amount of radiation for the whole day, we can determine the percent of solar energy lost by obstructions. Thus 432/1558 = 27.7 percent of the day's radiation is lost--a substantial amount.

This suggests the need to do whatever one could to remove significant obstructions. Moving the neighboring house is not practical, but the trees could be cut. If the trees have high aesthetic or privacy value for the property, you may wish to change the azimuth of the collector eastward (or the azimuth of the structure if using a passive solar design) to take greater advantage of the morning sun. Increasing the size of collection area is also an option and the increase should correspond to the percentage of blocked solar gain (about 28 percent in this case).

SOURCE: A Solar Design Manual by R. Seifert, pages 48 and 60.

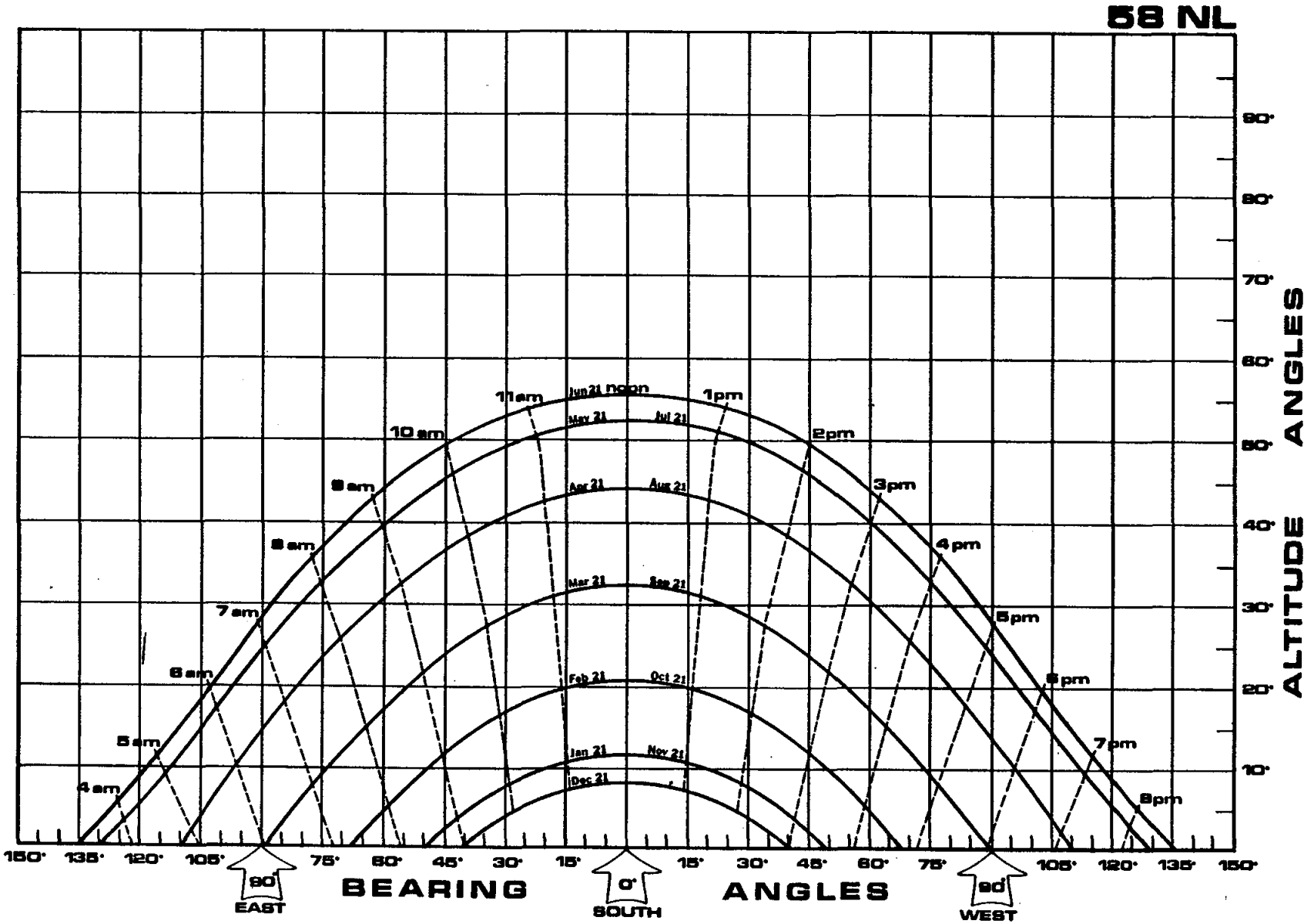


Example of horizon sketched on a sun path diagram.
SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



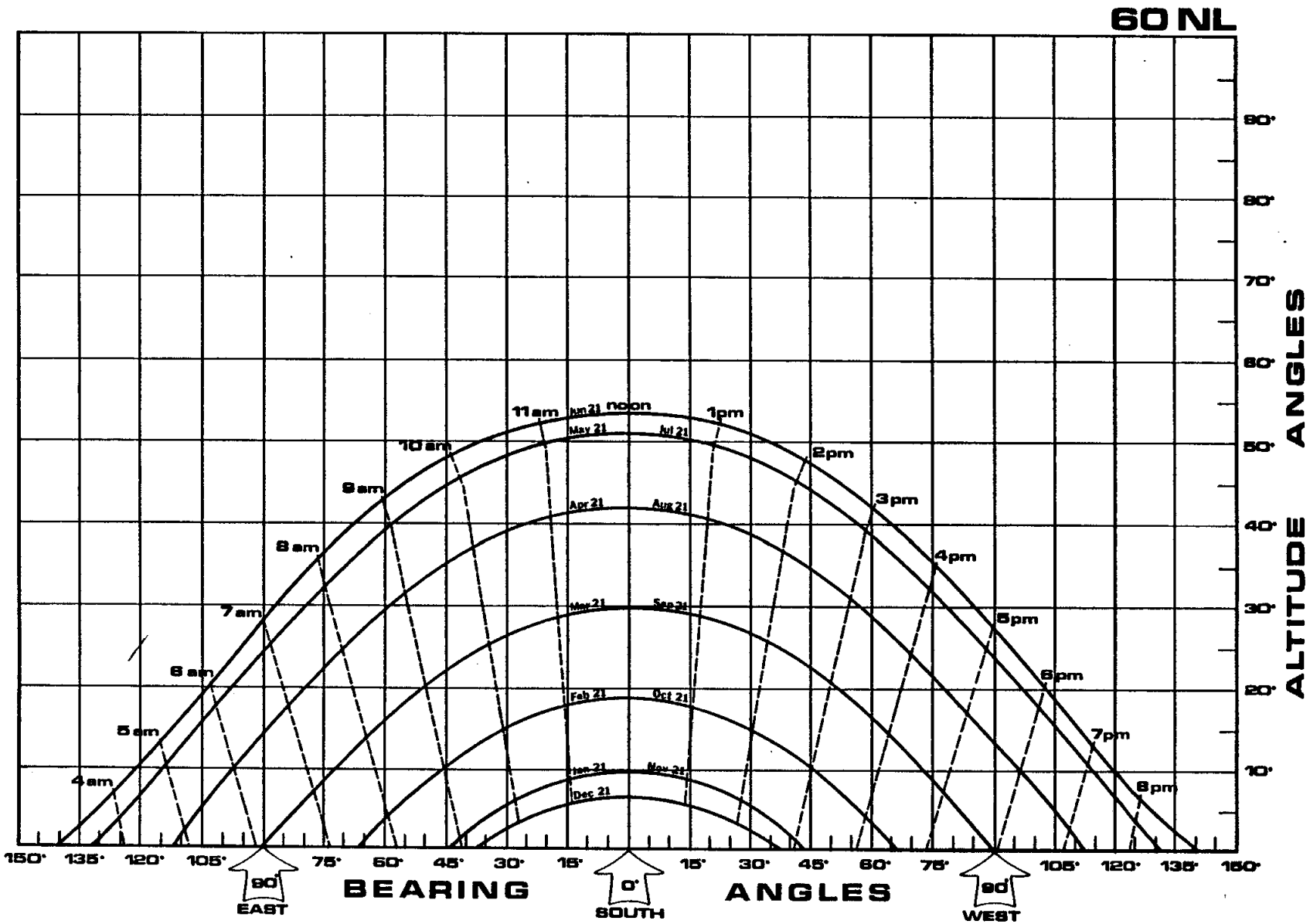
Sun path diagram for 56°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



