a solar design manual FOR ALASKA

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont.)

TABLE OF CONTENTS
(Cont.)

introduction

This manual is the first attempt to assemble all the Alaska-specific solar energy design information in a single volume. The manual is organized according to five major subject areas:

The first section is an introductory background discussion of solar energy and some of the important physical concepts that are necessary to understand it. This is followed by a discussion of Alaska-specific considerations regarding solar energy.

The next major section deals with the technologies used in solar energy applications. The discussions include both active solar energy technologies, where heat is moved by pumps from the collectors to a point of use, and passive systems, where heat is moved within a building through natural means. Passive solar energy applications generally include those in which the structure itself is used as the collector. Photovoltaic cells, which produce electricity directly from solar energy, are also discussed. Energy storage is discussed at length because it is very important to the prospect of renewable energy use at high latitudes. Storage of energy is a general need in all intermittent renewable energy applications.

A third section describes the heating of domestic or commercial hot water using solar energy. A review of solar simulation computer programs is included in this section as well as discussions of factors such as the solar geometry at high latitudes, shading, and snowcover effects, all of which influence the performance of solar hot water heating systems. A hand calculation for sizing active systems is included for those who don't have access to a computer.

Active solar space heating systems are covered briefly since we have little experience with this technology in Alaska and the economics of this application have not yet been demonstrated in Alaska.

The final section describes passive solar design applications in the far North. Examples of classic passive solar design options are analyzed, and a physical optimization of a building design is included.

A SHORT COURSE IN SOLAR ENERGY

Solar energy is radiation; most solar technologies capture this radiation as heat. Other technologies use solar energy directly for daylighting or for generating electricity.

Visible light is the largest component of solar radiation, and it is the portion of the spectrum that can be usefully converted to heat. Wavelengths shorter than visible light (called ultraviolet) are largely absorbed in the upper atmosphere. The other major component of solar radiation, infrared, has longer wavelengths than visible light. We perceive infrared radiation as heat. A hot object emits infrared radiation, allowing us to sense the object without touching it.

The amount of available solar radiation is not constant. Solar altitude at midday and day-length vary with the season. Light intensity changes with the time of day. Environmental conditions further modify the amount of solar energy that the earth receives at a particular location or time. Yet the sun does emit a relatively constant amount of radiation with time. Referred to as the **solar constant**, the amount of solar radiation at the outside of the atmosphere facing the sun is 428 BTU/ft^2/hr (or 1.940 cal/cm^2/minute). A BTU (British Thermal Unit) is the amount of heat needed to raise the temperature of a pound of water by 1°F. In the metric system (commonly used outside the United States), heat is expressed in calories. A calorie is the amount of heat needed to raise the temperature of a gram of water by 1°C.

As solar radiation passes through the atmosphere, some continues in a straight path and some is scattered by the atmosphere. The former is called **beam radiation** and the latter is called **diffuse radiation.** Beam radiation enables shadows to be cast, and diffuse radiation is characteristic of overcast days.

Solar radiation received on a surface is usually a combination of both beam and diffuse radiation. Diffuse radiation comes from all directions in the sky, so it cannot be focused. It is still useful to those solar heating systems that don't require focusing of the solar radiation. Some light striking an object on the earth's surface (or anywhere else) will be reflected and some will be absorbed by the object. The ratio between the amounts of absorbed and reflected radiation is called the **solar absorptance.** A solar absorptance of 0.94 means that 94 percent of the solar energy striking a surface is absorbed. This energy is absorbed as heat. Some of this heat will be lost to the surrounding environment.

Heat can be transferred by conduction, convection or radiation. **Radiation** is the transfer of energy by electromagnetic (light) waves. This flow occurs at the speed of light, even through a vacuum. Thermal radiation is largely restricted to the infrared wavelengths, which are invisible to man.

Conduction is the transfer of heat to adjacent molecules in a substance. The handle of a cast iron skillet gets hot during use by conduction, but the wooden handle of an aluminum skillet does not. Obviously, cast iron is a good conductor while wood is an insulator. Conduction operates in any substance whether solid, liquid or gas.

Convection is the transfer of heat from one object to another by an intermediate fluid (liquid or gas). Convection can occur naturally as hot air rises and cools (as it does in a thunderstorm). Or convection can be mechanically driven (like the fan on an automobile engine which cools the radiator).

Visible light can penetrate glass but infrared radiation cannot. This is why greenhouses tend to be warmer than the outside temperature. Visible light penetrates the glazing. Some is reflected from the materials inside the greenhouse; this radiation can pass through the glazing to the outside. The absorbed radiation warms the objects, and some of this heat is lost in the form of infrared radiation to the air and other objects inside the greenhouse. Since the glazing is opaque to infrared, the inside air temperature increases. This phenomenon is sometimes referred to as the **greenhouse effect.** A greenhouse can be regarded as a simple solar collector since it is a radiation and convection trap (Figure 1).

Greenhouses are effective collectors, but unless the glazing is insulated during periods when it is not receiving heat from the sun, greenhouses will lose heat very rapidly by conduction and convection. This is because greenhouses commonly do not have the built-in capacity to store heat. To overcome this design problem, "solar greenhouses" are now being built which incorporate thermal storage to cut down or eliminate the need to heat greenhouses with fossil fuels at night or during long cloudy periods. "Solar greenhouse" sounds redundant, but solar in this case is an adjective used to indicate that the greenhouse is heated by the sun entirely or to a maximum feasible extent, as opposed to the common practice of using fossil fuels to heat it when necessary.

The solar heating of a greenhouse is accomplished through passive solar means. Heat is stored in concrete, rocks, water or antifreeze drums, or gravel during the day when excess heat is available. This stored heat is then released to the greenhouse interior at night.

Attaching a greenhouse to the south side of a house so that excess heat from the greenhouse can be used to help heat the house is another common solar heating option. It may also be a valuable technique in Alaska (see Figure 2).

Greenhouses will not be discussed in further detail since the Alaska Department of Transportation and Public Facilities is developing a separate manual for this use in Alaska.

COMMON APPLICATIONS OF SOLAR ENERGY

Daylighting

The use of visible solar radiation to reduce or eliminate the need for artificial lighting in a building is commonly called daylighting. This obvious function of sunlight is sometimes overlooked, yet it can provide substantial economic benefit. Since research on the optimum use of daylighting in Alaska has only recently begun, it would be premature to discuss daylighting in this volume, yet it is the oldest and most common use of solar energy.

Electricity

Solar energy can be directly converted to electricity using photovoltaic cells. This application is widely used where small amounts of power are needed in remote Alaskan locations. Wider use may be possible, but these systems are often too expensive to consider except where energy costs are very high.

Active Heating

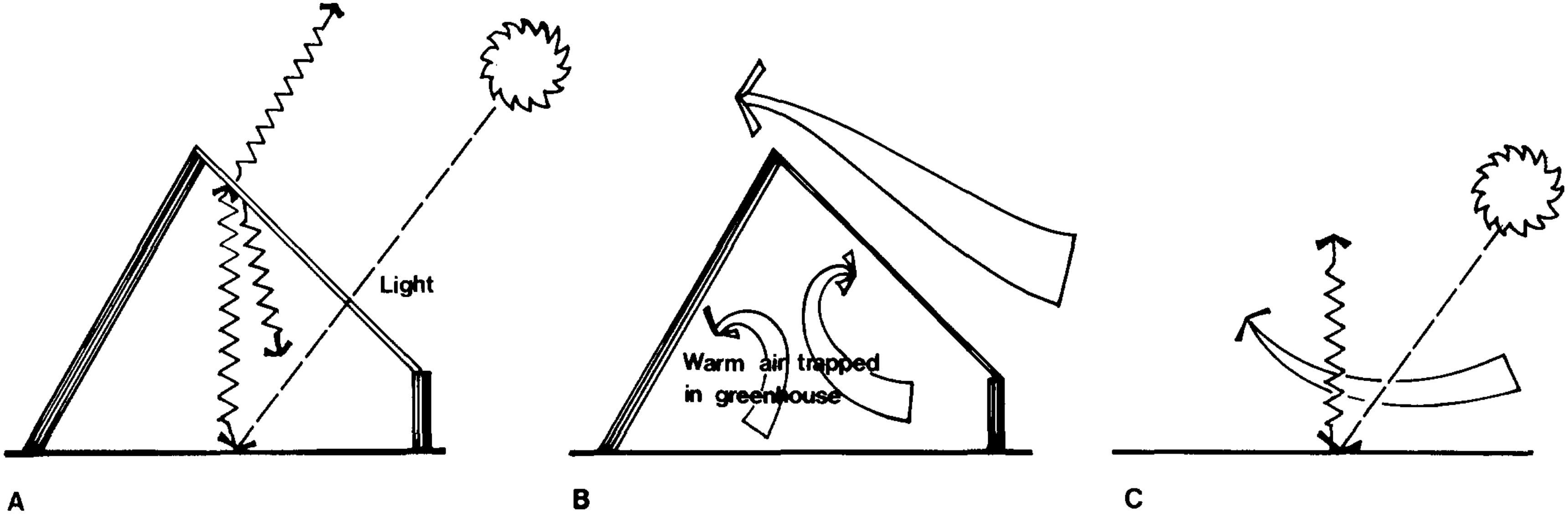
Active solar technologies employ an auxiliary energy source to move heat from where it is collected to where it is used or stored (usually by a pump or fan). Active solar technologies are practical for providing domestic hot water in Alaska. They may ultimately prove to be useful for space heating (particularly if installed on already existing structures), but there is little experience with active solar space heating in Alaska.

Passive Heating

Passive solar applications capture heat without the need for auxiliary energy to move the heat. Chiefly used for space heating, passive solar technologies move heat by conduction, convection or radiation. The building employs south-facing glazing to capture solar radiation, essentially making the entire structure a simple solar collector.

SOLAR ENERGY IN ALASKA

The potential for using solar energy in Alaska has long suffered from the notion that the sun simply doesn't offer any hope for Alaskans. From roughly November 15 until the end of January, little solar radiation is available and optimizing a system to collect it is not economically feasible. So what can the sun pro-



A Some light entering the greenhouse is absorbed, some is reradiated as infrared radiation which is trapped, some escapes through reflection and conduction.

B Warm air, heated by trapped infrared radiation, warms the greenhouse.

C The absorption, reradiation and convection of heat away from the surface of the earth as it naturally occurs without a greenhouse present.

Figure 1. The physical interactions occurring in a greenhouse.

vide?

There are 230 hours more of possible sunlight at the Arctic Circle than at the equator. The problem with solar energy is that it is dynamic, not reliable, and is out of phase with the space heating loads in the state. Yet solar energy is ever-present, on-site, and not subject to transportation system failures. It creates few environmental problems. And perhaps most important of all, solar energy is not inflationary.

Solar energy has many benefits not usually considered. In addition to fundamental security, solar energy is clean and safe. Once manufactured, there are no air pollution problems from solar equipment and there are not toxic waste disposal problems. Unlike the cost of depletable resources, which rise exponentially as reserves are depleted, the cost of energy from the sun should decline as we develop better and cheaper ways of using it.

Although the actual experience with solar energy use in Alaska is limited, it is clear that solar energy is a valuable resource for Alaskans if it is properly understood and utilized. It is possible to make a few important observations, relate some of the functional considerations, and make recommendations on the best ways to use solar energy.

1. The **solar heating of hot water** for domestic or commercial use is a viable option for many regions of Alaska. Anchorage is presently a major exception because inexpensive natural gas is available. Although it is not economically reasonable to heat 100 percent of hot water needs year-round, an investment in solar hot water heating is warranted in many Alaskan cities and villages. Hot water is needed

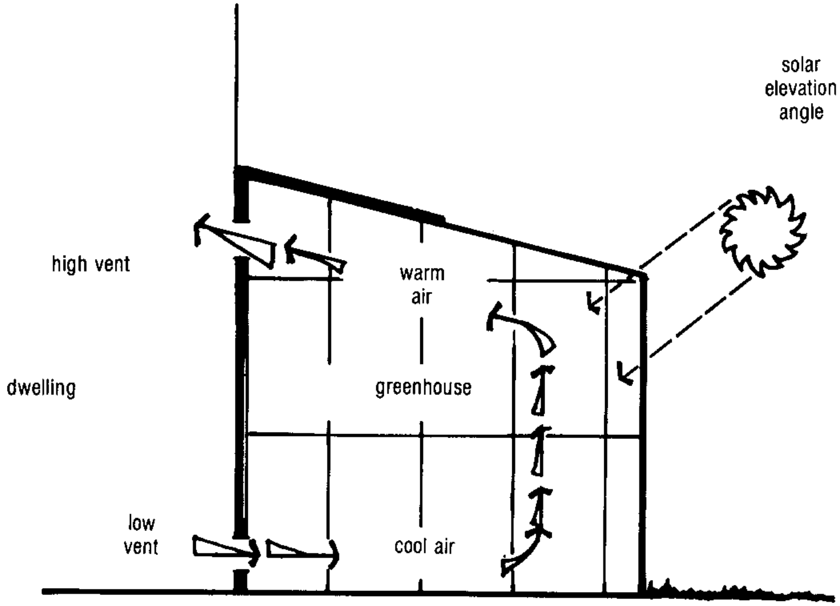


Figure 2. An attached solar greenhouse (also called a sunspace). Heat that is not needed in the greenhouse can be vented to the living area of the home.

year-round, and solar energy is available and useful for this purpose. This prospect is developed more completely in the section on solar heating of domestic and commercial hot water.

2. **Collector tilt** for active (pumped) systems is not exceedingly critical and it is recommended that collector arrays be mounted on the south wall or on the ground in Alaska at a 90° tilt. Vertical south wall mounts do not yield optimum collection of energy, but they do eliminate snow and dirt accumulation and are easier to mount. Roof penetrations are also avoided. Ground mounts enable easier cleaning of collectors and removal of snow.

3. **Active solar systems for space heating** are a less economic option than their passive counterpart. Because of the extreme annual variation of available solar radiation in Alaska, it is rare to obtain more than 25 to 35 percent of the annual heating requirements for even a highly insulated structure. Although annual or long-term heat storage systems may alter this situation, storage systems are not perfected, not readily available, or inexpensive. The capital productivity and capital costs of active heating systems are often very high because of the large collector area required to heat structures common today.

4. **Passive solar design in Alaska** can be useful and economical. The most common approach to passive solar design is to maximize the use of south-facing windows in a structure, and use good conservation design throughout (good vapor barrier, weatherstripping, large amounts of insulation, and insulated shutters).

5. **Shutters** are crucial for effective passive solar design in Alaska. Without shuttering, passive solar designs cannot be efficient, and large window areas will lose a great deal of energy. The effects of shuttering are discussed in the passive solar design section.

Availability of Solar Radiation

Generally, the availability of solar energy is directly related to latitude, because the intensity of solar radiation is proportional to the angle of the sun above the horizon (solar elevation). However, due to the climatic effects of oceans, mountains, and other geographical relationships in Alaska, solar radiation does not correlate well with latitude. Rather, it is related to the physiography and the amount of rainshadowing due to the large Alaskan mountain ranges such as the Chugach and Alaska ranges. This rainshadowing isolates the interior and continental climatic regions of Alaska from cloudy weather and precipitation. For these reasons, practical applications of solar energy are feasible in the continental and transitional areas of Alaska. Both of these areas dominate the Alaskan railbelt (see Figure 3). The definitions of these areas are given below.

Transitional:	Pronounced temperature variations throughout the day and year, low precipitation and humidity. Surface winds generally light. Mean annual temperature generally 25-35°F.
Continental:	Dominated by continental climatic conditions. Great diurnal and annual temperature variations, low precipitation, low cloudiness, and low humidity. Surface winds generally light. Mean annual temperature 15-25°F.

Since the sun's rays strike the ground at a lower angle at higher latitudes, the energy received on the ground surface is less than it would be if radiation struck from directly overhead. Thus, radiation intensity is less than at lower latitudes. In summer, however, the days are longer and total daily radiation received is approximately equal to that at lower latitudes (Hartman and Johnson, 1978).

A second facet of the solar resource in Alaska is the annual variability. Not only does day length change from approximately 3½ to 4½ hours in winter to 20-22 in summer, but the elevation angle varies from a meager 2.6° above the horizon on December 21 in Fairbanks to 49½° above the horizon on June 21. The sun is never overhead (at 90°) in Alaska. The maximum height it can reach above the horizon for any place can be calculated by subtracting the latitude from 113½°. Thus at 64°N the highest the sun reaches is 113½° - 64° = 49½°.

Table 1 gives some idea of how solar radiation in Alaska compares to other latitudes. It shows the percentage of the year that is twilight, sunlight, and a sum of both at latitudes from the equator (0°) to 75°N. Note that sunlight, twilight, and all light combined reach a maximum at 70°N, about the latitude of Barrow, Alaska.

It is clear from Table 1 that Alaskan lati-

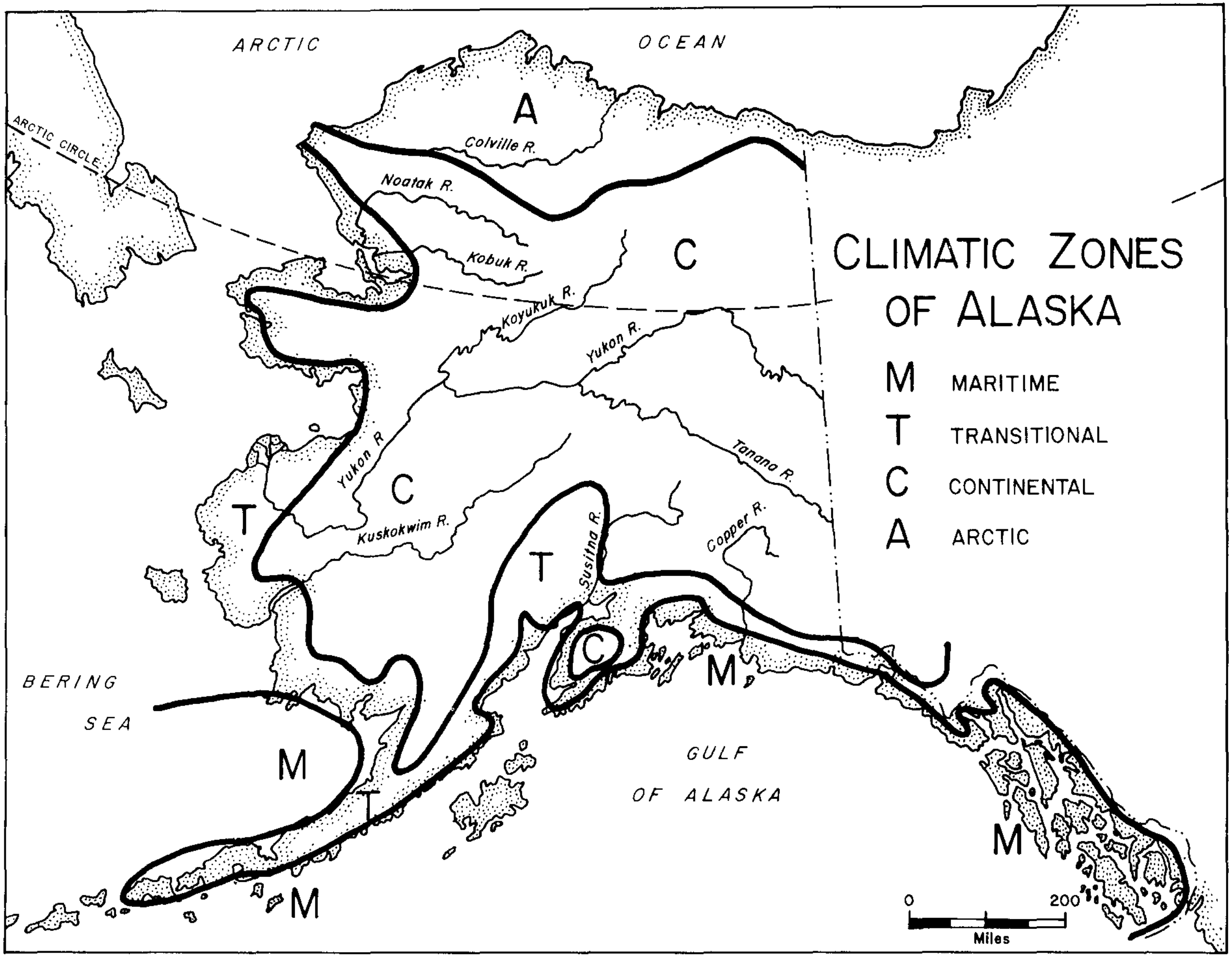


Figure 3. Climatic zones in Alaska. There is a correlation between the climatic zones of Alaska and the annual available solar energy. The continental zones yield the most available annual solar radiation. The transitional zone and arctic zone have the next highest. The marine climatic zone is characterized by cloudy, rainy weather and is a less suitable climate for solar energy applications.

tudes receive, on an annual basis, a small bonus of extra sunlight and a large bonus of extra twilight compared to lower latitudes. The sun, in rising or setting, crosses the horizon at a shallow angle at the northern latitudes and, consequently, takes longer to rise or set. This lengthens the day slightly and the twilight a great deal. In addition, refraction (the bending of the sun's rays by the atmosphere) lengthens the day by making the sun visible even when it is below the horizon. Refraction is small in the tropics but fairly large in Alaska, particularly during the winter (Hartman and Johnson, 1978). Another means of understanding the solar variation at Alaskan latitudes is to study the sun's orientation with time (see Figure 4).

Figure 4 shows that in order to get the maximum (called "normal" or "perpendicular") radiation, it is necessary to change the tilt of a surface from the horizontal. Optimum tilts for each season are shown.

Figure 5 shows geometrically why solar intensity is related to the elevation of the sun. The intensity of the sun is maximum on a surface oriented at right angles ("normal" or "perpendicular") to it. As the solar elevation decreases both during the day and seasonally, the same amount of radiation is spread over increasingly more and more area. Therefore, the amount falling on each unit area is less.

Alaskan Solar Radiation Data

The Geophysical Institute recently began gathering sophisticated solar radiation data (primarily for Fairbanks). No long-term solar radiation data exist for Anchorage; the Matanuska site at the Palmer Agricultural Experiment Station is the closest site to Anchorage for which any data exist.

TABLE 1: PERCENTAGE OF THE YEAR THAT IS TWILIGHT, SUNLIGHT, OR BOTH AT VARIOUS LATITUDES (Hartman and Johnson, 1978).

Latitude °N	Twilight %	Sunlight %	Sunlight and Twilight %
0	3.10	50.30	53.40
25	3.49	50.50	53.99
35	3.92	50.60	54.52
45	4.68	50.75	55.43
55	6.24	51.30	57.27
60	8.11	51.28	59.39
65	10.39	51.87	62.26
70	10.94	51.97	62.91
75	8.93	51.89	60.82

Historically there are five sites in Alaska where solar radiation data have been acquired:

Annette Island (southeast Alaska)
Barrow (arctic Alaska)
Bethel (southwest Alaska)
Fairbanks (interior Alaska)
Matanuska (southcentral Alaska)

These five sites have had varied histories.

Hourly solar radiation data in the formats indicated are available from the National Climatic Center (NCC), National Oceanic and Atmospheric Administration (NOAA) in Asheville, North Carolina, for the following sites and years:

	Strip Chart	Magnetic Tape
Barrow	4/51-09/74	1/57-03/57
Bethel	1/50-11/75	1/57-03/57
Fairbanks	8/31-07/76	1/57-03/57
Matanuska	11/55-07/76	1/57-03/57

Because the hourly data for extended periods of time are available only on strip charts, all data analysis would have to be done by hand, which is extremely time consuming. More recently, the NCC has rehabilitated solar radiation measurements for 25 stations in the U.S. under the SOLMET program funded by the U.S. Department of Energy. Upon developing correlating equations that related solar radiation measurements to weather data and extraterrestrial solar radiation for these 25 stations, values were derived using these equations for the remaining 222 weather stations in the United States. The correlating equation developed for Great Falls, Montana, was used for all sites in interior Alaska, while the Seattle-Tacoma equation was used for coastal locations. Data tapes with these derived values of hourly solar radiation and actual weather data are available from NCC for 15 sites in Alaska,

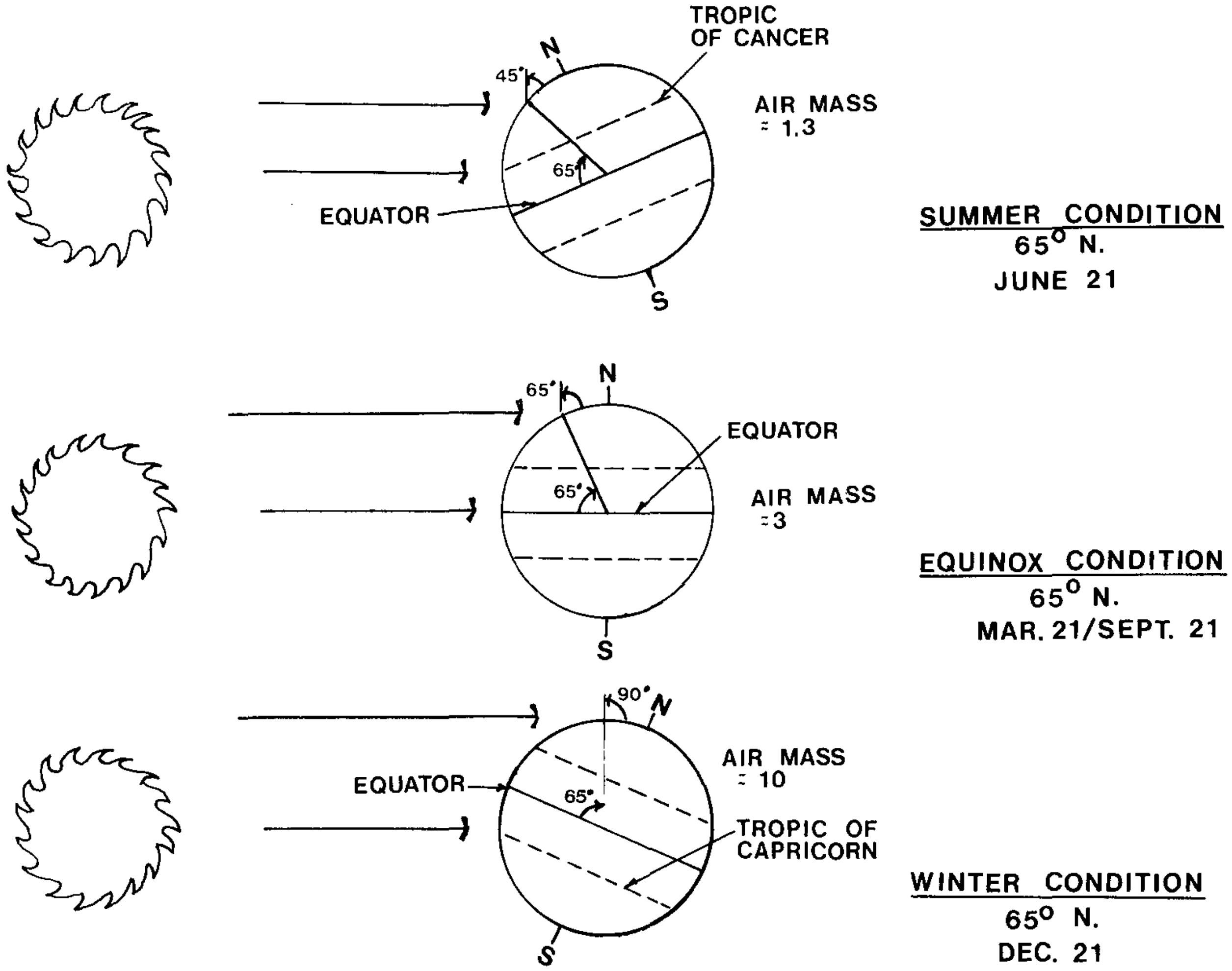


Figure 4. Basic solar geometry at noon during different seasons, showing how the changing effects of seasonal solar elevation affects the optimum tilt of a surface for collecting solar energy. The air mass is an indicator of the absorption of solar energy in the atmosphere due to the increasing thickness of atmosphere that solar energy must pass through before reaching the surface of the earth. This air mass is proportional to the secant of the solar elevation angle.

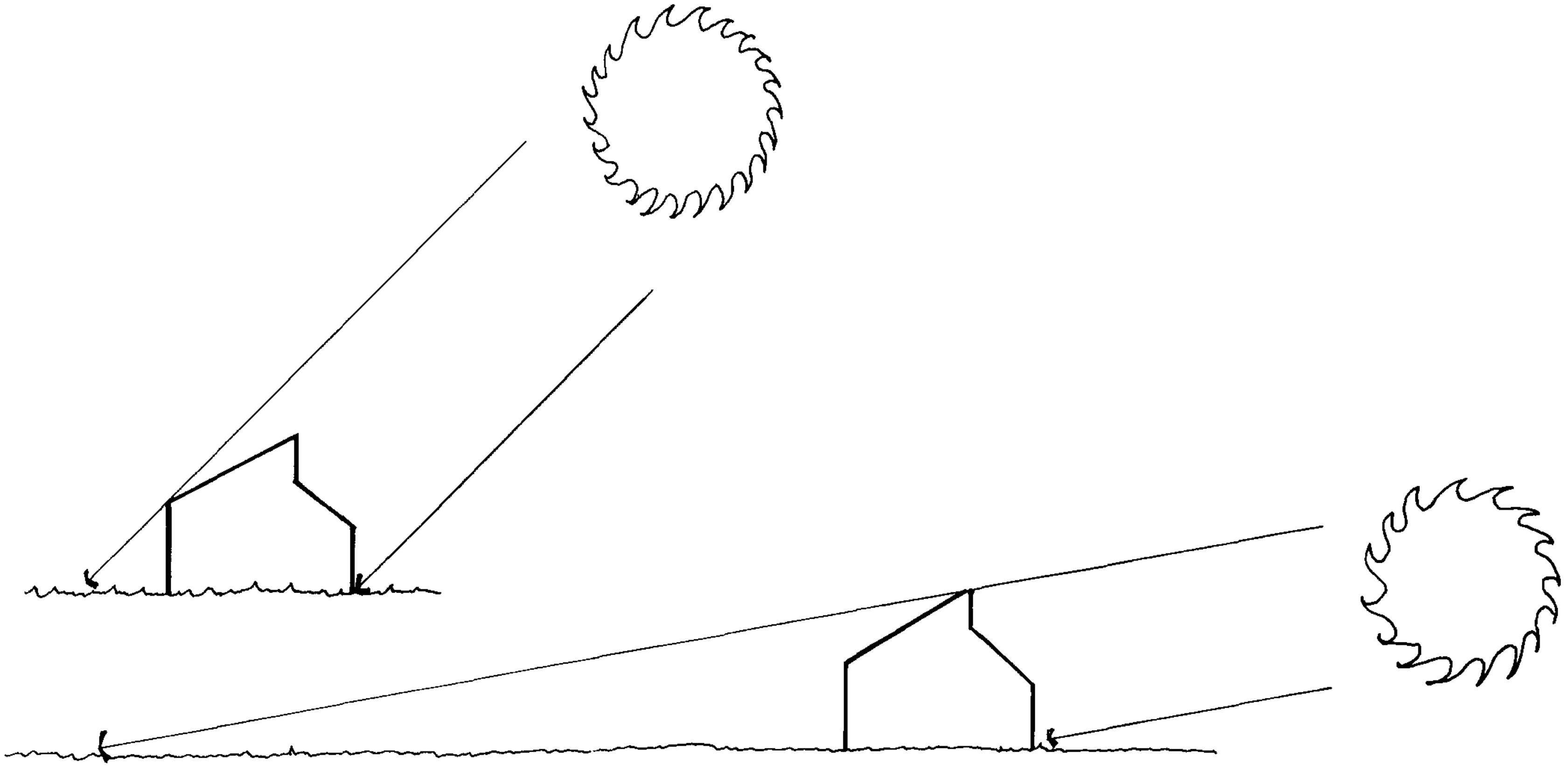


Figure 5. Elevation of the sun and its relationship to the intensity of energy striking a horizontal surface. The amount of solar radiation striking the top of the atmosphere is similar at different times of the year. Yet the intensity (amount) of radiation striking each square foot of surface area is less during winter, because the radiation is spread over a much larger area at low solar elevation angles. The radiation at low solar elevation angles is further diminished because it travels through more of the atmosphere, allowing more scattering and atmospheric absorption. Since at the top of the atmosphere, the intensity of solar radiation is everywhere equal on a surface perpendicular to the sun, the elevation angle (number of degrees above the horizon) and the amount of atmosphere the radiation passes through are very important variables. The result is that the same amount of solar radiation is spread over ever larger areas as the sun gets lower and lower in the sky.

TABLE 2: INSOLATION AND TEMPERATURE DATA FOR FIVE ALASKAN LOCATIONS (Liu and Jordan, 1977).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Annette Island: Latitude 55°02′N; Elevation 110 ft												
A^1	236.2	428.4	883.4	1357.2	1634.7	1638.7	1632.1	1269.4	962	454.6	220.3	152
R_t^2	0.427	0.415	0.492	0.507	0.484	0.441	0.454	0.427	0.449	0.347	0.304	0.361
t_o^3	38.5	37.5	39.7	44.4	51.0	56.2	58.6	59.8	54.8	48.2	41.9	37.4
Barrow: Latitude 71°20′N; Elevation 22 ft												
A	13.3	143.2	713.3	1491.5	1883	2055.3	1602.2	953.5	428.4	152.4	22.9	–
R_t	–	0.776	0.773	0.726	0.553	0.533	0.448	0.377	0.315	0.35	–	–
t_o	13.2	-15.9	-12.7	2.1	20.5	35.4	41.6	40.0	31.7	18.6	2.6	-8.6
Bethel: Latitude 60°47′N; Elevation 125 ft												
A	142.4	404.8	1052.4	1662.3	1711.8	1698.1	1401.8	938.7	755	430.6	164.9	83
R_t	0.536	0.557	0.704	0.675	0.519	0.458	0.398	0.336	0.406	0.432	0.399	0.459
t_o	9.2	11.6	14.2	29.4	42.7	55.5	56.9	54.8	47.4	33.7	19.0	9.4
Fairbanks: Latitude 64°49′N; Elevation 436 ft												
A	66	283.4	860.5	1481.2	1806.2	1970.8	1702.9	1247.6	699.6	323.6	104.1	20.3
R_t	0.639	0.556	0.674	0.647	0.546	0.529	0.485	0.463	0.419	0.416	0.47	0.458
t_o	-7.0	0.3	13.0	32.2	50.5	62.4	63.8	58.3	47.1	29.6	5.5	-6.6
Matanuska: Latitude 61°34′N; Elevation 180 ft												
A	119.2	34.5	–	1327.6	1628.4	1727.6	1526.9	1169	737.3	373.8	142.8	56.4
R_t	0.513	0.503	–	0.545	0.494	0.466	0.434	0.419	0.401	0.390	0.372	0.364
t_o	13.9	21.0	27.4	38.6	50.3	57.6	60.1	58.1	50.2	37.7	22.9	13.9

[1] A = Monthly average daily total radiation on horizontal surface, BTU·day/ft^2.

[2] $R_t = A/H_o$, where H_o = solar radiation on a horizontal surface outside the earth's atmosphere, BTU·day/ft^2.

[3] t_o = Average daytime temperature, °F.

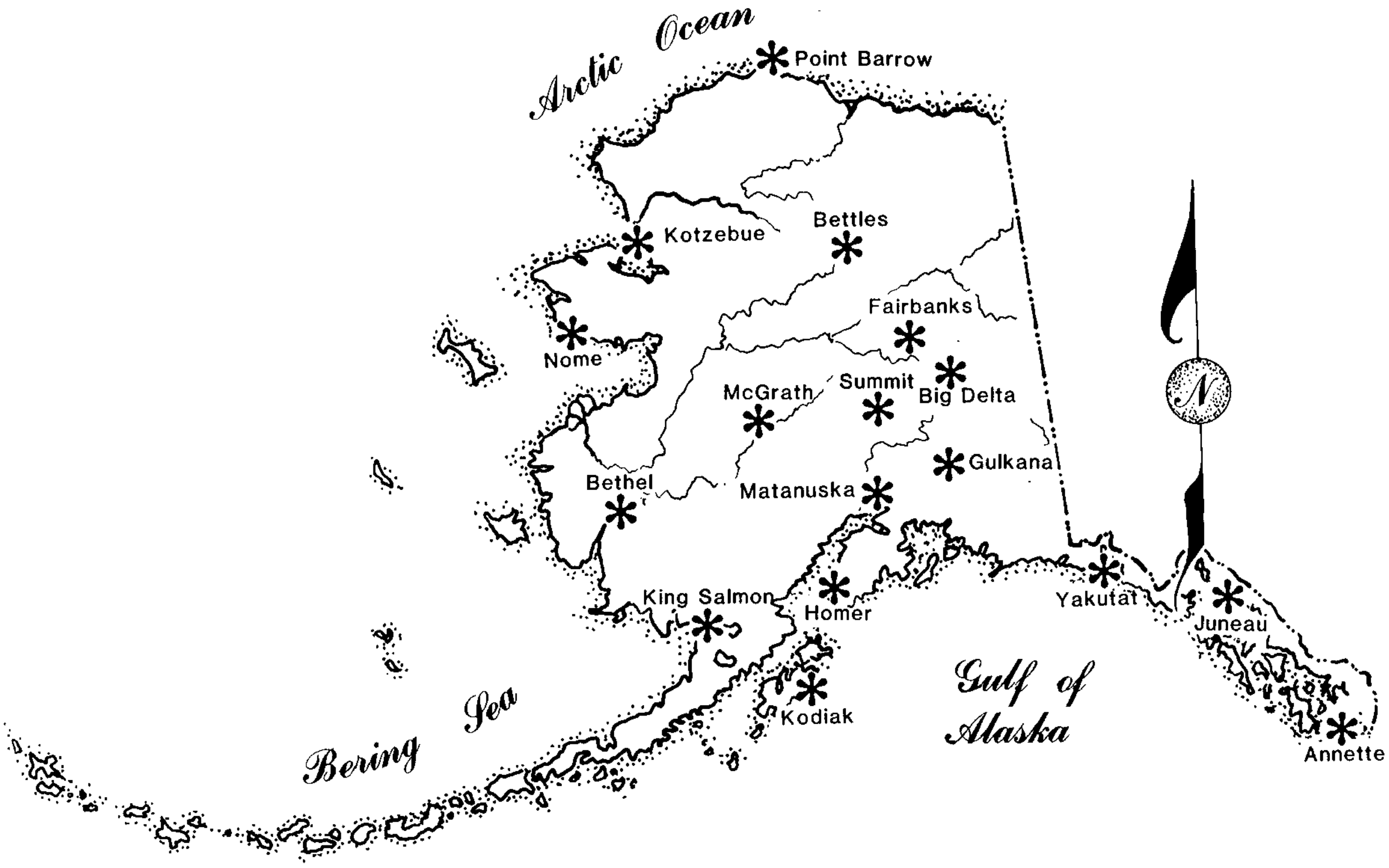


Figure 6. Sites in Alaska for which SOLMET solar radiation data exist. These are tabulated in Appendix B.

which are shown in Figure 6.

In 1977, NOAA began operating its updated solar radiation network with the support of the U.S. Department of Energy. Fairbanks is the only Alaskan site included in this effort. Apparently, the program has been beset with problems so only a limited amount of Alaskan data has been available through this program. The last known source of hourly solar radiation measurements is from the Solar Energy Meteorological Research Site established at the Geophysical Institute of the University of Alaska, Fairbanks, in 1978 by the U.S. Department of Energy. Data beginning with March 1979 include direct and diffuse measurements on a horizontal surface, and total incident radiation striking horizontal, 65° tilted, and vertical surfaces.

Daily total radiation data measurements are available from the NCC for the following sites and years:

	Strip Chart	Magnetic Tape
Annette Island	07/49-07/75	07/52-07/75
Barrow		07/52-10/74
Bethel		07/52-10/75
Fairbanks		07/52 to date
Matanuska		12/54 to date
Palmer	03/67-07/76	01/67 to date

Data averaged over the periods of record from these sites are shown in Table 2. These are the only "real" data available for Alaska. Several sources of solar radiation data are actually calculated from theoretical values, and some use the horizontal data in Table 2 to calculate solar intensities on surfaces inclined at different angles to the sun. Such information is useful for engineering purposes. Since solar energy use in Alaska is a fairly new concept, the question of which data set to use for design purposes is not yet resolved. With time, the superiority of one set over another may be empirically determined.

Rather than list all the solar radiation data available, the interested reader is referred to Appendix B. Much of the available solar radiation data is contained in *Solar Energy Resource Potential in Alaska* by R. D. Seifert and J. P. Zarling (1978). While out of print, it is available statewide at local libraries.

solar technologies

To get a better idea of how solar technologies function, each one is described briefly and a sketch is included if appropriate.

FLAT-PLATE SOLAR COLLECTORS

Figure 7 shows a schematic of a typical flat-plate solar collector. This is the most common type of solar collector used today in "active" solar energy systems. Flat-plate collectors convert solar radiation to heat energy. They consist of a flat absorbing surface with several parallel paths running lengthwise through it. A fluid is pumped through the collector. Sunlight heats the absorbing surface which conducts heat to the fluid. Some flat-plate collectors use air or another gas, others use liquid as the working fluid.

Flat plates can accept direct or indirect light from a wide range of angles. The absorbing surface is usually made of a material that is a good conductor of heat (like copper or aluminum). The flat plate is painted black to absorb as much light as possible. As the absorber warms, it transfers heat to the fluid within the collector but it also loses heat to its surroundings. To minimize this loss of heat, the bottom and sides of a flat-plate collector are insulated, and a glass or plastic cover is placed above the absorber with an air space between the two. The cover permits the light to come through but reduces the amount of heat escaping. If the collector is located in a cold region, sometimes two glazings are used--although the true efficiency of double glazing needs to be researched.