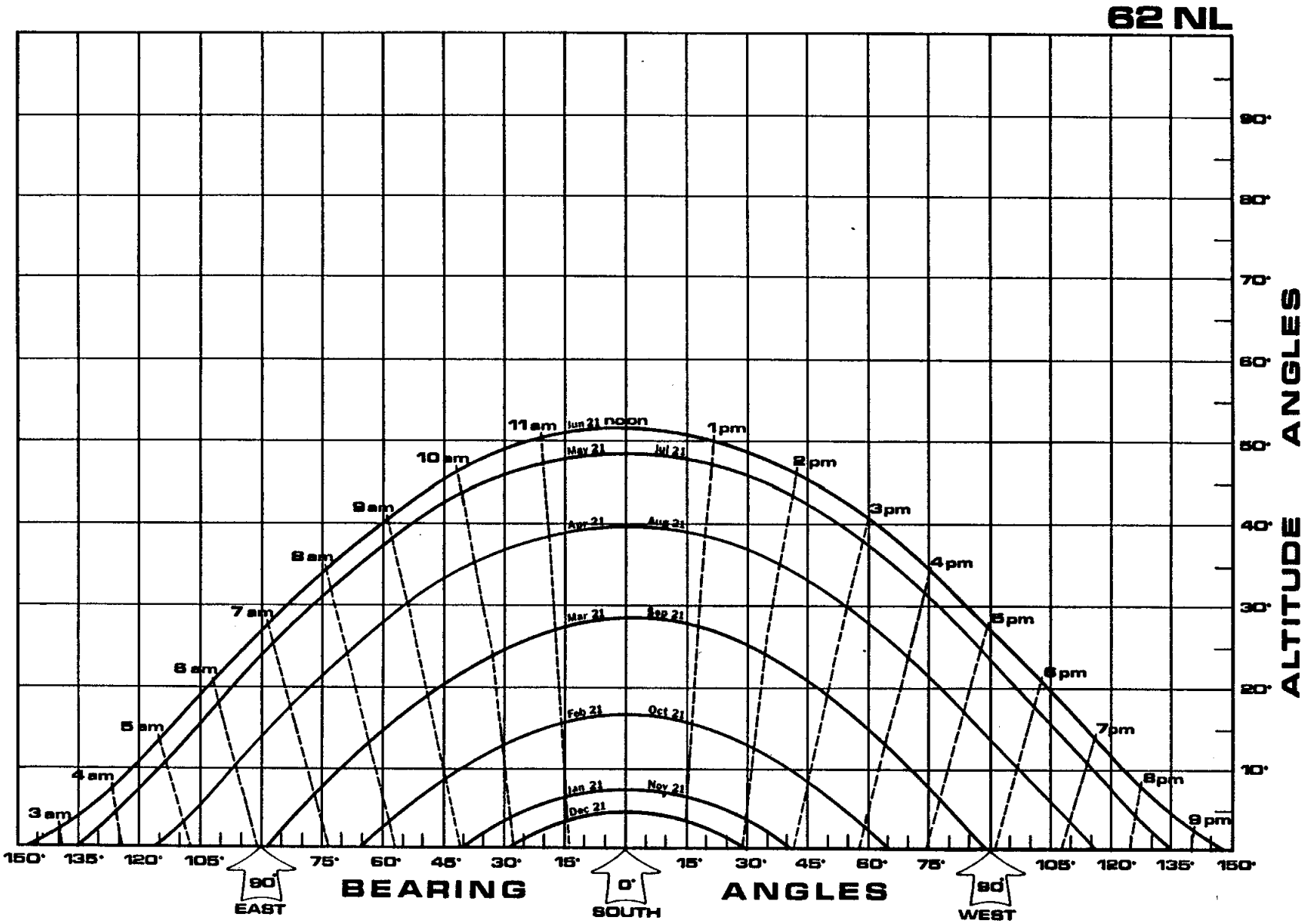
Sun path diagram for 58°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



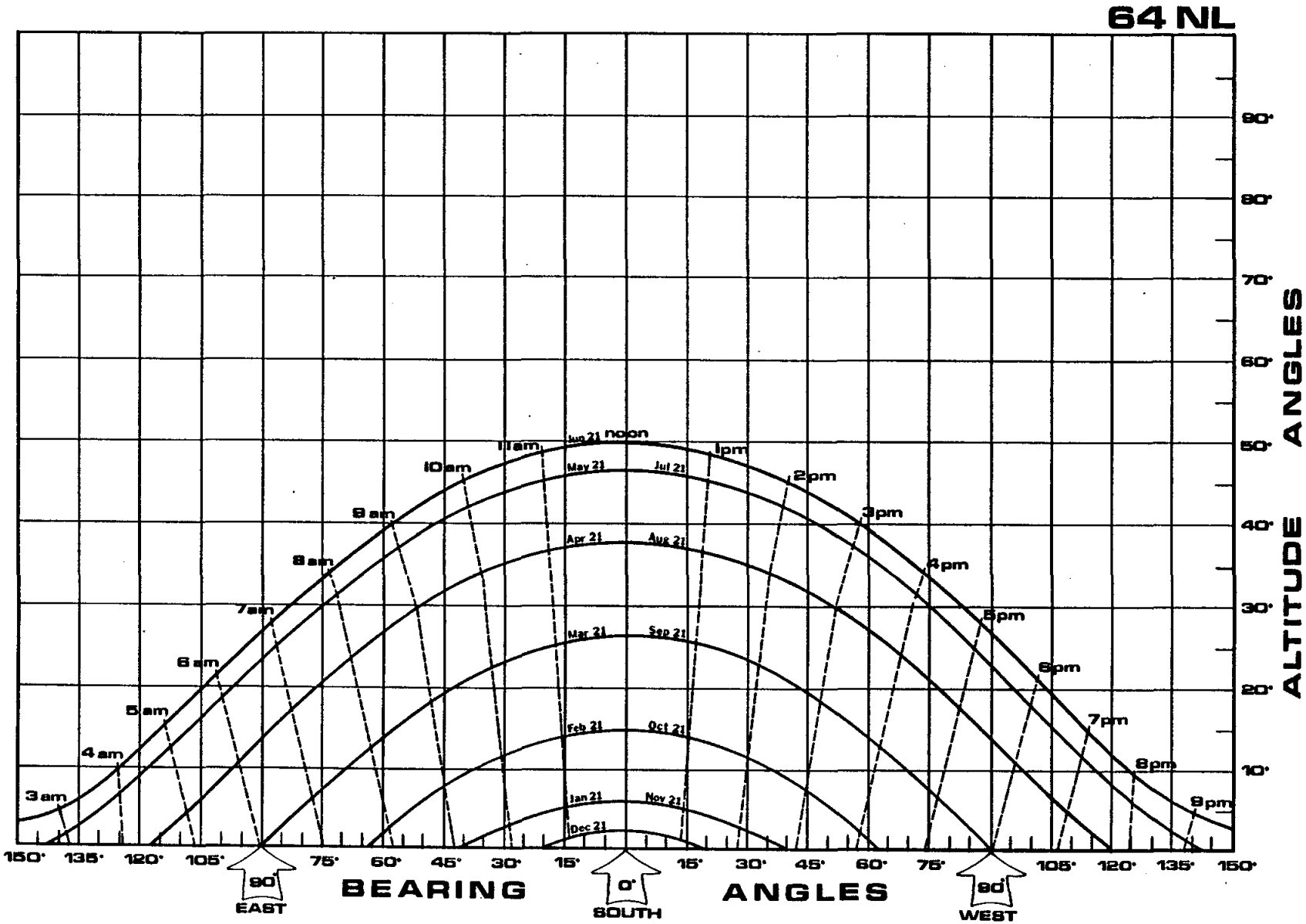