For year-round use, a liquid-type collector must incorporate antifreeze for external circulation and a heat exchange loop to prevent the antifreeze from contaminating the potable

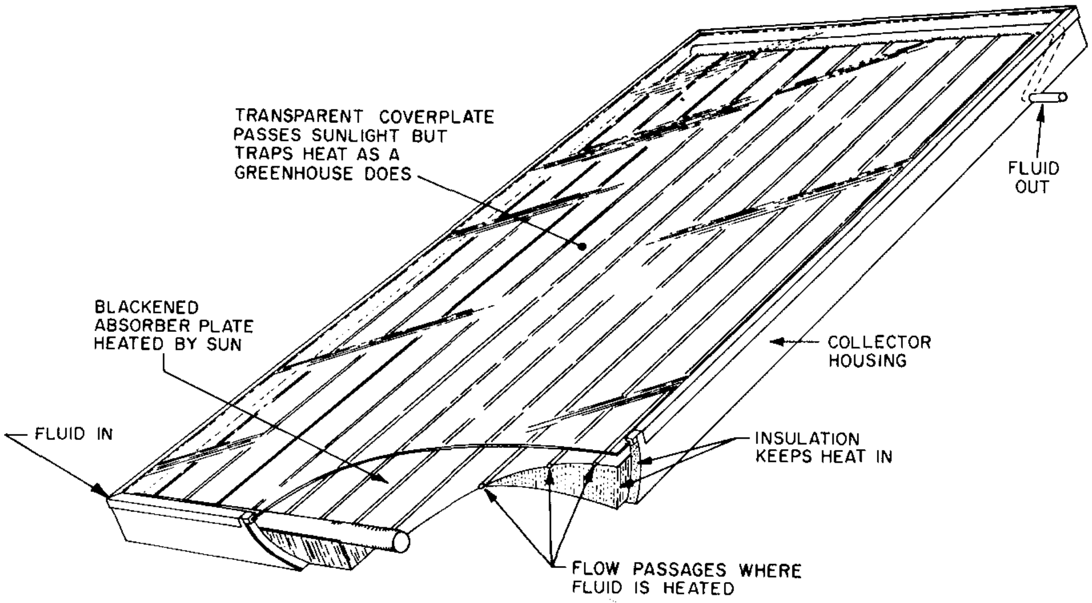


Figure 7. Schematic view of a typical flat-plate solar collector. Solar radiation (primarily visible wavelengths) strikes the surface of the glazings and is transmitted through them with a loss of 10-13 percent for each layer of glazing (only one glazing is illustrated). About 95 percent of the solar radiation striking the blackened collector plate is absorbed. This surface reradiates energy in the form of infrared radiation, which is trapped between the glazings and the absorber plate; this causes the collector plate to get hot. The collector fluid (liquid or air) is pumped through the collector to move the heat to where it is needed.

water supply in the event of a leak. Liquid-type collectors also function in diffuse light, which is dominant on cloudy days.

Active systems employing flat-plate solar collectors are the most common type used to retrofit homes and businesses, due to the greater installation options.

EVACUATED-TUBE COLLECTORS

One technological development in solar collector design is the evacuated-tube collector. The absorber tube is surrounded by a glass tube. An additional glass tube surrounds the first, and they are separated by a vacuum (like a Thermos bottle). This means that there is almost no air to transport heat from the inner glazing to the outer glazing. Sunlight easily comes in through the glass, but the heat loss is greatly reduced by the evacuated space between the glazings. This makes the evacuated-tube collector highly efficient, especially when the temperature difference between the hot absorber and the cold outside air is great.

The tubes (which look like black, oversized, fluorescent lights) are almost always installed with reflective troughs beneath them (see Figure 8). Light passes between the tubes, and the troughs reflect it back to the bottoms and sides of the tubes. When a fluid temperature of about 200°F is needed, the evacuated tube is a good option.

CONCENTRATING COLLECTORS

The concentrating collector takes solar radiation and focuses it onto a small absorber area. This multiplies the amount of energy (per unit area) striking the absorber and makes it hotter faster than a flat-plate collector. The advantage is not that more energy is collected but that a higher temperature is produced in the working fluid. At the same time, the small absorber surface area limits the heat loss. Light is reflected from a carefully designed trough or dish, which is lined with a reflective coating. Sunlight also can be refracted through a lens that works somewhat like a magnifying glass. In both cases, the absorber receives a high concentration of light energy, sometimes as high as 50 times that of a flat plate (see Figure 9).

But there are several drawbacks. Concentrators work only in direct sunlight. They don't work well on cloudy days. The focusing requires that the light hit the reflector or lens at a certain angle. For this to occur, a sun-tracking system is often employed and is another item

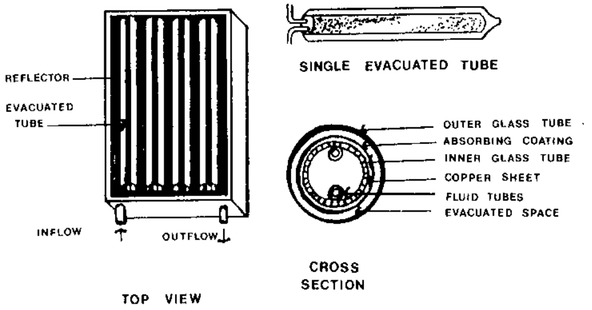


Figure 8. Various components of an evacuated-tube solar collector.

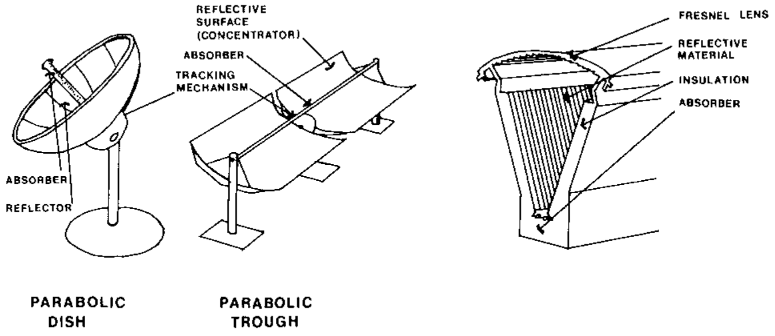


Figure 9. Two types of concentrating collectors. One employs a parabolic reflector, the other uses a fresnel lens and internal reflection.

that will require preventive maintenance periodically.

Concentrators are usually built into a heavy frame. If the wind catches the reflective surface and makes it vibrate or shake, the focus is disturbed and efficiency decreases. The weight of the frame and trough or dish limits the practicality of concentrators for many applications.

COMPARING ACTIVE SYSTEMS

Costs

Both concentrators and evacuated tubes are more expensive than flat-plate collectors; very few of these concentrating collectors and evacuated tubes are being manufactured at the present time. Mass production and technological breakthroughs could reduce costs and perhaps lower the prices of concentrators and evacuated tubes.

Matching Collector to Application

The choice of collector depends upon three basic factors: the operating temperature that is required, the amount of sunshine in the area, and the average outdoor air temperature. Table 3 illustrates the most commonly used collectors for several applications.

TABLE 3: TECHNICAL APPLICATIONS OF VARIOUS TYPES OF SOLAR COLLECTOR.

Application	Collector
Agriculture and pool heating	Unglazed or single-glazed* flat-plate (often plastic)
Space and hot water heating	Flat-plate (metallic)*, evacuated-tube, nontracking concentrator
Solar air conditioning	High performance flat-plate*,evacuated-tube, concentrator (tracking or nontracking)
Industrial process heat (200-400°F)	Evacuated-tube*, concentrator (tracking or nontracking)
Industrial process heat (over 400°F)	Tracking concentrator
Solar thermal electric power	Heliostats*, tracking concentrator

*Most common choice.

PASSIVE SOLAR SPACE HEATING

A significant amount of solar energy can be captured by passive means. Passive solar heating is simply a way of using the building itself as a solar energy collector. Many northerners are familiar with the heat gain from large south-facing windows during the day; this is a form of passive solar heating.

In passive solar heating, the sun's energy enters a building and heats the building without the use of fans, pumps, or other mechanical devices. This energy is sometimes stored for later use. The heat moves by natural means (conduction, convection and radiation).

Passive designs go hand in hand with energy-conscious building design; if designed into the building from the start, passive designs are often less expensive than active systems. Existing buildings are sometimes adaptable to passive designs.

On the other hand, since passive designs are an actual part of the building, new and improved building styles are possible (National Solar Heating and Cooling Information Center, 1979).

Heat Gain Through Glazing

The most widely used form of solar heating is sunlight entering a building directly through windows. This provides light (displacing artificial lighting) and eventually ends up as heat after striking objects in the room.

Heat Loss Through Glazing

To effectively reduce heat loss through windows, at least two layers of glass are needed in cold climates. A third layer of glass can reduce heat loss further. The best way to reduce such heat loss is to cover the windows with insulation during periods when there is no direct or indirect sunlight available. This movable insulation is sometimes called a thermal shutter or night insulation.

The use of thermal shutters can often be forgone in the warmer climates of the Lower 48, because there is enough solar gain available during the day (usually) to offset the high heat loss from uninsulated glazing at night. However, to obtain the best performance on an annual basis in Alaska, thermal shutters are imperative. A small net gain in heating can be obtained from triple-glazed south-facing windows in many Alaskan locations. But this gain is insignificant compared to the 25-40 percent heating load reduction which can be provided in some parts of the state by the creative use of south-facing glazing that is covered with R9 shuttering during periods without solar gain.

A further problem of shuttering is the lack of a mature technology. Although many variations of mechanical and automatic shutters exist, none could truly serve the broad-ranging Alaskan applications adequately. Several options for night insulation are discussed further in the passive design section.

Aspnes and Zarling (1979) have calculated the heating value of windows with double, triple and quadruple glazings for Anchorage and Fairbanks. Monthly and heating season performance data have been developed that account for window orientation, solar heat gain, and night-time use of thermal insulating shutters (Figures 11 through 16).

Thermal Storage

When heavy material for storing solar heat is placed directly behind the windows in the path of sunlight, the temperature fluctuations in the building are reduced. The thermal storage wall is made of dense materials such as concrete, stone, brick, adobe, earth or containers of water.

Figure 17 shows how heat is absorbed and conducted through the concrete wall. At night, the moderately warm wall radiates heat to the building. With the addition of vents at the bottom and top of the wall, some of the heat enters the building immediately by natural convection.

In Alaska, the value of thermal storage remains questionable. It appears that latitude, and the consequent lack of winter sun, diminish the value of massive rock or concrete thermal storage. This is because the minimal solar radiation levels in winter do not yield enough solar gain inside a structure to build up a surplus that can be stored. Thus, for the winter season, storage is of little value.

PHOTOVOLTAIC OR PHOTO-ELECTRIC CELLS

It is possible to generate electricity directly from incoming solar radiation using photovoltaic "solar cells." Development of these cells was primarily a result of the space program, and they were initially extremely expensive. Such photovoltaic units have no moving parts, are quiet, nonpolluting, reliable and easy to operate. While they are still expensive, they offer a promising way to use the sun's energy here on

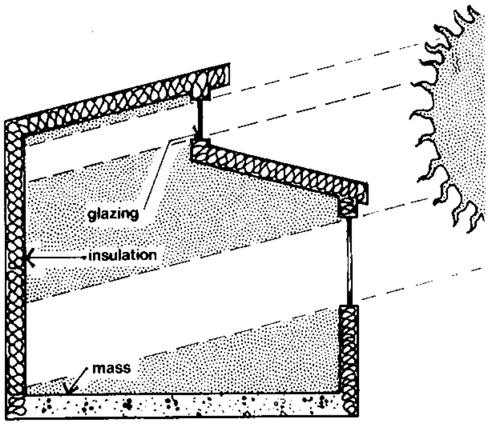


Figure 10. Passive solar heating employs the entire structure as the solar collector and the thermal storage medium.

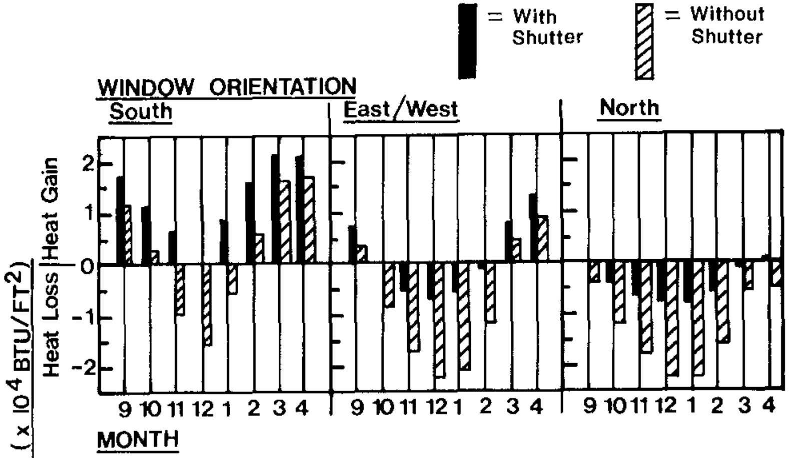


Figure 11. Monthly thermal performance of double-glazed windows in Anchorage, Alaska, with and without nighttime use of R9 insulating shutters.

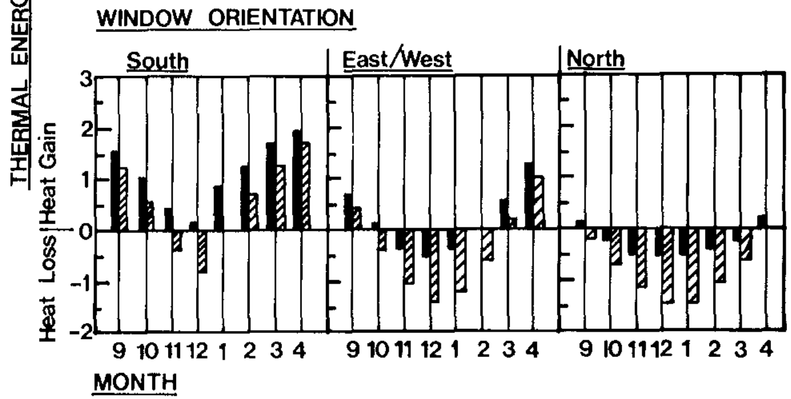


Figure 12. Monthly thermal performance of triple-glazed windows in Anchorage, Alaska, with and without nighttime use of R9 insulating shutters.

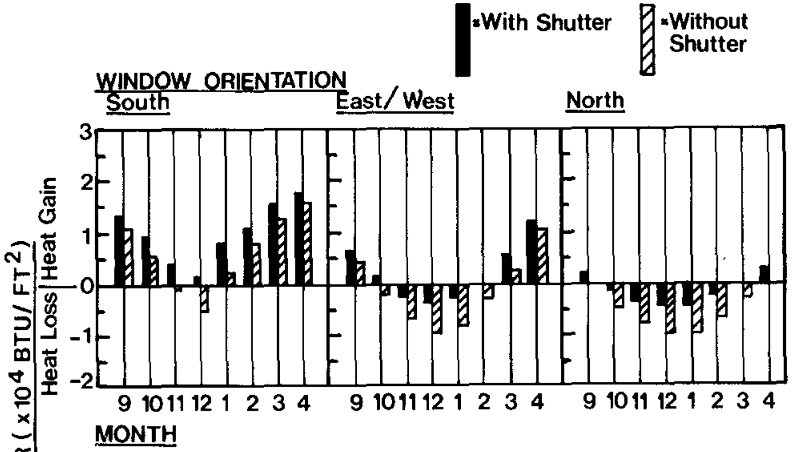


Figure 13. Monthly thermal performance of quadruple-glazed windows in Anchorage, Alaska, with and without nighttime use of R9 insulating shutters.

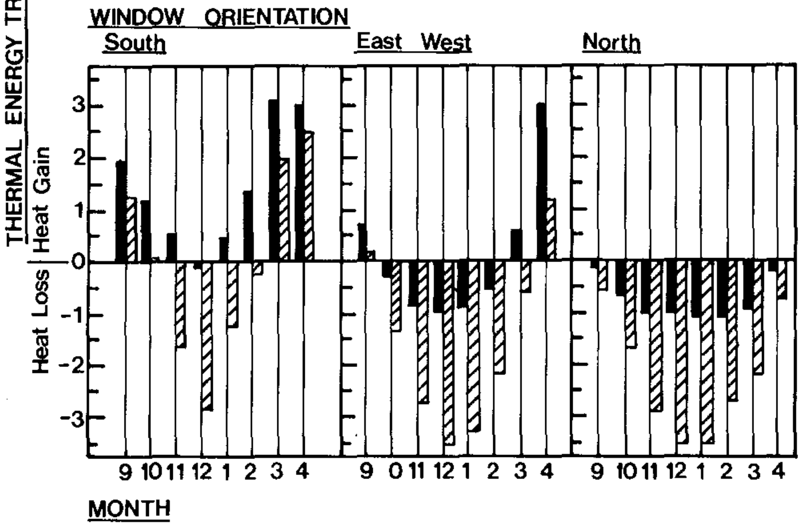


Figure 14. Monthly thermal performance of double-glazed windows in Fairbanks, Alaska, with and without nighttime use of R9 insulating shutters.

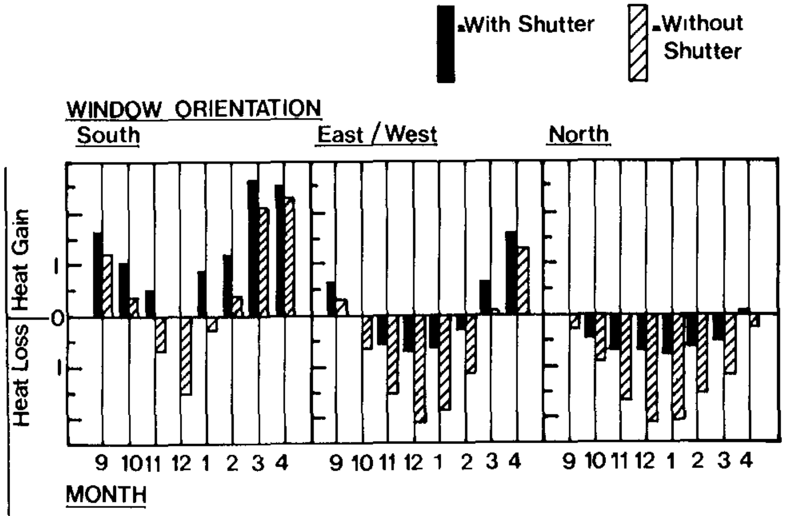


Figure 15. Monthly thermal performance of triple-glazed windows in Fairbanks, Alaska, with and without nighttime use of R9 insulating shutters.

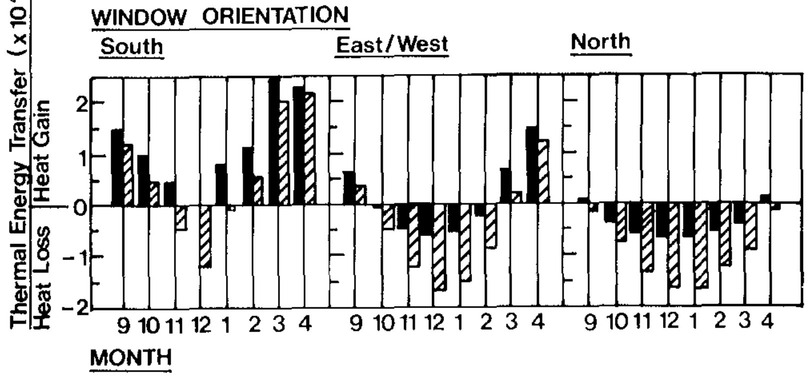


Figure 16. Monthly thermal performance of quadruple-glazed windows in Fairbanks, Alaska, with and without nighttime use of R9 insulating shutters.

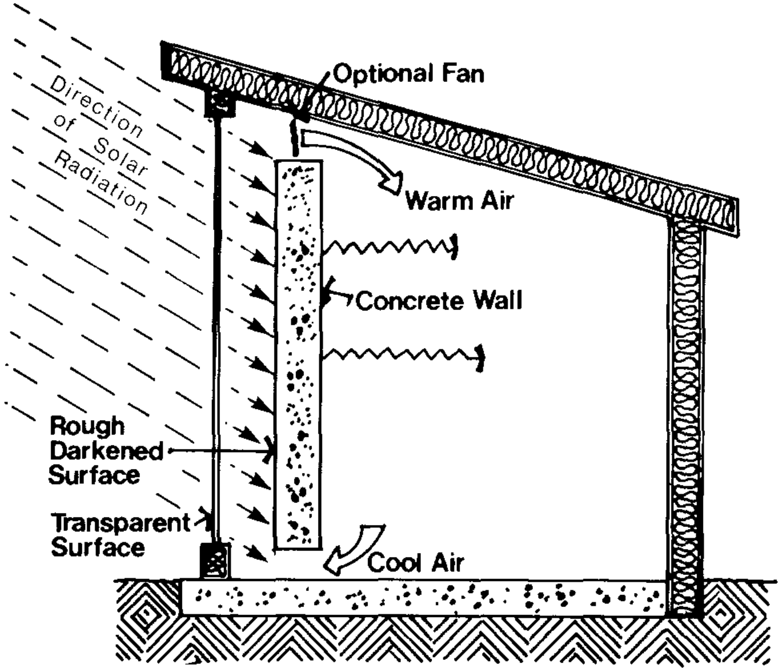


Figure 17. The Trombe wall is a passive solar design. Heat gained by the wall during the day is stored and released at night to the interior space.

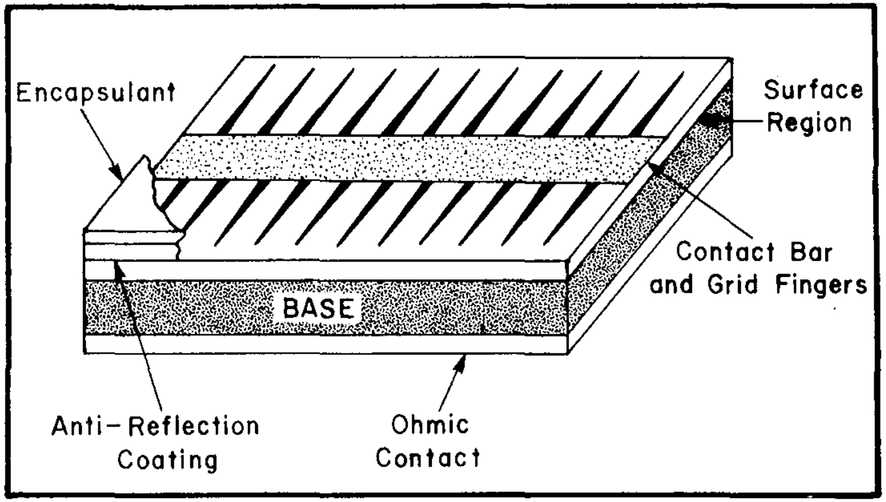


Figure 18. Typical photovoltaic cells are 1-4 square inches. An array is usually oriented like a flat-plate collector, and cells are connected in series.

Earth. The technology of solar cells is complex. It is important to understand the basics of this technology to gain a realistic expectation for photovoltaics.

A high quality silicon solar cell is capable of producing a maximum current of about 30 milliamperes per cm^2 (0.030 amperes) and a maximum voltage of 500 millivolts (0.500 volts). The conditions for these maximum values are not, however, the same and the maximum power that can be generated in full sunlight is about 15 milliwatts/cm^2 (0.015 watts per square centimeter).

A typical solar cell is 2 cm by 2 cm. Its power output is very small (about 0.60 watts), so many cells must be connected together to obtain an appreciable power output (Figure 18). As an example, a 14 volt, one watt panel measures 150 x 150 x 30 millimeters (a surface area of 225 cm^2) and has a mass of one kilogram (about 2¼ pounds).

As an example for sizing in English units, we use a 1 square foot module to show what can be expected of a photovoltaic system. This module will deliver 300 milliamperes under a light intensity of 100 milliwatts per centimeter squared, even at an operating temperature of 140°F. (This is an intensity of 317 BTU/ft^2/hr, a high rate of solar radiation.) The output in Alaska (peak) would likely be about 75 percent of this.

In determining the quantity of electricity made available in kilowatt-hours, average figures are sometimes based on eight hours of sunlight. Often, a more conservative figure of 5 hours of sunlight per day is more practical. Thus, a solar panel delivering 60 peak watts for a period of 5 hours would supply 300 watt-hours (5 x 60) for storage. Averaged over a day this would correspond to a continuous drain of 12.5 (300 ÷ 24) watts. On a monthly basis, using a 30-day figure, the quantity of electricity made available would be 9 kwh (30 x 0.3).

Variations in solar energy must be considered in planning a solar power system. These involve weather conditions, the earth's rotation, and seasonal declinations, just as in other applications of solar energy.

The average power output of a solar panel is approximately 1/5 of the peak power rating of the panel. Thus, a panel with a 60 watt rating would provide an average of 12 watts of power (60 ÷ 5). The figure can be above or below this value depending upon geographical location and average weather conditions at the site. In a practical vein, this amounts to about 0.7 watt per square foot of solar cell area. A figure often used for rough approximations is 1 watt per square foot.

A typical commercial panel supplies 3.6 watts of peak power per square foot. Using average figures and energy storage, the continuous power capability would be in the 0.75-1 watt capability per square foot. This is the present state of the technology (Noll, 1975).

Performance can also be predicted when the figures are based on the average number of sunshine hours per year at the operating site (Appendix E). As an example, we will use the value for Nome, which has 1,884 hours of sunshine in an average year. This corresponds to 21.5 percent of the hours in a year (8,760). Thus at an output of 0.75-1 watt per square foot per hour, we could expect a photovoltaic array at Nome to produce in the range of 1.41-1.88 kwh per year for each square foot. The roof or south wall of an average building (perhaps 300 square feet) might produce 565 kwh per year if covered with photovoltaic cells.

Photovoltaic systems have received wide use for more than a decade throughout Alaska. They are used for communications repeaters at remote sites and for airport lighting systems. The Alaska Railroad recently installed crossing signals powered by photovoltaic arrays. Such systems are very useful for remote sites where electrical demand is intermittent.

The Jet Propulsion Laboratory has a series of test arrays at Fort Greely (near Delta Junction) which is being exposure tested to determine cell life in the subarctic.

As prices decline and photovoltaic cells continue to receive broader use, their applications will gradually become more familiar and useful to Alaskans.

ENERGY STORAGE

Storage technologies include seasonal thermal storage, diurnal (daily) thermal storage, battery storage of electricity, and storage of hydrogen.

The element of energy storage appears again and again in the application of renewable energy sources. It is a pressing technological problem that is limiting the optimum use of solar, wind, and photovoltaic energy, as well as such cyclic energy sources as tidal energy. A sophisticated, inexpensive, and reliable energy storage system would overcome many of the physical barriers to using renewable energy resources. At present, solar seasonal storage systems for space heating are not very practical. Using water to store 25 million BTU for heating during the four coldest months in Alaska (November, December, January, and February) would require about 8,012 cubic feet of storage, a volume equal to 31x31x8 ft, a little larger than a common basement. The 25 million BTU would be only adequate if the building were superinsulated (an integrated R-value of about 25). Standard buildings older than 10 years often require 200 million BTU of heat annually, 60 percent of which is required during the four coldest months.

The problem is clear. Both thermal and electrical storage systems, and storage efficiencies need to be improved since each would greatly improve the usefulness, cost, and reliability of renewable energy resources.

Water and Water Tanks

Water is not only an inexpensive heat storage medium, it also has the highest heat capacity per pound of any ordinary material (1 BTU/lb·^{o}F). Although other liquids may be used to transfer heat from the collector, the storage tank generally contains potable water (for domestic water heating systems), or a corrosion-inhibited water with antifreeze (for space heating systems). For a residential space heating system, one day's storage requirement is about 1 to 2½ gallons per square foot of collector. Water is commonly used for active system storage, but can also be used in passive systems in the form of large tanks, waterwalls, and other containers of water which are placed in a sunlit area to gain and store heat.

Rocks and Rock Bins

Rocks are used with air heating collectors rather than with liquid collectors. Hot air is blown into a rock storage bin, which should contain about 1 cubic foot per square foot of collector. This is about 2½ to 3 times the size of a water storage tank for the same size collector.

The bins used to store the rocks can be constructed inside the basement. Underground bins are not recommended. Water seepage can ruin insulation and, in some cases, can infiltrate the walls of the container. It is essential that the bin be constructed so that no water vapor, vermin, or insects can enter. All sides of the bin must be insulated.

Phase-change Materials and Containers

Phase-change materials store and release heat at a constant temperature by melting and freezing. As heat comes from the collectors to the storage, the material changes to liquid. Upon cooling, it changes back to a solid and releases heat that can be used to heat the home. The size of the storage bin need only be one-quarter to one-half the size of water storage for a comparable amount of collector area.

The phase-change media now in experimental storage units are: (1) disodium phosphate dodecahydrate; (2) sodium thiosulfate pentahydrate; (3) paraffin; and (4) sodium sulfate decahydrate (Glauber's salts). The performance of sodium sulfate degrades after several cycles of melting and solidifying. Its melting temperature, 89°F, is lower than the usual temperature used in forced-air heating systems, so increased air-flow rates and larger ducts are needed.

Phase-change materials are most often contained in small tubes or trays, which are tightly sealed to prevent leakage, moisture transfer, and oxidation. The containers should be chemically compatible with the phase-change medium selected. A large number of these containers are needed to provide the large surface area needed for heat exchange. This makes phase-change storage more expensive than rock bins or water tanks.

Advantages and Disadvantages

Although other materials have been used to store heat, the most commonly used are water, rock, and phase-change substances. Each has its advantages and disadvantages. The ultimate decision must be based on one's own needs and economic resources. Table 4 lists relative advantages and disadvantages for storage systems.

Seasonal Storage

Further mention is made here of seasonal storage, which is a logical step to pursue in developing solar energy use in the far North. Since more than enough solar energy for normal heating needs occurs in the summer season, the need for a seasonal storage technology in Alaska is great. It is the best long-term approach to achieve 100 percent solar heating in the far North; this is feasible but not economic at present. In Sweden, long-term thermal storage is being built and tested at the neighborhood scale, which is more economic. In this conception, the storage tank is sized (several hundred thousand gallons) to supply heat for an entire block, and collectors are mounted atop the storage tank and collect the summer sun. Such solar development requires planning and land use that is not common in Alaska today. Perhaps these options will be more attractive as they become better known.

A design analysis by Hooper (1978) shows that annual storage of available solar energy could supply virtually all the heat necessary for a building in Toronto with less than half of the collector area needed to directly heat the building in December and January. With careful design, this savings in the required collector area can offset the higher costs of the required storage.

There are other major advantages. Annual storage is virtually immune to short-term weather variation. It is practical and economical to design for 100 percent solar heating for an average year. This compares to 30 to 35 percent solar which is apparently the economic choice for short-term storage systems.

Since the cost of storage is more important with annual storage (it accounts for more than one-third of the total system's cost), larger installations have a major advantage. This is due to the squared-cube laws: as the size of storage increases, the surface area rises only as the square of the dimension while the volume increases as the cube of the dimension. Therefore, the cost of the storage—which depends mainly upon the surface area—decreases rapidly as the capacity increases.

It is to be expected that annual storage systems will be favored in high-latitude locations and that, initially, larger installations will show considerably greater advantage over smaller systems.

Because of the higher annual heat loads in the North, much higher investments in solar heating systems can be amortized than in more moderate climates. The cost of a solar heating system does not increase linearly with the capacity; therefore northern locations look particularly favorable, despite their somewhat lower annual average collector efficiencies caused by the lower ambient temperatures.

For all these reasons, it is anticipated that larger systems may find application in the near future in the northern states and in Alaska, especially district heating and large-scale storage systems.

Storage of Photovoltaic Electricity

The storage of electricity remains a problem for photovoltaic systems. The most common solution is batteries, which are charged at intervals by the photovoltaic cells.

In applications where large electric grids are available, the energy from a home-based photovoltaic system may be dumped into the grid to run the electrical meter backward. Obviously, there are physical limitations to this type of "storage," but it can work well with utility cooperation. The actual degree of photovoltaic saturation attainable on a grid has not yet been determined, but individuals could proceed toward providing solar electricity while these problems are being solved.

Efficient batteries and research into photo-electro-chemical processes will determine the ultimate storage mechanism for photovoltaic electricity. Meanwhile, the unit cost of photovoltaic cells remains their biggest drawback to wider application. Until this fundamental cost problem is overcome, photovoltaic cells will remain a small factor in the solar future.

TABLE 4: ADVANTAGES AND DISADVANTAGES OF VARIOUS THERMAL STORAGE MEDIA

Storage Medium	Advantages	Disadvantages
Water	Least expensive for retrofitting because of compactness	Possible corrosion Some lost efficiency because of the need for heat exchangers when nonfreezing liquids or corrosion inhibitors are used Leakage can be destructive
Rock	No heat exchanger needed between collectors and storage Leakage, though not good for efficiency, is not destructive	Location of any air leakage difficult to detect Retrofitting expensive due to large size of storage bin and of ducts
Phase-change materials	Very compact storage and good for retrofitting	Expensive container/heat exchanger Long-term reliability not proven
Naturally occurring zeolite minerals	Perhaps as much as 3 times the heat capacity of phase-change materials Water vapor is the working fluid No thermal losses, since "dryness" is stored	Unproven performance Not at stage of commercialization Will occupy large volume
TEPIDUS—a new commercially available system from Sweden, based on a hydration cycle of sodium sulfide	High energy density Water vapor is the working fluid Modular design Stores waste heat	Economics of distribution may be unfavorable in Alaska System uses chemical storage (sodium sulfide hydration); this chemical is cheap in Sweden but expensive in Alaska Waste heat not as readily available in Alaska

active solar water heating

For Alaska, the heating of domestic or commercial hot water using solar energy is the most economic active solar option to consider. This is due to several factors:

1. The cost of energy is high in most areas.

2. Although annual solar variability is high and solar energy provides a minimal amount of heating during the winter, hot water is needed year-round and solar energy can provide 40 to 60 percent (see Table 5) of the hot water load on an annual basis in many locations. Unlike the heating load, the hot water load is not directly out of phase with the solar energy availability.

3. Solar hot water heating is usually accomplished by using an active collector system, and it can be easily retrofitted to most buildings.

For these reasons, solar hot water heating should be of primary concern in initial solar design of buildings.

COMPUTER SIMULATION

The recent development of sophisticated simulation computer programs has provided the architect and engineer with a convenient means for predicting the performance of active and passive solar systems. It is now possible to evaluate various solar design options rapidly and at relatively small expense. This permits the designer to investigate new ideas and to best use existing systems.

Although modeling solar systems is inherently complicated, it is essential that the simulation programs be easily accessible and relatively simple to use. Now that many of the basic computational algorithms have been written and verified, increased attention is being given to making programs more user oriented. A summary of available computer programs for solar design and analysis can be found in Appendix A.

It should be noted that the results of extensive simulations at universities, government laboratories, and architectural-engineering offices are increasing our knowledge regarding

TABLE 5: ANNUAL PERCENTAGE OF ENERGY FOR HOT WATER PRODUCED BY 150 SQUARE FEET OF STANDARD[1] SOLAR COLLECTORS FOR VARIOUS ALASKAN LOCATIONS.

Location	Latitude °N	Annual Percentage of Solar Hot Water Heating[2] %
Annette	55°2′	52.3
Barrow	71°20′	36.5
Bethel	60°49′	48.4
Big Delta	64°0′	57.9
Bettles	66°55′	53.1
Fairbanks	64°49′	54.0
Gulkana	62°9′	58.3
Homer	59°38′	58.0
Juneau	58°37′	41.3
King Salmon	56°41′	56.1
Kodiak	57°45′	55.7
Matanuska	61°34′	62.6
McGrath	62°58′	49.3
Kotzebue	66°52′	49.6
Nome	64°30′	48.9
Summit	63°39′	51.8
Yakutat	59°31′	40.9

[1] A standard solar collector is assumed to have a heat removal factor $(F'_{r}T\alpha)$ of 0.80, where T is "tau."

[2] Calculated from the f-chart simulations done to support the development of Figures 20-36. Water requirements were assumed to be 80 gallons per day at 140°F. SOLMET solar radiation data were used.

the efficient application of solar energy. Simple correlations and rules of thumb are being developed to serve as guidelines for the design of cost-effective, energy-conserving solar buildings.

SIZING THE ACTIVE SYSTEM BY COMPUTER

Conceptually, an active solar system for heating domestic water consists of the following elements (Figure 19): collectors, piping, heat exchanger, storage tank and auxiliary heater (commonly a standard hot water heater). There are rules of thumb for sizing solar collectors. In Alaska, they should be used with caution; it is advisable to use a computer simulation program such as f-chart for sizing (see Beckman et al., 1977). Sizing a system is a complicated process involving the optimization of many different physical and economic factors. In fact, f-chart uses a set of 43 different parameters in the optimization of active solar water or space heating versus standard water heating options.

A listing of the parameters and their description is included here (Table 6). Some of these parameters are more critical to the performance of an active solar system than others. These include items 4, 5, 6, and 12 which are the collector area, the intercept $(F_RT\alpha)$ and the slope (F'_RU_L) of a standard collector efficiency curve, and the building heat load coefficient (UA product). The U here is the overall heat loss coefficient in BTU/ft^2/hr·$^{\circ}$F and A is the total surface area of the

TABLE 6: A LISTING OF TYPICAL VARIABLES USED IN AN F-CHART COMPUTER SIMULATION FOR AN ACTIVE SOLAR DOMESTIC HOT WATER HEATING SYSTEM IN MATANUSKA, ALASKA.

Code	Variable Description	Value	Units
1	AIR SH&WH=1,LIQ SH&WH=2,AIR OR LIQ WH ONLY=3	3.00	
2	IF 1,WHAT IS (FLOW RATE/COL.AREA)(SPEC. HEAT)?	2.15	BTU/H-F-F2
3	IF 2, WHAT IS (EPSILON)(CMIN)/(UA)?	2.00	
4	COLLECTOR AREA	87.00	FT2
5	FRPRIME-TAU-ALPHA PRODUCT (NORMAL INCIDENCE)	0.70	
6	FRPRIME-UL PRODUCT	0.83	BTU/H-F-F2
7	INCIDENCE ANGLE MODIFIER (ZERO IS NOT AVAIL.)	0.	
8	NUMBER OF TRANSPARENT COVERS	2.00	
9	COLLECTOR SLOPE	61.00	DEGREES
10	AZIMUTH ANGLE (E.G. SOUTH=0, WEST=90)	0.	DEGREES
11	STORAGE CAPACITY	30.00	BTU/F-FT2
12	EFFECTIVE BUILDING UA	0.	BTU/F-DAY
13	CONSTANT DAILY BLDG HEAT GENERATION	0.	BTU/DAY
14	HOT WATER USAGE	70.00	GAL/DAY
15	WATER SET TEMP. (TO VARY BY MONTH, INPUT NEG.\)	140.00	F
16	WATER MAIN TEMP. (TO VARY BY MONTH, INPUT NEG.\)	35.00	F
17	CITY CALL NUMBER	14.00	
18	THERMAL PRINT OUT BY MONTH=1, BY YEAR=2	1.00	
19	ECONOMIC ANALYSIS ? YES=1, NO=2	1.00	
20	USE OPTMZD. COLLECTOR AREA=1, SPECFD. AREA=2	1.00	
21	SOLAR SYSTEM THERMAL PERFORMANCE DEGRADATION	0.	/YR
22	PERIOD OF THE ECONOMIC ANALYSIS	20.00	YEARS
23	COLLECTOR AREA DEPENDENT SYSTEM COSTS	25.00	$/FT2 COLL
24	CONSTANT SOLAR COSTS	1000.00	$
25	DOWN PAYMENT (% OF ORIGINAL INVESTMENT)	10.00	
26	ANNUAL INTEREST RATE ON MORTGAGE	9.50	
27	TERM OF MORTGAGE	20.00	YEARS
28	ANNUAL NOMINAL (MARKET) DISCOUNT RATE	8.00	
29	EXTRA INSUR., MAINT. IN YEAR 1 (% OF ORIG. INV.)	1.00	
30	ANNUAL % INCREASE IN ABOVE EXPENSES	6.00	
31	PRESENT COST OF SOLAR BACKUP FUEL (BF)	9.70	$/MMBTU
32	BF RISE: %/YR=1, SEQUENCE OF VALUES=2	1.00	
33	IF 1, WHAT IS THE ANNUAL RATE OF BF RISE	15.00	
34	PRESENT COST OF CONVENTIONAL FUEL (CF)	9.70	$/MMBTU
35	CF RISE: %/YR=1, SEQUENCE OF VALUES=2	1.00	
36	IF 1, WHAT IS THE ANNUAL RATE OF CF RISE	15.00	
37	ECONOMIC PRINT OUT BY YEAR=1, CUMULATIVE=2	2.00	
38	EFFECTIVE FEDERAL-STATE INCOME TAX RATE	40.00	
39	TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST.	2.00	
40	ANNUAL % INCREASE IN PROPERTY TAX RATE	6.00	
41	CALC. RT. OF RETURN ON SOLAR INVTMT? YES=1, NO=2	1.00	
42	RESALE VALUE (% OF ORIGINAL INVESTMENT)	0.	
43	INCOME PRODUCING BUILDING? YES=1, NO=2	2.00	

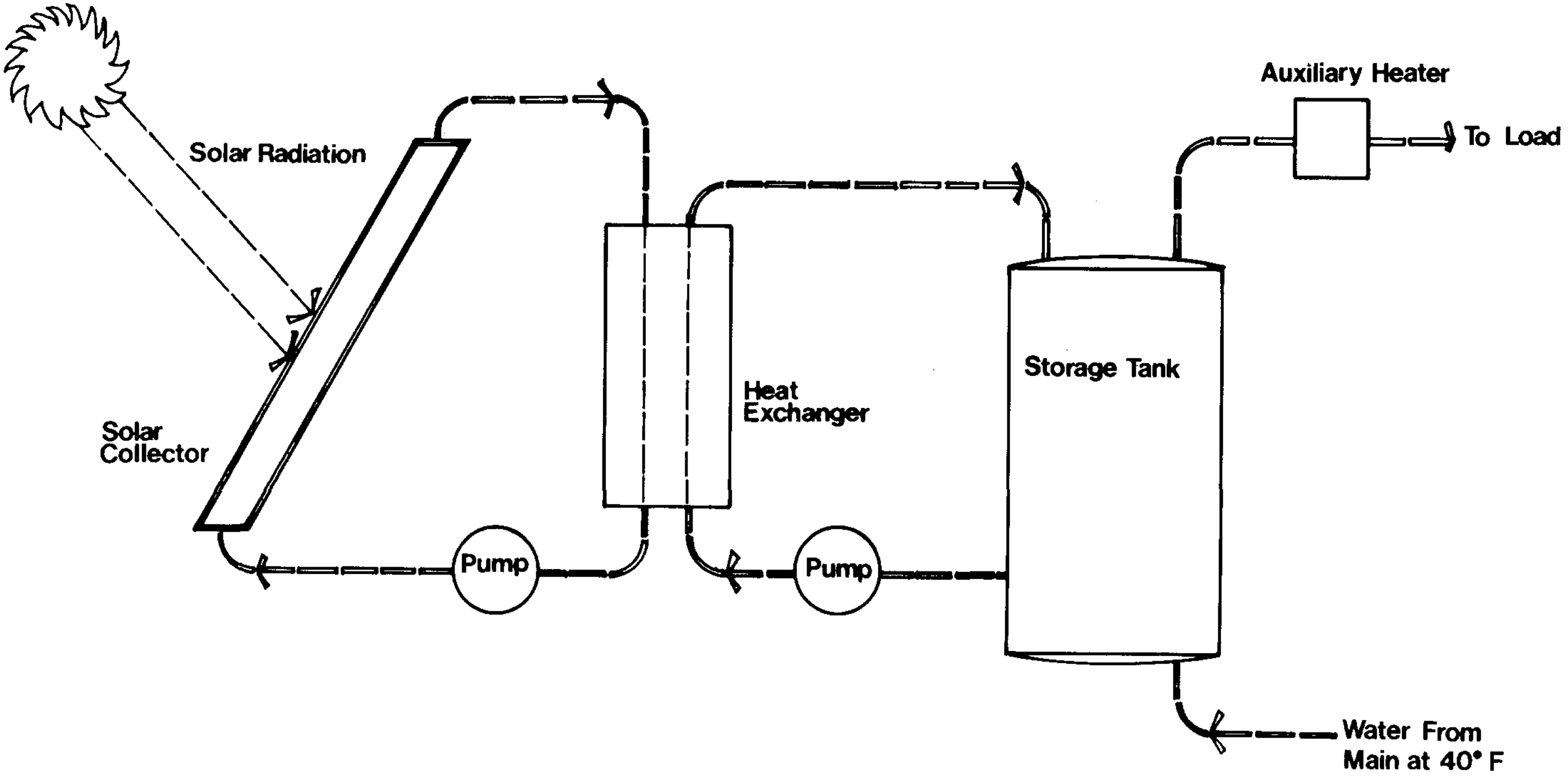


Figure 19. Schematic of a typical active solar domestic hot water heating system.

structure.