Sun path diagram for 60°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



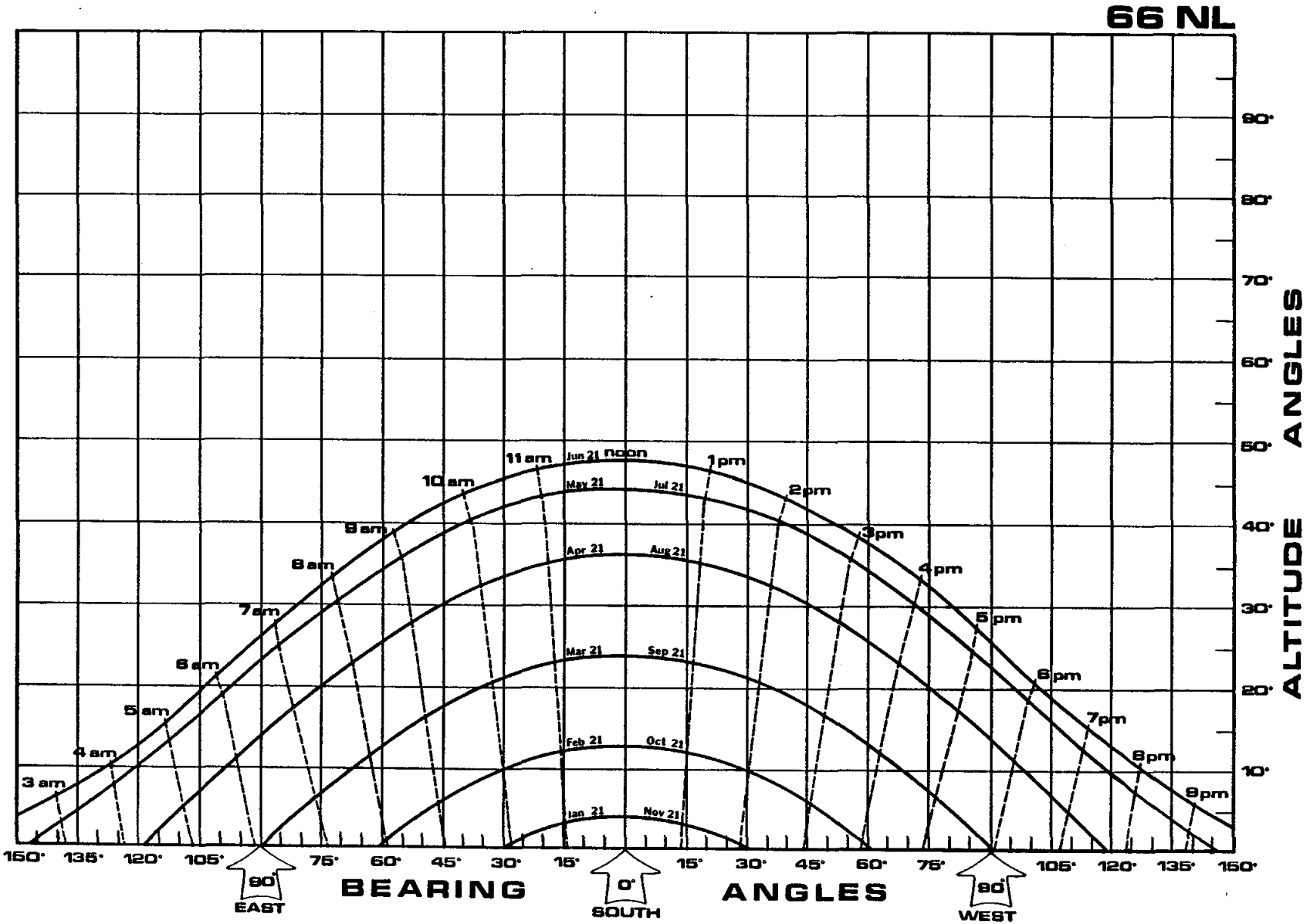
Sun path diagram for 