The slope and intercept of the collector efficiency curve are most easily determined from the specifications of a given collector system's descriptive materials. The collector efficiency curve is a test of collector performance under controlled conditions and provides a means of comparing collectors. The efficiency curve is a plot of efficiency (percent of energy removed from collector) versus the quantity (T_{in}-$T_{ambient}$/Incident Solar Radiation). The slope and intercept (on the y-axis) of the relationship describes the necessary information for simulating the performance of such a collector system in an f-chart optimization.

Other important factors in determining the optimum collector size are the cost of storage, the cost of backup fuel for the system (i.e., electricity, propane, fuel oil), the water use rate, and the cost of money if the system is amortized.

F-chart can evaluate the addition of solar hot water heating as an add-on to a standard system. It assumes the backup system is purchased and does not compare its amortization versus the solar system amortization. In this regard it is a conservative analysis.

An example of sizing using f-chart is very instructive.

Assume the following:

Location: Palmer, Alaska (code no. 14)
Latitude: $61^{\circ}34'$N
Family: 2 adults, 2 children
Water use: (hot) 70 gallons/day (see Table 6)
Mortgage rate: 9.5%
Collectors: South-facing, tilted at the latitude and costing \$25/ft^2. Standard performance $F_R T\alpha$ = 0.70, $F'_R U_L$ = 0.83 BTU/hr·$^{\circ}$F·ft^2
Backup fuel: electricity at \$9.70 per million BTU or 3.3 cents per kwh inflated 15%/yr.

The results of this simulation follow in Table 7.

The optimum collector area for Palmer, comparing it to electricity as a backup fuel, is 87 square feet. Note that this collector area contributes varying amounts of energy to the total hot water requirements, depending on the solar radiation available throughout the year. The total solar energy contribution to the hot water needs on an annual basis is 49.6 percent, half the total requirement. The economics on this particular example are not striking. However, with a federal tax credit of 40 percent, the first cost becomes \$1,905. This substantially lowers the cost of the collectors. From an optimization point of view, the tax credit is difficult to evaluate. If it is deducted (40 percent) from the first costs to lower the cost per square foot of collectors, then a larger system can be economically installed (compared to the backup fuel costs). This method yields a distorted optimization because the variable relationships are not linear. It is more advisable to optimize using true estimated first costs; then after the optimization is done, deduct the tax credit. The net effect is to lower amortization costs and lower the initial capital requirement.

The Palmer example is used here to show the results obtainable from the f-chart computer simulation. It would be both interesting and a good point of reference to do this same type of analysis for all of the 17 sites in Alaska for which there are SOLMET solar radiation data available. There is one very big problem with this, however. Because the costs of fuel and solar collectors are constantly changing, a single analysis quickly becomes out-dated.

To overcome this problem, Figures 20-36 were developed to evaluate the economic worth of an investment in a solar collector system for a changing set of circumstances. The charts are designed to compare total solar system costs on the basis of the cost per square foot of collector area. This is a common index of cost comparison for active solar collector systems. To ease the comparison, 150 square feet of collector was always used. This is about the optimum area for solar systems heating domestic water in Alaska. The cost of the collectors was then increased in increments of \$10 from \$10 to \$60 per square foot, and compared to the cost of backup fuels. Economic worth is measured in the very conservative economic evaluation known as undiscounted payback. In simple terms, this means, "How many years will it be until the cost of the fuel I save equals the investment I've made in solar energy?"

The charts also are based on the following assumptions and f-chart parameters. Ground reflectivity is varied by month to account for the added performance of tilted collectors due to snow cover in the autumn, winter and spring. The reflectances are given as fractions of the total incident solar radiation on a surface. They are assumed to be 0.6 for snow cover, and 0.2 for dry land, as in the summer. The values used for developing the economic charts are given in Table 8 by month.

The assumed storage capacity for these charts is 30 BTU/$^{\circ}$F·ft^2, or about 500 gallons. Although this is a large amount of storage, it is not critical to the cost comparisons. Hot water

TABLE 7: TYPICAL RESULTS OF AN F-CHART COMPUTER SIMULATION FOR AN ACTIVE SOLAR DOMESTIC HOT WATER HEATING SYSTEM IN MATANUSKA, ALASKA.

			Thermal Analysis			
Time	**Percent Solar**	**Incident Solar (MMBTU)**	**Heating Load (MMBTU)**	**Water Load (MMBTU)**	**Degree Days (F-DAY)**	**Ambient Temp (F)**
Jan	18.8	1.47	0	1.90	1645	12.2
Feb	39.9	2.02	0	1.72	1285	19.4
Mar	88.5	4.72	0	1.90	1240	26.6
Apr	82.9	4.17	0	1.84	859	35.6
May	80.3	4.05	0	1.90	558	46.4
Jun	77.2	3.66	0	1.84	302	53.6
Jul	71.3	3.40	0	1.90	232	57.2
Aug	60.2	2.85	0	1.90	304	53.6
Sep	43.3	2.08	0	1.84	518	46.4
Oct	26.3	1.58	0	1.90	947	33.8
Nov	8.7	1.01	0	1.84	1328	21.2
Dec	0	0.55	0	1.90	1627	14.0
Yr	49.8	31.55	0	22.41	10847	

Economic Analysis

Optimized collector area = 87 FT2
Initial cost of solar system = $3175
The annual mortgage payment for 20 years = $324
The rate of return on the solar investment (%) = 8.8
Years until undisc. fuel savings = investment 13
Years until undisc. solar savings = mortgage principal 17
Undiscounted cumulative solar savings = $3176
Present worth of yearly total costs with solar = $7677
Present worth of yearly total costs without solar = $7799
Present worth of cumulative solar savings = $122

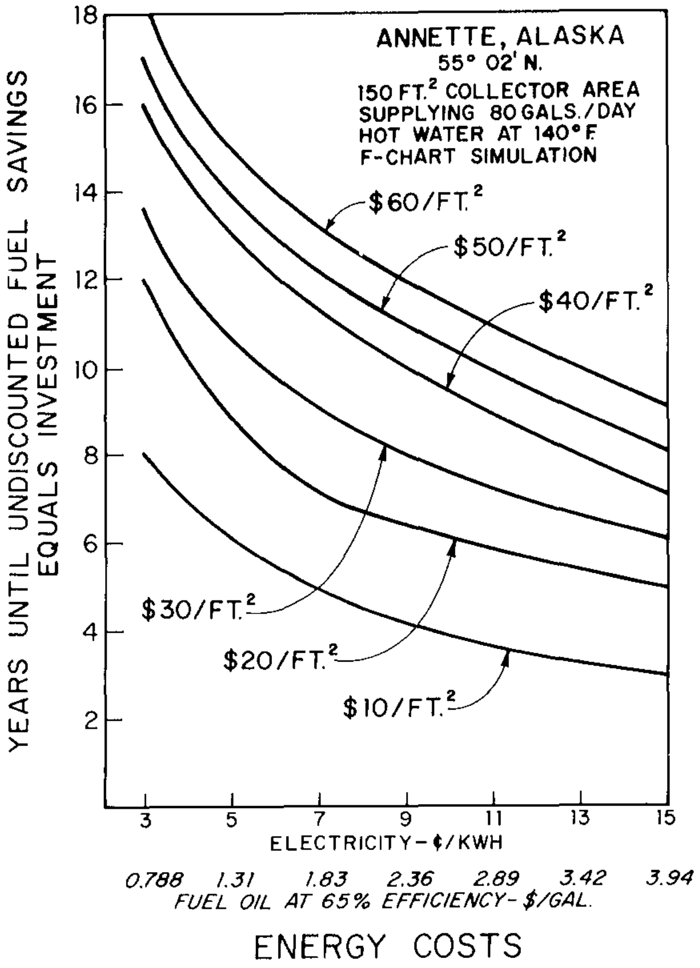


Figure 20. Payback period for solar domestic hot water heating system in Annette, Alaska.

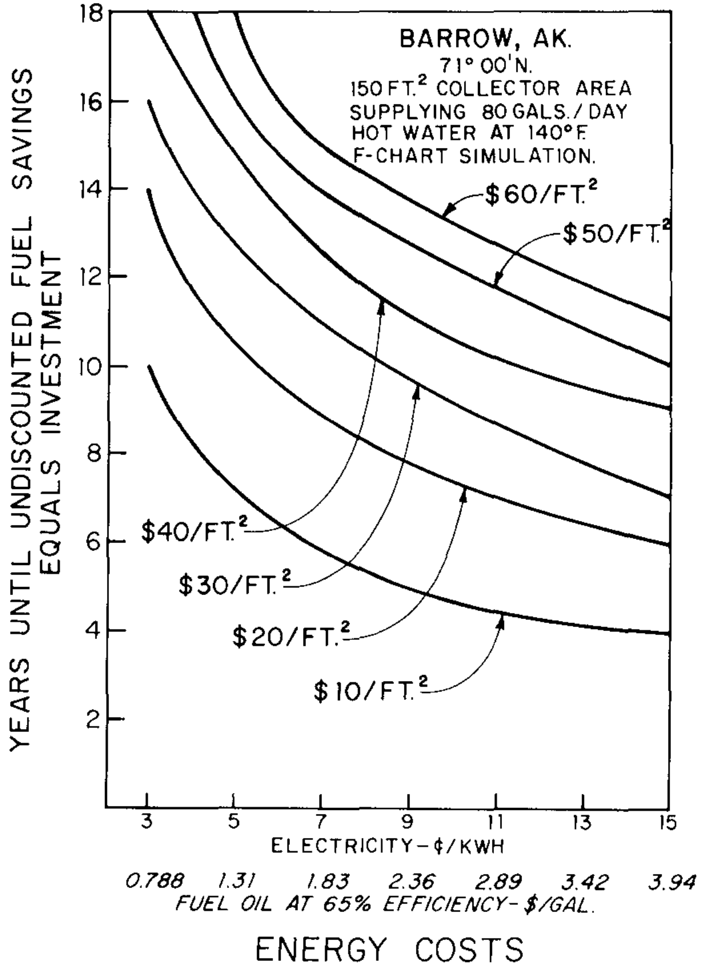


Figure 21. Payback period for solar domestic hot water heating system in Barrow, Alaska.

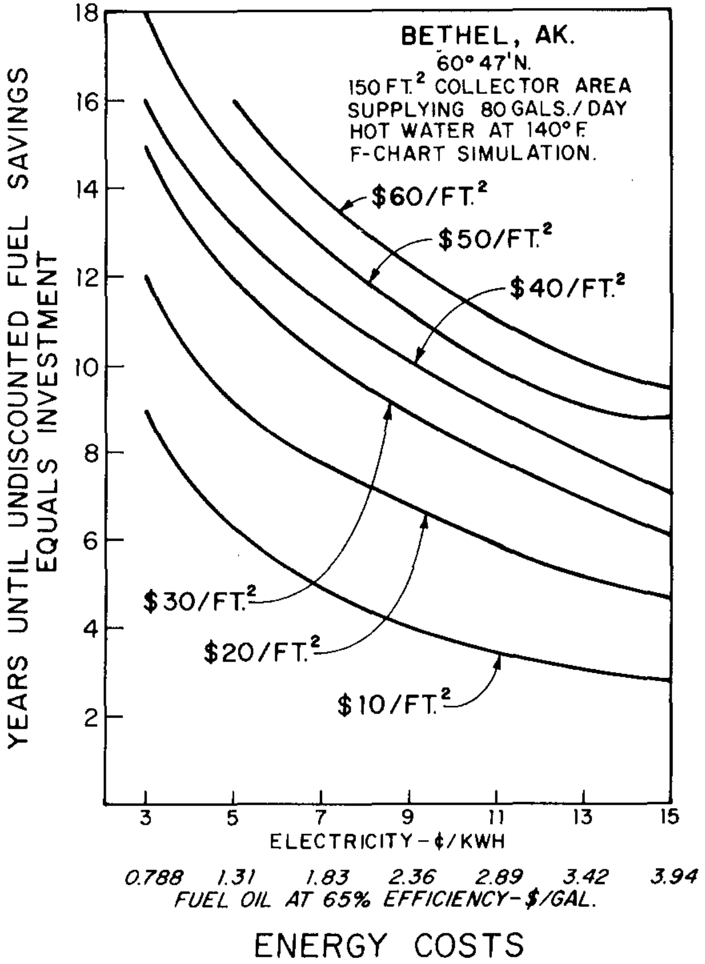


Figure 22. Payback period for solar domestic hot water heating system in Bethel, Alaska.

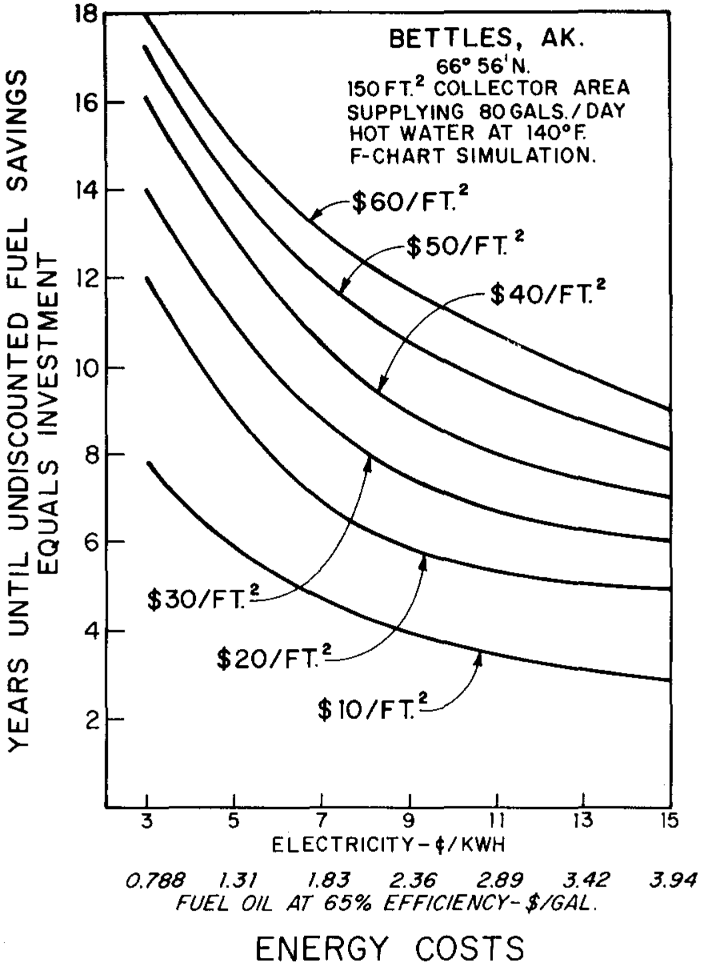


Figure 23. Payback period for solar domestic hot water heating system in Bettles, Alaska.

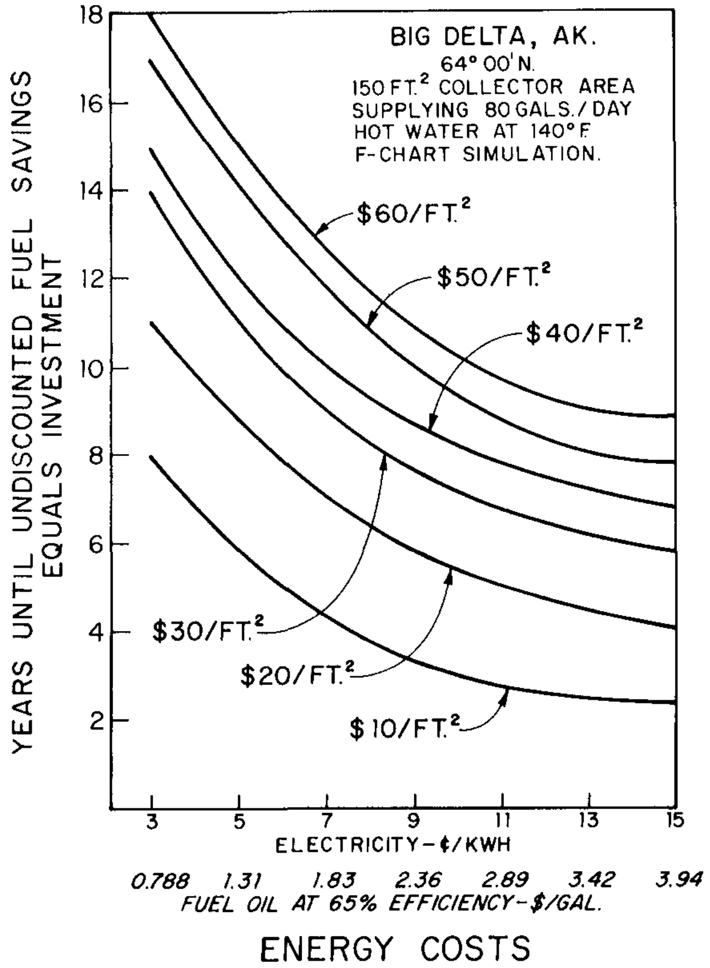


Figure 24. Payback period for solar domestic hot water heating system in Big Delta, Alaska.

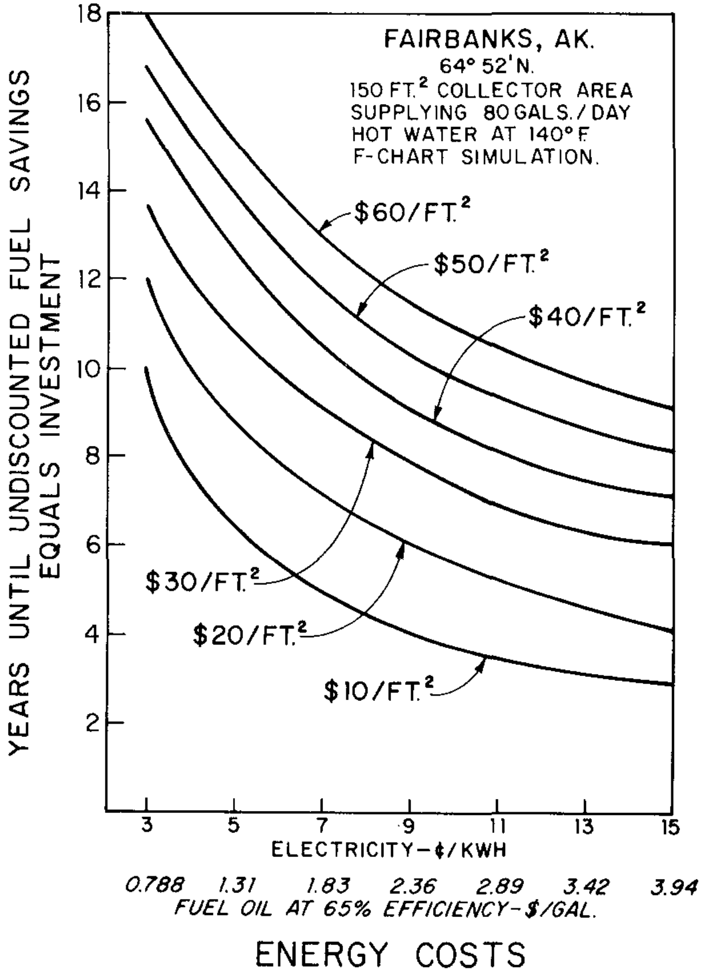


Figure 25. Payback period for solar domestic hot water heating system in Fairbanks, Alaska.

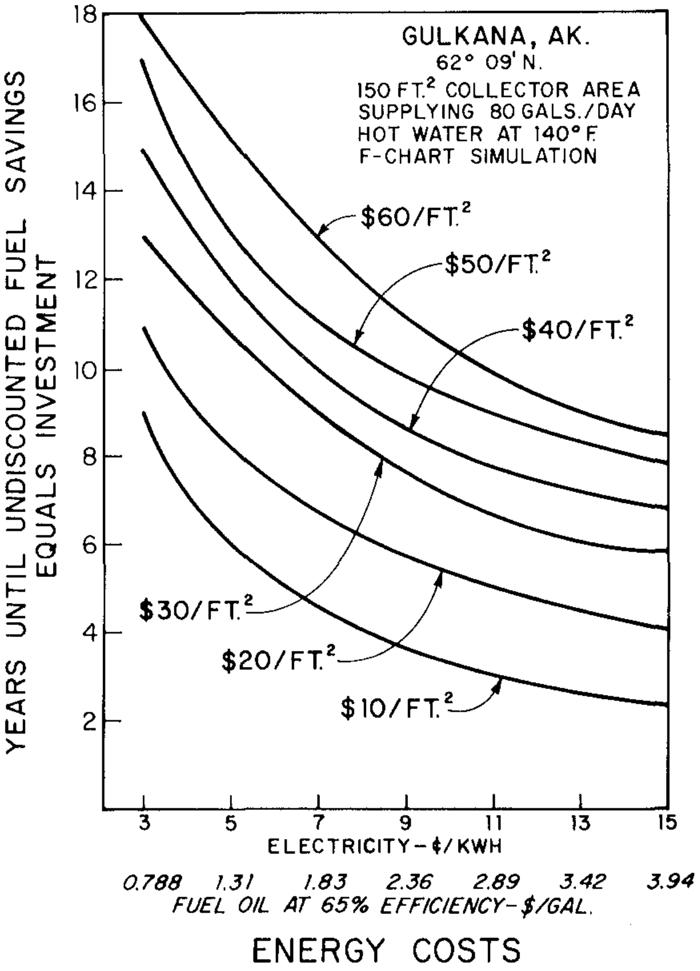


Figure 26. Payback period for solar domestic hot water heating system in Gulkana, Alaska.

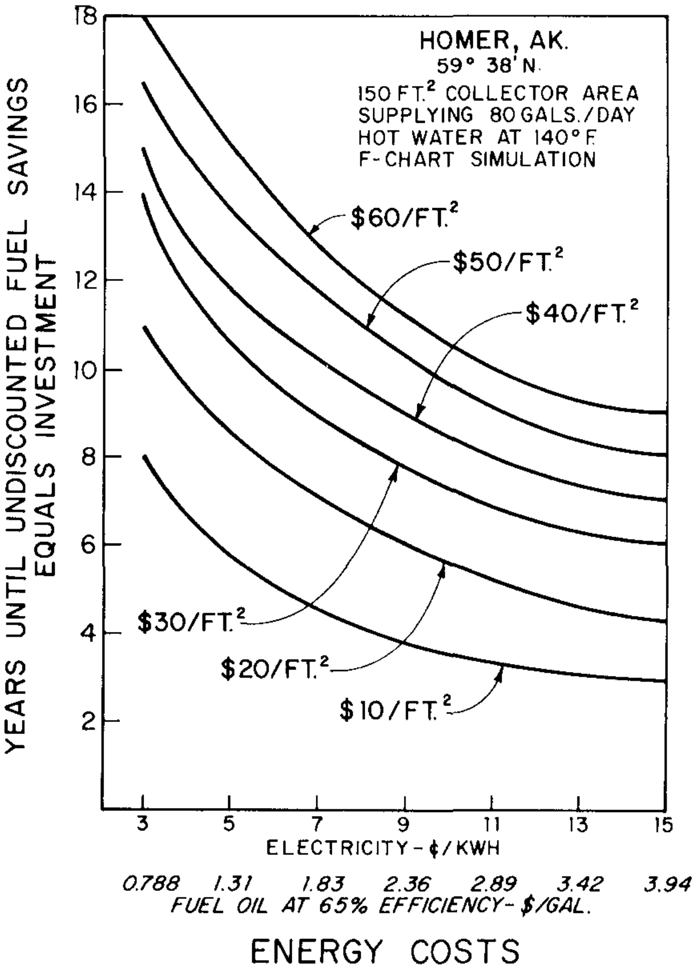


Figure 27. Payback period for solar domestic hot water heating system in Homer, Alaska.

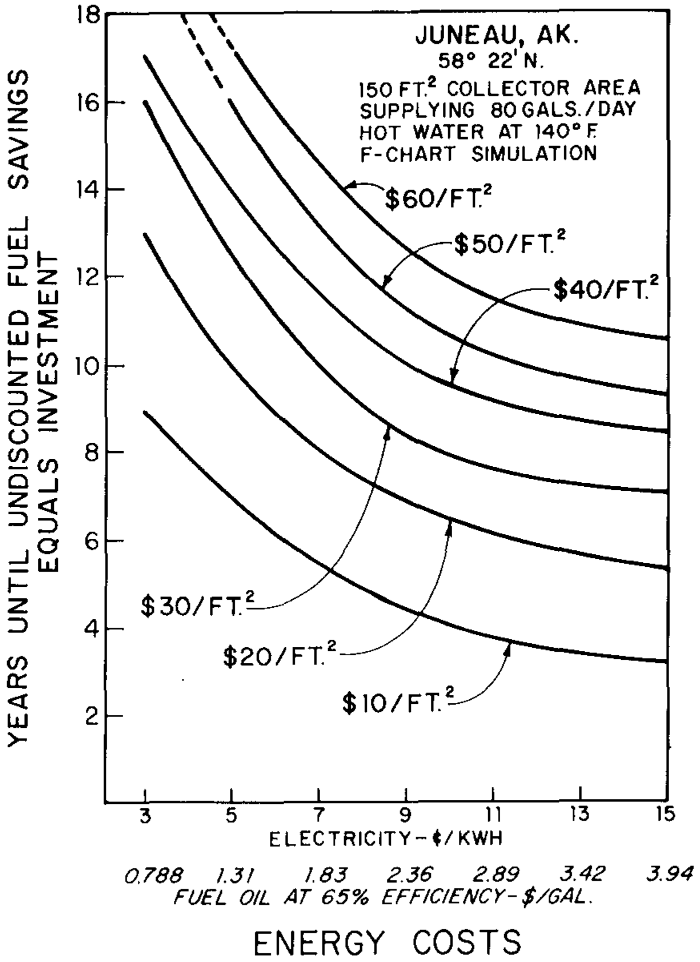


Figure 28. Payback period for solar domestic hot water heating system in Juneau, Alaska.

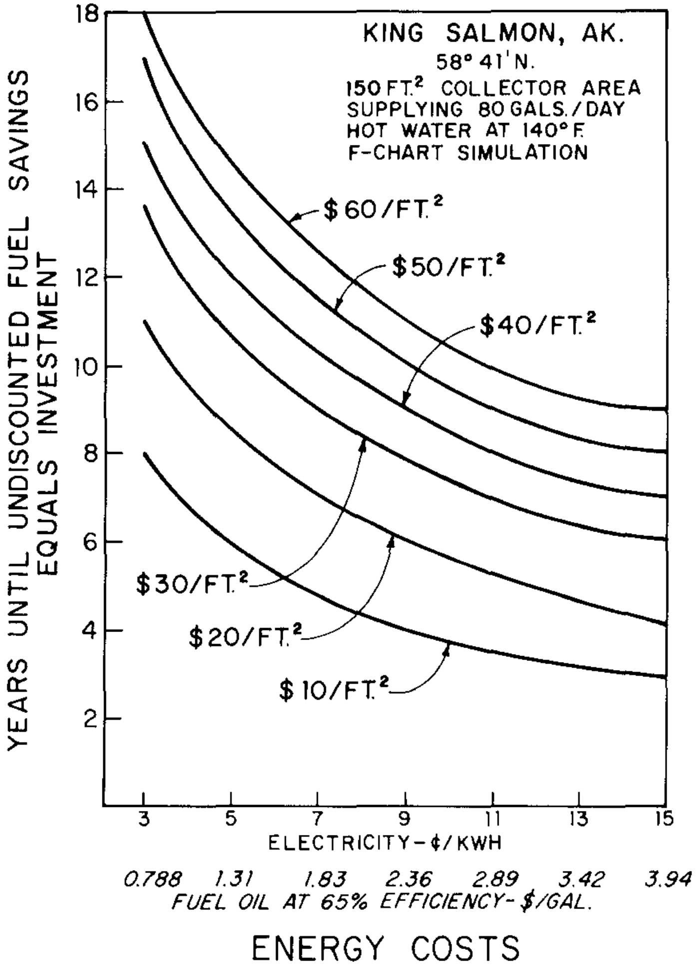


Figure 29. Payback period for solar domestic hot water heating system in King Salmon, Alaska.

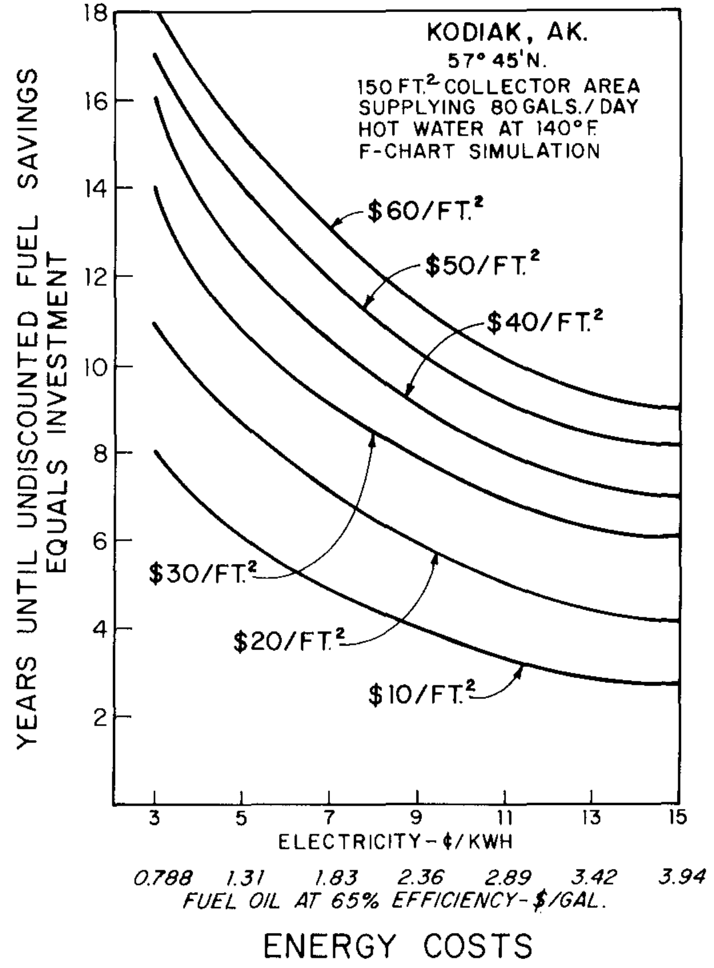


Figure 30. Payback period for solar domestic hot water heating system in Kodiak, Alaska.

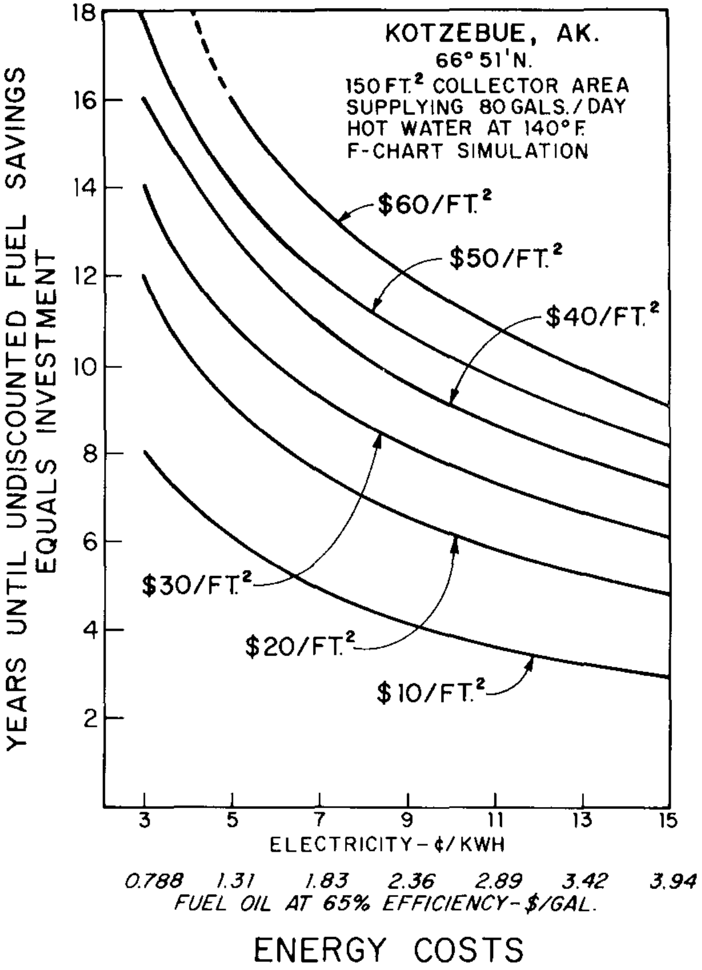


Figure 31. Payback period for solar domestic hot water heating system in Kotzebue, Alaska.

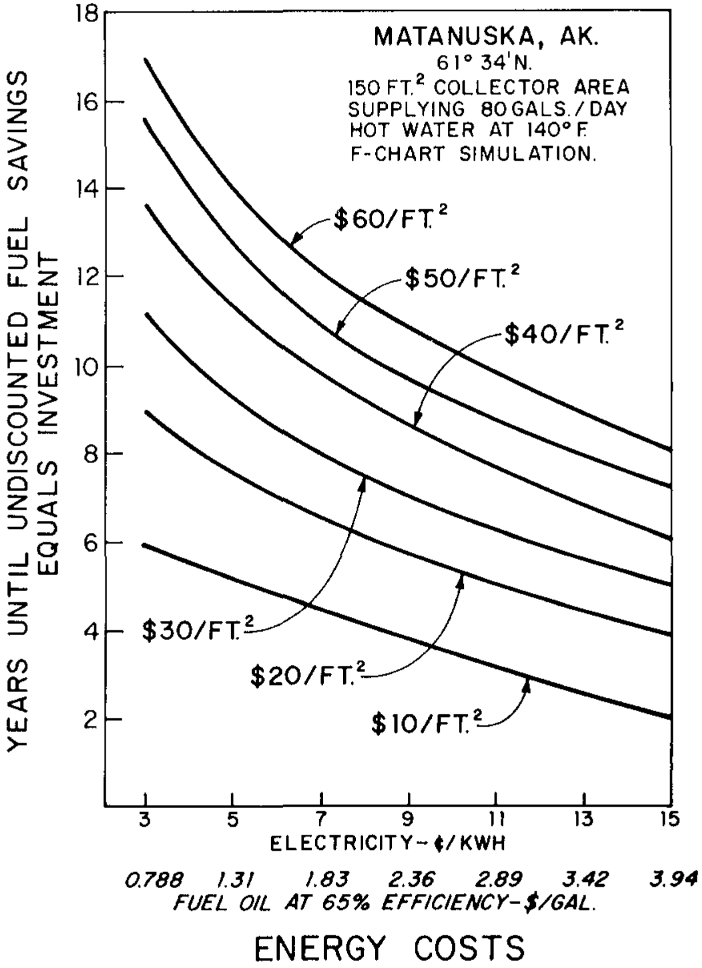


Figure 32. Payback period for solar domestic hot water heating system in Matanuska, Alaska.

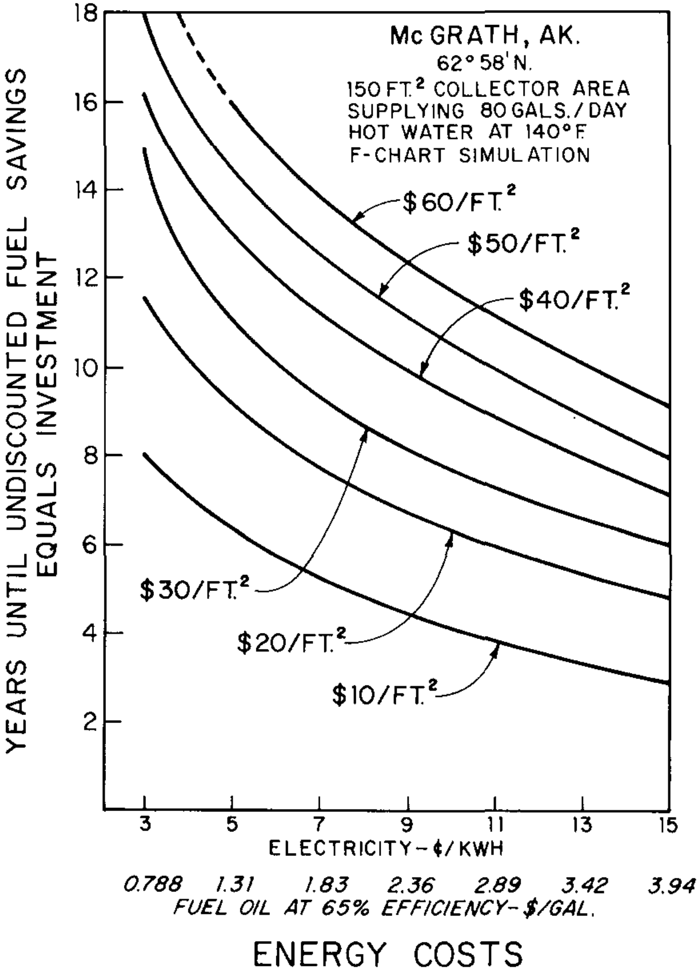


Figure 33. Payback period for solar domestic hot water heating system in McGrath, Alaska.

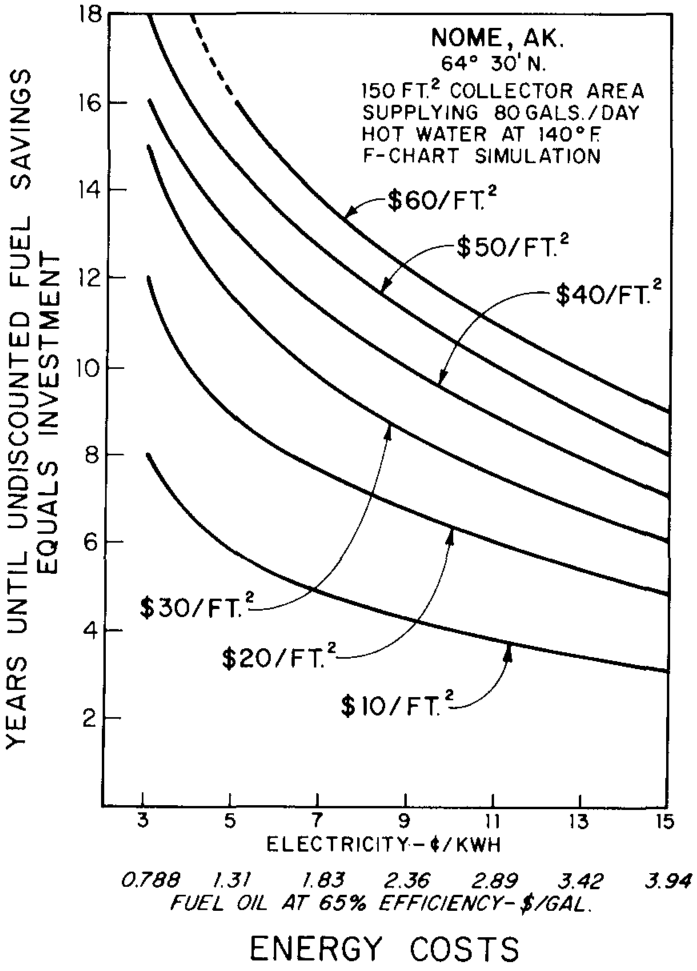


Figure 34. Payback period for solar domestic hot water heating system in Nome, Alaska.

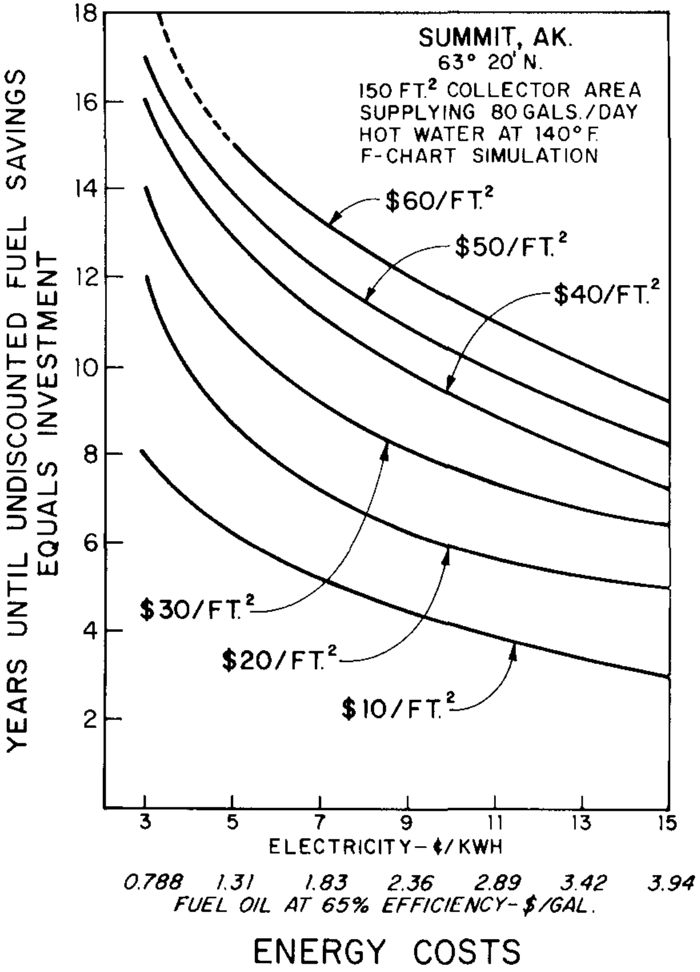


Figure 35. Payback period for solar domestic hot water heating system in Summit, Alaska.