62°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



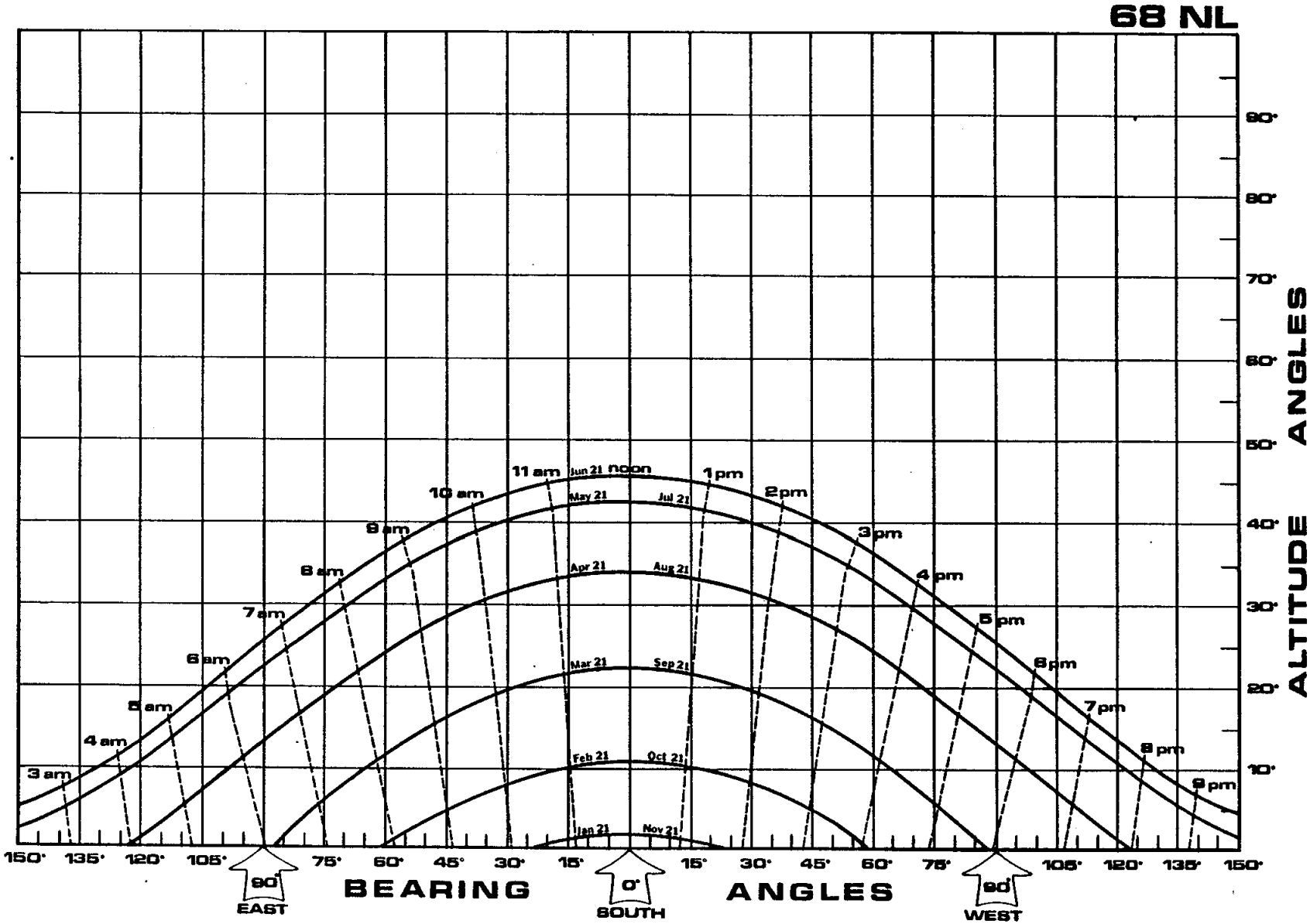
Sun path diagram for 64°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