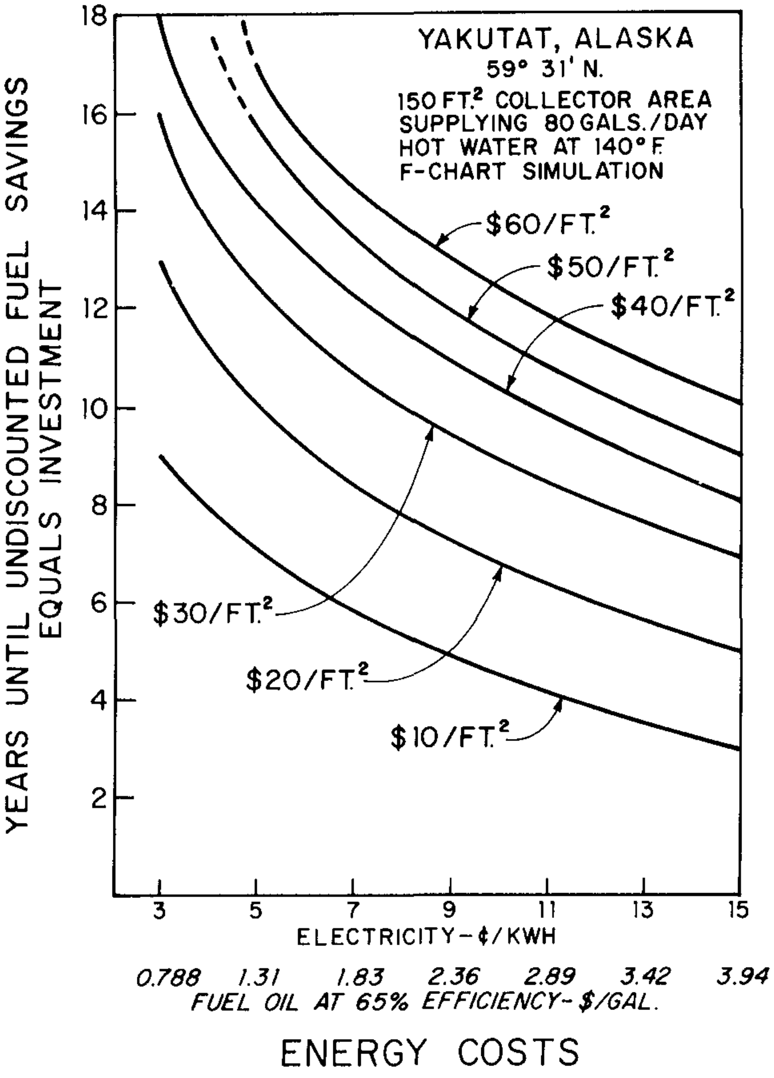


Figure 36. Payback period for solar domestic hot water heating system in Yakutat, Alaska.

use is assumed to be 80 gallons per day at 140°F. Backup fuel is assumed to inflate at the rate of 15 percent each year, and the collectors are tilted at an angle from the horizontal equal to the latitude of the site.

SIZING THE ACTIVE SYSTEM BY HAND

Not everyone has access to a computer, so a method of hand calculation is given here. To calculate the optimum area of solar collectors, you will need to determine the following things: building heat loss, storage size for the stored solar energy, and site conditions.

A well-sized and designed collector can collect 1,000-1,200 BTU/ft^2 during a large portion of the heating season on sunny days. Not all this heat will be useful, however, since some of it will be lost from storage and transport. The example used here is from the *Solar Home Book* by Bruce Anderson (1976). The example is changed slightly to make it relevant for Alaska. First, we will calculate the collector performance for March in Palmer. We will use this as an example for estimating the collector size needed for providing 70 percent of an average home's needs for domestic hot water during March. This method can be used to size liquid-type active systems used for domestic hot water or space heating because the amount of available heat still depends on the collector area, and its size must be matched to a load. The method is not limited to domestic hot water heating applications.

Hand calculations are time consuming and they solve only parts of a problem. But they do

TABLE 8: MONTHLY GROUND REFLECTANCE VALUES FOR ALASKA.

Month	Reflectance
January	0.6
February	0.6
March	0.6
April	0.4
May	0.2
June	0.2
July	0.2
August	0.2
September	0.2
October	0.4
November	0.6
December	0.6

provide important additional information for evaluating design options for those without access to a computer program like f-chart.

The calculation needs a starting point to begin the process known as iteration, which is really a fancy word for a series of "cut-and-try" calculations that are modified based on the earlier calculations of the series. Each subsequent calculation gives the designer a better idea of the relationships among average collector performance, hot water heating needs, and the size (and cost) of collectors. Only after at least one entire calculation will the designer know if his assumptions are reasonable.

You must decide at what angle your collectors will be tilted before starting a hand calculation. For optimum heating of domestic hot water in Alaska, collectors should be tilted at the latitude (or as much as 10-15° less than the latitude).

We will illustrate a hand calculation based on the previous Palmer example which was solved by f-chart. F-chart is an excellent tool for sizing collectors, but its predictions have never been tested against the performance of an actual system in Alaska. Studies elsewhere have indicated that f-chart often overestimates collector performance by 5-15 percent at various times of the year. In the f-chart example for Palmer (Table 7), the results indicated that 88.5 percent of the domestic hot water needs for March could be supplied by an 87 square feet of collectors. The experience with f-chart is very valuable for giving a suggested starting point for our hand calculation.

When using a hand calculation for an Alaskan site, a collection area should be sized to provide 70 percent of the domestic hot water needs for March. This should provide 40-60 percent of the *annual* domestic hot water needs for a given site (assuming the collectors are tilted at the latitude and face south). This starting point of 70 percent of the March needs allows for the possible over-prediction of collector performance by the f-chart computer simulation.

From an economic standpoint, the hand calculation does not optimize the solar investment. Yet the hand sizing procedure should yield a collector size that will pay for itself with backup fuel savings within 10 to 12 years. Often the payback is faster than this if electricity is used to heat domestic hot water, because it is more than twice as expensive as fuel oil. Anchorage is the only exception to this. Because cheap natural gas is available in Anchorage, the payback periods there are longer. Elsewhere, as long as energy prices continue to rise as fast or faster than the consumer price index, solar energy systems become more economically valuable with time.

We must first determine the potential performance of each square foot of collector. This collector output is then used to determine how much collector area is required to heat a percentage of the domestic hot water needs during March, as described in the f-chart example (70 gallons per day at 140°F).

Determining Collector Performance Per Square Foot

STEP 1. Determine the total hours of available sunshine (mean) from Table F2 in Appendix F. We must use Anchorage data since none is available for Palmer. There are, therefore, 210 hours of available sunshine in March.

STEP 2. Find the average day length for the month from Table F5 in Appendix F by using the latitude closest to the actual latitude of the site. For Palmer, 60°N is the closest latitude, so the average day length is 11 hours 44 minutes in March.

STEP 3. From Tables F3 and F4 in Appendix F, it is necessary to interpolate a value for the number of "collection hours" per day, since these data are only available for 56 and 64°N. (A collection hour is any hour with a radiation rate greater than 150 BTU/ft^2/hr. Hours with rates between 100 and 150 BTU/ft^2/hr should be counted as additional half hours.) Assuming the collector will be tilted at the latitude (61°), there are about 8 collection hours per day. This value is obtained by adding the number of hours for which solar radiation is greater than 150 BTU/ft²/hr.

STEP 4. Determine the total collection hours per month by multiplying the sunshine hours per month (from STEP 1) by the collection hours per day (from STEP 3); divide this quantity by the average day length (from STEP 2). Thus, collection hours per month = (210 hours/month) x (8 collection hours per day) ÷ (11 hours/day) = 153 hours.

STEP 5. Determine the total useful hourly radiation (defined as the total radiation during collection hours) by adding the interpolated hourly radiation from Tables F3 and F4 in Appendix F, as in STEP 3. Interpolation based on latitude is required using the solar hourly radiation values on a south-facing surface for both 56° and 64° tilts.

This example will show how to arrive at values for hourly solar radiation when the site (or collector tilt) is something other than 56° or 64°N. Using interpolation, we can estimate the solar radiation at Palmer (61°N). The values of the noon solar radiation for surfaces tilted at 56° and 64° on March 21 can be read from Tables F3 and F4. They are 300 and 277 BTU/ft²/hr, respectively. Their difference is 23 BTU/ft²/hr.

Thus, the difference between the noon hourly solar radiation rates at latitudes 8° apart is 23 BTU/ft²/hr. We are interested in the hourly solar radiation rate at 61°N on a 61° surface. Note that 61° is 3° less than the full 8° latitude difference which causes the 23 BTU/ft²/ hr decrease in solar radiation. Thus 3/8 of the 23 BTU/ft²/hr is lost by the change in latitude from 61 to 64°N, assuming a straight-line relationship. The noon solar radiation rate is found by multiplying the noon solar radiation difference between 56 and 64° (i.e., 23 BTU/ft²/hr) by 3/8, the fraction of the latitude change in going from 61 to 64°N (i.e., 3/8). The result (rounded to the nearest whole number) is 9 BTU/ft²/hr. The noon solar radiation rate at 61°N is found by adding this 9 BTU/ft²/hr to the rate at 64°N (277 BTU/ft²/hr). Note: the noon rate at 61°N is *higher* than the rate at 64°N, so the difference is *added*. The noon solar radiation at 61°N is therefore: 277 + 9 = 286 BTU/ft²/hr.

The hourly solar radiation rate for any site between 56° and 64°N can be found in this way.

The interpolated values for Palmer in March are 109 + 180 + 237 + 271 + 286 + 271 + 237 + 180 + 109 = 1,880 BTU/day. Both end numbers were counted as half hours because they were less than 150, as was explained in STEP 3.

STEP 6. Determine the average hourly radiation rate by dividing the total daily useful radiation (from STEP 5) by the average collection period per day (from STEP 3). Thus, (1,880 BTU/ft²) ÷ (8 hours) = 235 BTU/ft²/hr.

STEP 7. Determine the average outdoor temperature for the month. Use the temperature on the SOLMET data tables (Appendix C) for Matanuska, which is 26.6°F for March.

STEP 8. Select an operating range for the collector. This is commonly 100°F for domestic hot water heating, since the groundwater temperatures are usually 35-40°F and the normal temperature of domestic hot water is 140°F.

The operating range is determined by subtracting the mean monthly temperature from the highest operating temperature. This is often referred to as the ΔT (pronounced "delta tee"; it's also called the temperature differential) over which the collector operates. In this example, 140°F - 26.6°F = 113.4°F.

STEP 9. Figure 37 shows a set of performance curves for a typical (Revere brand) flat-plate liquid-type solar collector. Read off the efficiency by interpolating the value corresponding to an operating ΔT of 113.4°F and a radiation rate of 247 BTU/ft²/hr. The efficiency is, therefore, about 27 percent.

STEP 10. We can now determine the average hourly collector output by multiplying the average hourly radiation rate (from STEP 5) by the efficiency (from STEP 9). Thus (235 BTU/ft²/hr) x (0.27) = 63 BTU/ft²/hr.

STEP 11. The useful monthly solar heating for March is found by multiplying the average hourly collector output (from STEP 10) by the number of collection

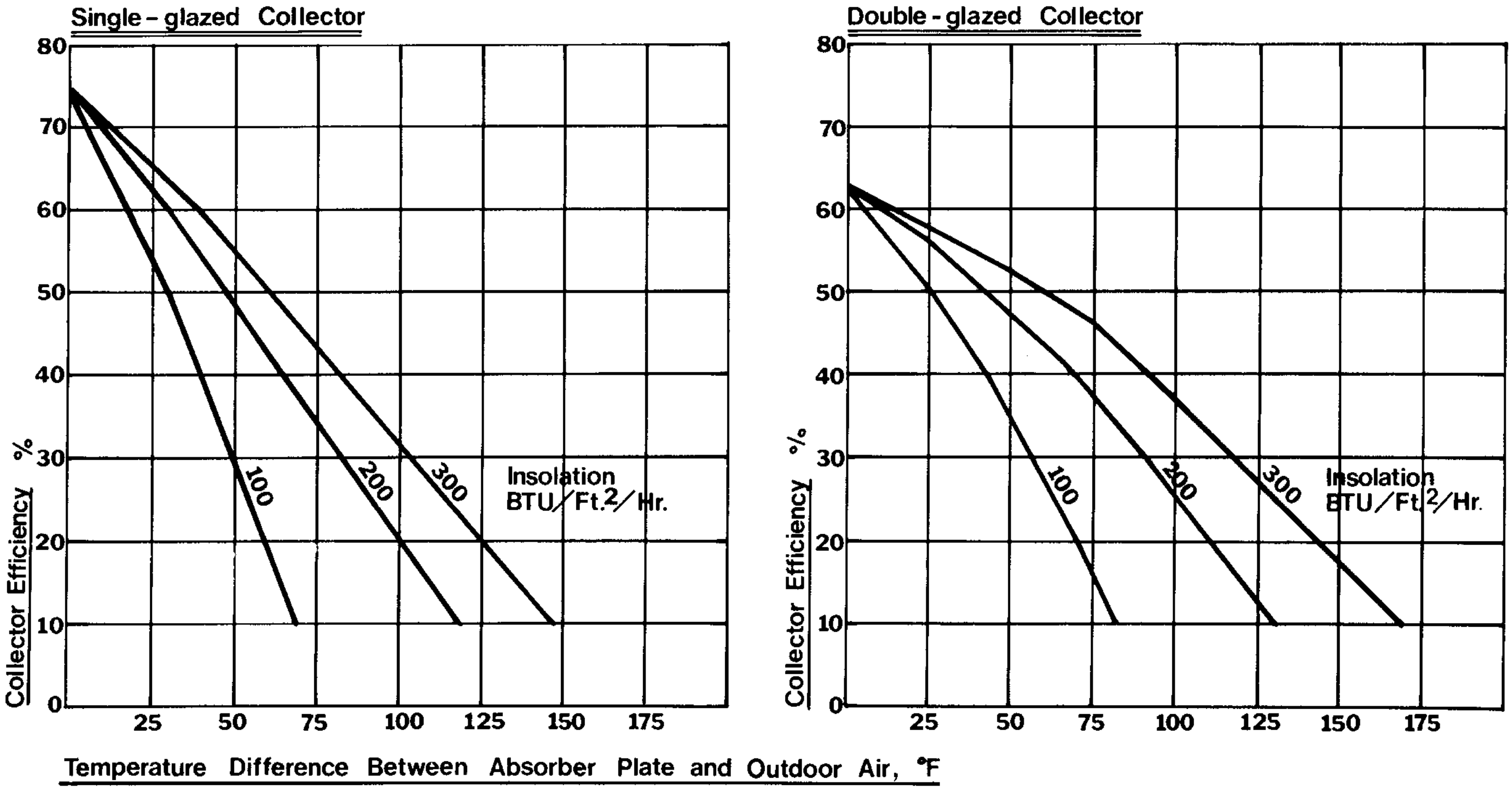


Figure 37. Efficiency graphs for a common flat-plate collector (Revere Corporation). Graphs for collectors with single (left) and double (right) glazing are shown.

hours in the month (from STEP 4). Thus (153 hours/month) x (63 BTU/ft^2/hr) = 9,639 BTU/ft^2/month which are available for heating in March.

Sizing the Collector

We have now obtained an estimate of collector output per square foot for the month of March in Palmer. We can use this information to size the collector. Recall that we want to size a collector to provide 70 percent of our hot water load in March at Palmer.

STEP 1. Determine the monthly domestic hot water heating requirement in the following way. Assuming a family of 4 that uses 70 gallons per day (see Table 9), the heating requirement is (70 gallons/day) x (1 BTU/lb·°F) x (8.34 lb/gallon) x (31 days) x (140°F - 35°F) = (61,299 BTU/day) x (31 days) = 1.90 million BTU required for March.

STEP 2. To provide 70 percent of this load, the collector must deliver (0.70) x (1.90 million BTU) = 1.33 million BTU per month. To determine the required collector area, divide 1.33 million BTU by the average useful monthly heat that is available (STEP 11 of the performance estimation). Thus (1.33 million BTU) ÷ (9,639 BTU/ft^2) = 138 ft^2.

Conclusions

This collector area is more than that determined using f-chart. There are several probable reasons for this.

1. There is no economic consideration in the hand calculation, but the f-chart optimization is based on economic comparisons.

2. The collector performance and operating efficiency are higher than our estimate.

3. The f-chart estimate of collector output may be optimistic for Alaskan latitudes.

4. The average operating differential of the collector is much less than the (140°F - 26.6°F) used in the hand calculation. This is a strong probability, because the highest daily air temperatures occur during the main operating period of the collector, so using an operating ΔT of 113.4°F may underestimate collector efficiency.

From this sample hand calculation, we can see that much of the experience needed to estimate collector performance does not yet exist. This example also serves to emphasize the value of Figures 20-36, which give a range of payback periods for solar domestic hot water systems throughout the state, based on f-chart calculations and backup fuel costs. A careful and complete monitoring program of an active solar hot water system in Alaska will enable the development of more accurate and reliable hand calculation methods.

Before leaving the hand calculation, it should again be noted that the method can be used for liquid or air active solar heating systems, whether for domestic hot water or space heating systems. Determining the average collector output is done in the same way for all these systems. Collector efficiency curves should be obtained from the manufacturer for each type of collector, and used in place of the Revere curves in Figure 37. For space heating, the heating load for the building will need to be calculated; this process is described in the section on the Building Load Coefficient of the passive solar section of this manual. If desired for any type of solar heating system, the entire annual load by month can be calculated using the collector performance method given here. Once the size has been determined in the manner given here, the collector performance calculation can be repeated for each month, the monthly solar energy contribution calculated, and the monthly calculations can be summed to give an annual solar energy contribution to the particular heating application.

GEOMETRY OF SOLAR COLLECTION IN ALASKA

A solar collector's performance is somewhat sensitive to the tilt of the collector from the horizontal, as well as its azimuthal (east or west of south) orientation. Figures 38 and 39 indicate the important angles to consider in active solar design. Collector tilt in Alaska depends upon the desired application of captured heat. Space heating needs peak in the winter, so a collector tilt greater than the

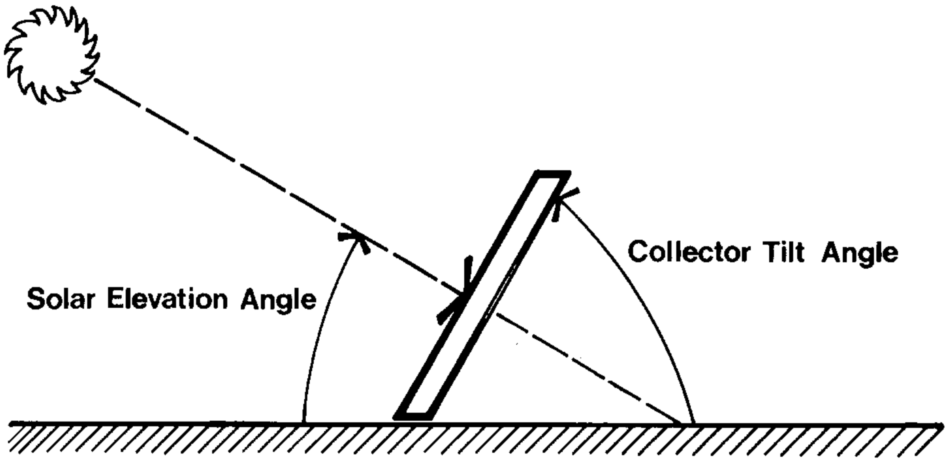


Figure 38. Collector tilt angle in relation to the ground surface and the solar elevation angle. Collector tilt is optimum when the sum of the collector tilt angle and the solar elevation angle (at noon) equals 90°, indicating the maximum solar intensity possible at noon on the collector surface. This optimum tilt changes daily, so an annual optimum tilt must be selected if collectors are not movable.

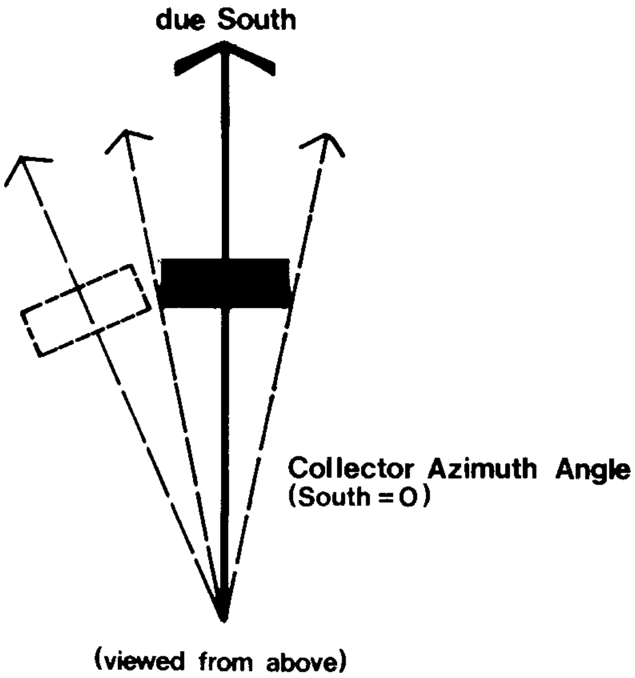


Figure 39. All illustration of what is meant by the azimuth angle of a collector. Any nonsouth orientation will reduce the total daily solar radiation gain in proportion to the azimuth angle. The largest theoretical sum of total daily radiation will fall on a surface that faces due south.

latitude would provide optimum radiation capture during the peak heating season. Domestic hot water needs are relatively constant throughout the year, so a collector tilt less than the latitude would be more efficient on an annual basis. A collector tilt equal to the latitude optimizes solar collection during the equinox periods of the year, March and September. In the Lower 48, it is often recommended to tilt the angle of the collectors 10 degrees or more greater than the latitude of the site to optimize energy capture during the winter. This is a bad strategy in Alaska because solar radiation is so limited in the winter. Such a strategy would reduce the amount of solar energy captured on a yearly basis.

Table 10 shows the effect of collector tilt on collector performance for two cases, (solar hot water heating, and solar space and hot water heating combined) for the examples of Matanuska and Fairbanks. The examples show that collector tilt is **not** critical in the performance of collectors, but that an optimum tilt of collectors for hot water heating is between 10 and 20° less than the latitude of the site in Alaska. For space heating and hot water heating combined, the optimum tilt is approximately equal to the latitude of the site.

Azimuth, the angular placement of a collector east or west of south, is also **not** critical to within 30° east or west of due south. Even an azimuthal orientation of 50° west (or east) of due south decreases the total amount of the solar percentage of energy by only 8.5 percent.