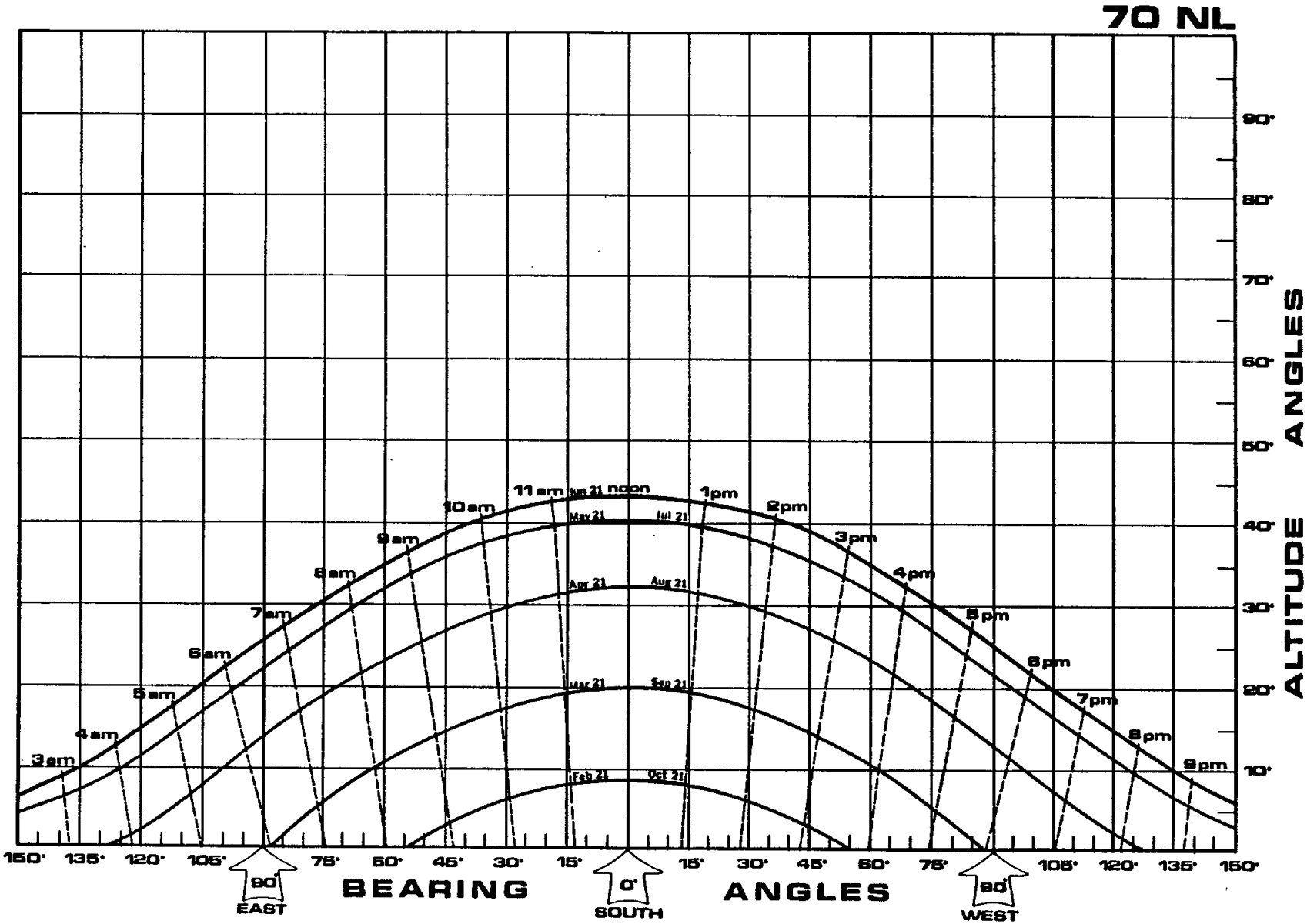
Sun path diagram for 66°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



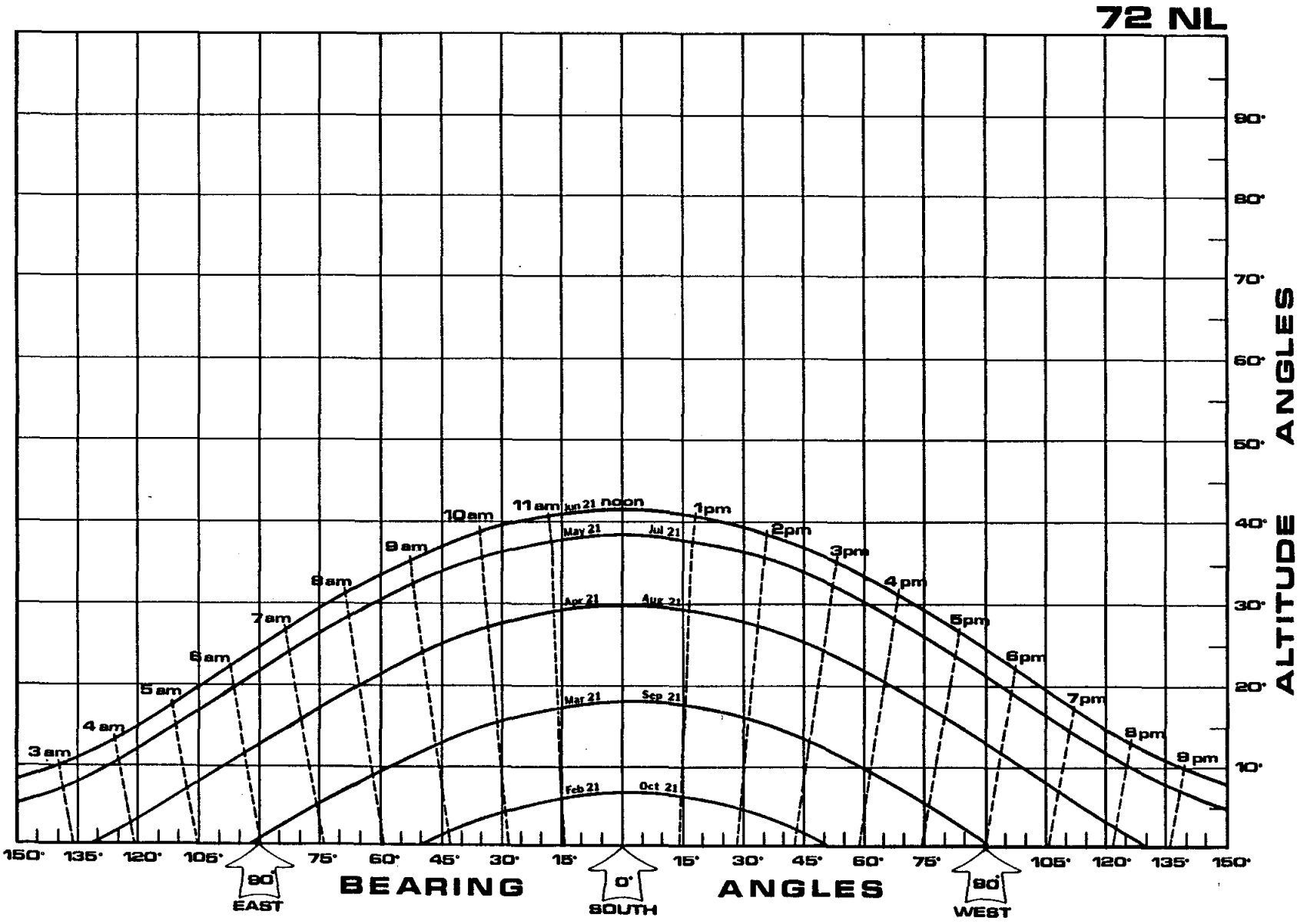
Sun path diagram for 68°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



Sun path diagram for 70°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling



Sun path diagram for 72°N latitude.

SOURCE: A Solar Design Manual for Alaska by Richard Seifert
Prepared by J. Matheson, AIA and L. Tusaint, AIA from data provided by John Zarling