These facts imply much more opportunity for architectural and siting variation than is normally assumed. The actual orientation of a collector can have a tilt from 20 to 90° without decreasing the useful energy obtained from it by more than 13 percent. Azimuthal orientations can vary by as much as 50° east or west of south without changing the total useful solar gain of a collector by more than 10 percent.

This also points up the question of movable collectors. Is it useful to adjust the tilt of collectors to keep them at the optimum solar incidence? From Table 10, it appears that adjusting the collectors monthly or seasonally may provide an additional 2-5 percent of solar energy.

TABLE 9: DAILY HOT WATER USAGE (140°F) FOR SOLAR SYSTEM DESIGN.

Category	One and Two Family Units and Apts. up to 20 Units[1]					Apts. of 20-200 Units	Apts. of Over 200 Units[2]
Number of People	2	3	4	5	6	—	—
Number of Bedrooms	1	2	3	4	5	—	—
Hot Water/Unit (gal/day)	40	55	70	85	100	40	35

[1] Assumes 20 gallons per person for first 2 people and 15 gallons per person for additional family members.

[2] From Werden and Spielvogel (1969).

SHADING AND TOPOGRAPHY

One of the naturally occurring benefits of deciduous trees (trees that lose their leaves annually) is that their shading during the warm period of the year disappears as the heating season begins, and shade only begins again as heating requirements end in the spring. Ideally, an active system for space heating could be located in a stand of deciduous trees without a great decrease in its efficiency. Trees and shading from other buildings should be carefully reviewed on site before a final collector design is chosen, however. It may be necessary to negotiate or purchase a solar easement from neighboring properties to insure "solar access"—the guarantee that nothing will be constructed or allowed to grow that will shade your solar collectors.

More on shading will be discussed in the section of the manual describing direct gain in passive solar applications.

SNOW COVER EFFECTS

A positive factor for solar heating in Alaska (a plus for both active and passive designs) is the seasonal snow cover. As can be seen from Figure 40, new snow has a reflectivity (also called albedo) of 70 to 80 percent. This is four times the reflectivity of normal

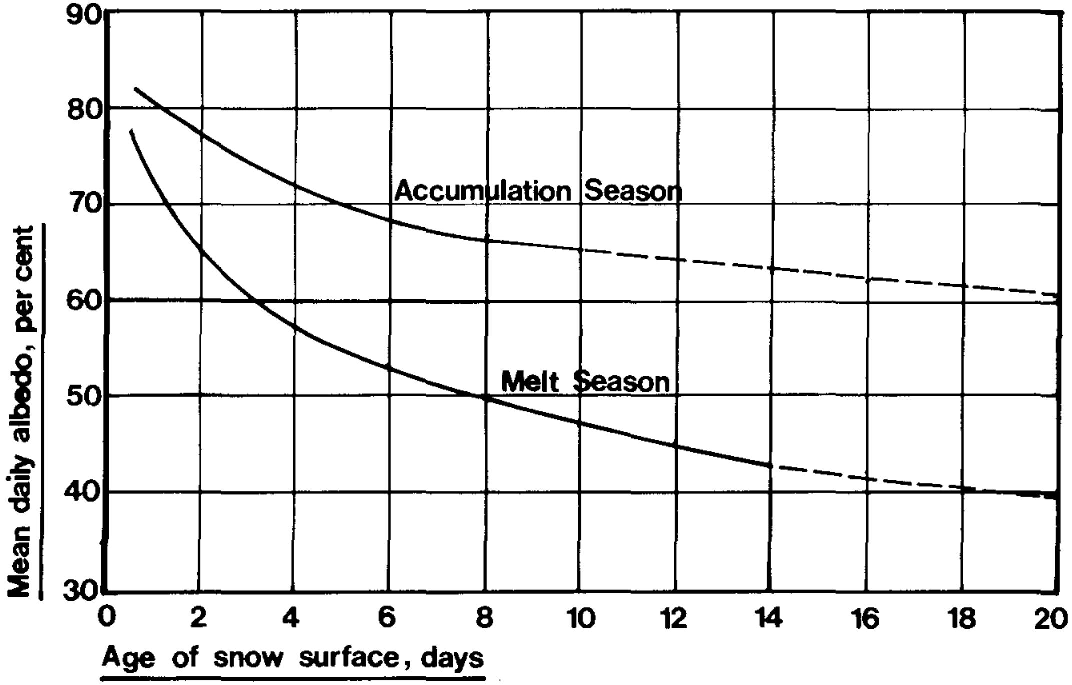


Figure 40. The relationship between the age of snow (in days) and its albedo (reflectance), expressed as a percentage of incident solar radiation, for both the accumulation (early to midwinter) and melt seasons.

ground cover. In effect, this snow acts as a very efficient mirror, reflecting additional radiation onto the collector. Anderson (1976) states that snow cover can enhance the collection of solar energy from 15 to 30 percent. Although no measurements of the actual effect have been made in Alaska, it appears prudent not to disturb the snow in front of solar collectors.

SUN PATH DIAGRAMS

It is possible to predict the position of the sun at any time (Figures 41 to 49). 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 perspective. A hand level can be used to get the angular elevations of obstacles. Figure 50 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

TABLE 10: EFFECT OF TILT AND AZIMUTH ANGLE ON SOLAR COLLECTOR PERFORMANCE.[1]

Fairbanks, Alaska 64°49′N						Matanuska, Alaska 61°34′N					
Water Heating Only[2]			Space and Water Heating[3]			Water Heating Only[2]			Space and Water Heating[3]		
Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %
0	64	54	0	64	27	0	61	63	0	61	41
0	54	55	0	74	26	0	51	63	0	71	40
0	44	54	0	84	24	0	41	62	0	81	38
0	34	53	0	89	23	0	31	59	0	89	36
0	24	51	0	54	27	0	21	56	0	51	41
0	0	44	0	44	27	0	0	47	0	41	39
10	64	54	10	64	26	10	61	63	10	61	40
20	64	54	20	64	26	20	61	62	20	61	40
30	64	53	30	64	26	30	61	61	30	61	39
40	64	52	40	64	25	40	61	60	40	61	38
50	64	51	50	64	25	50	61	58	50	61	36
40	44	53	40	44	25	40	41	59	40	41	37

[1] F-chart computer simulations were used to develop this table. Collectors were not at tilts greater than latitude for water heating because smaller angles are more efficient on an annual basis. However, nearly vertical tilts are optimum for space heating since they maximize winter capture of solar energy.

[2] 150 ft^2 collector area.

[3] 400 ft^2 collector area.

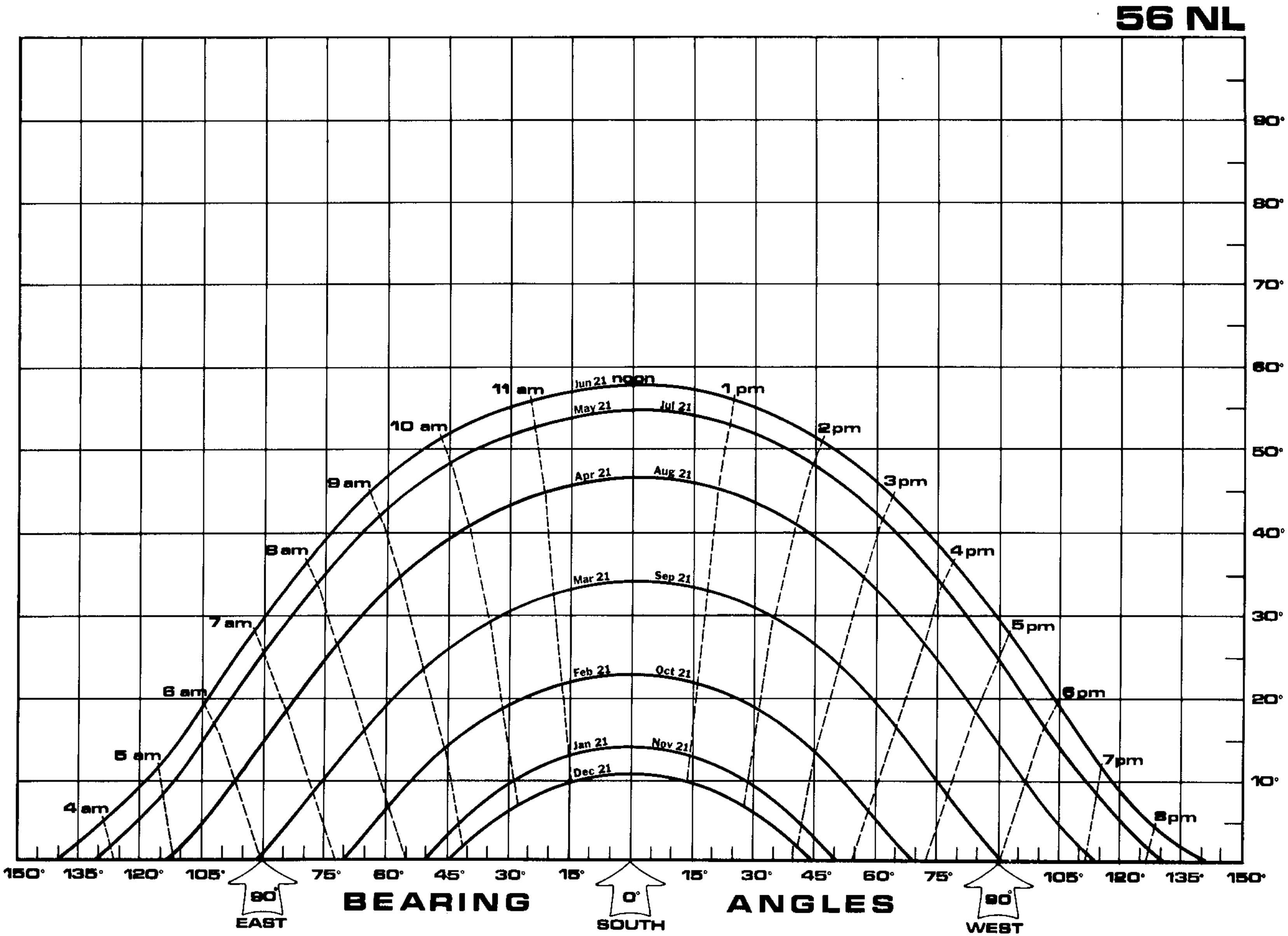


Figure 41. Sun path diagram for 56°N latitude.

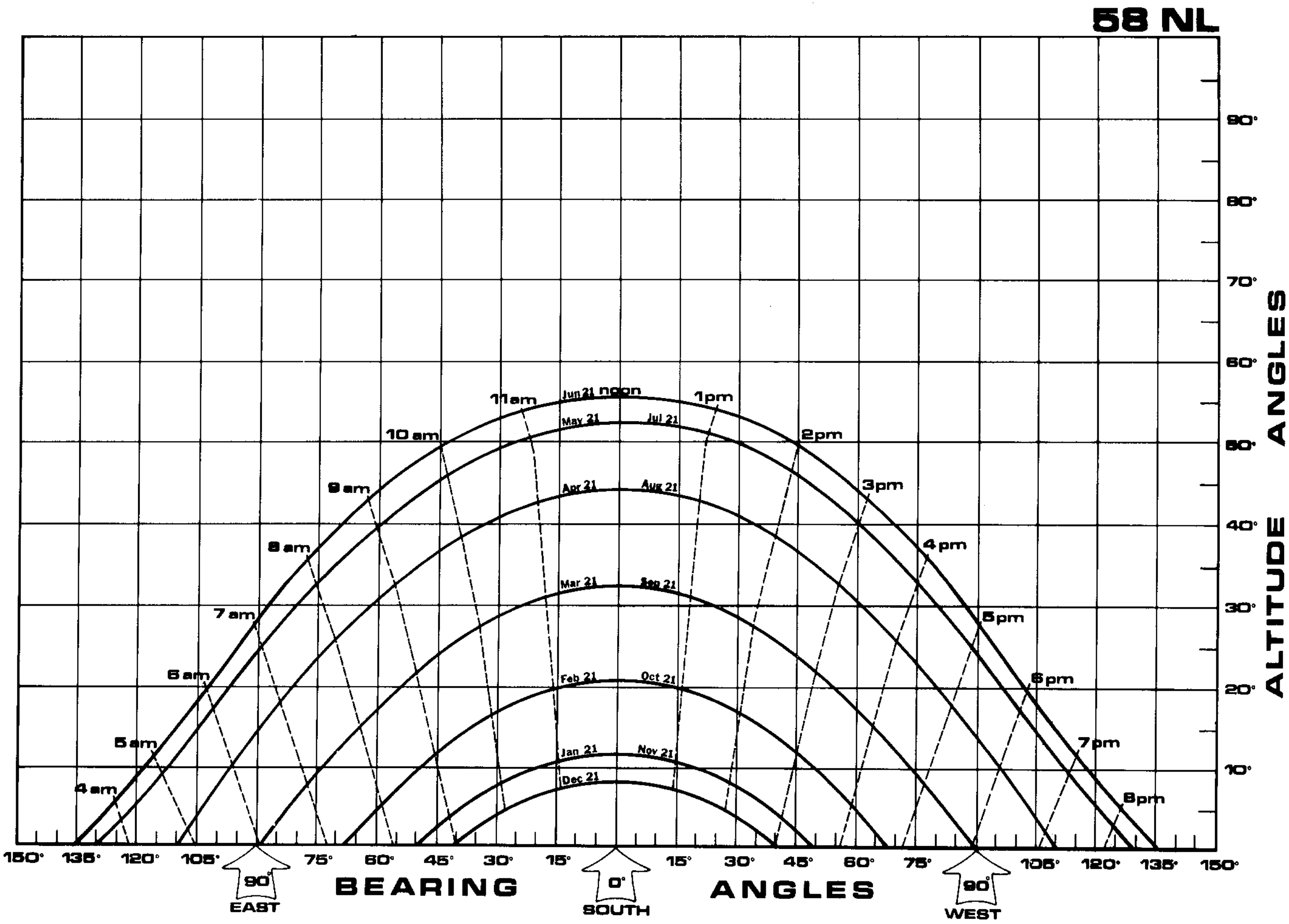


Figure 42. Sun path diagram for 58°N latitude.

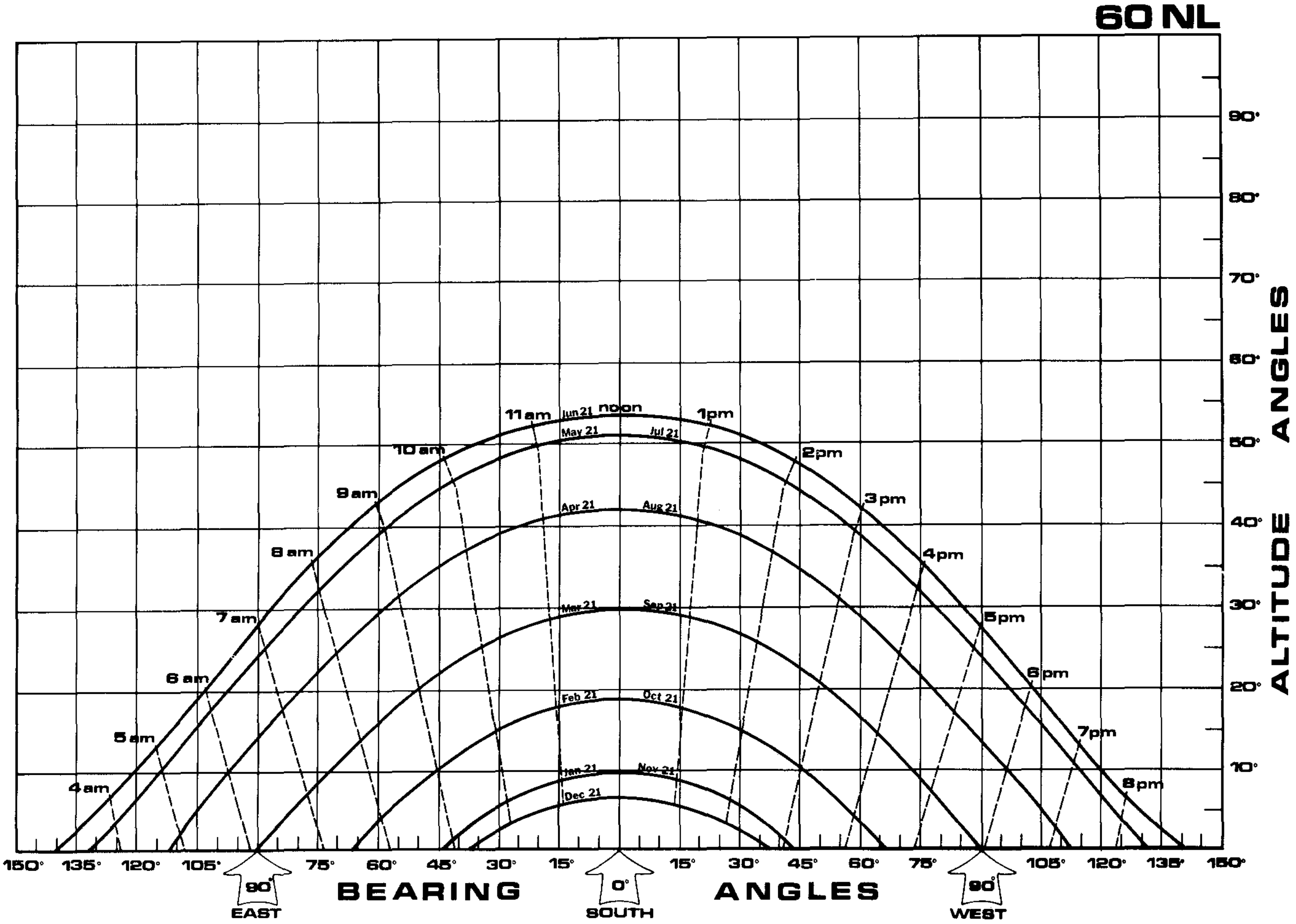


Figure 43. Sun path diagram for 60°N latitude.

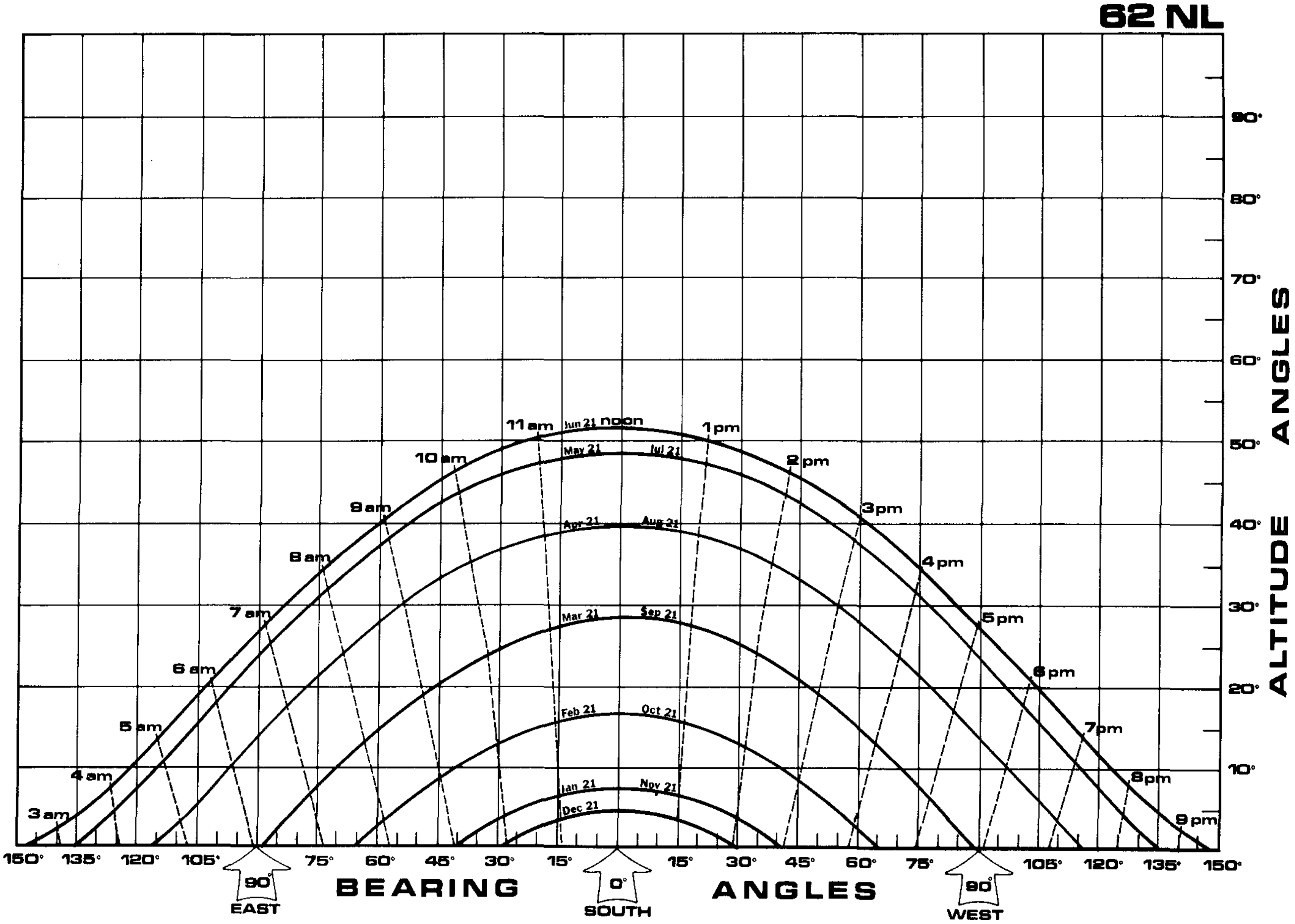


Figure 44. Sun path diagram for 62°N latitude.

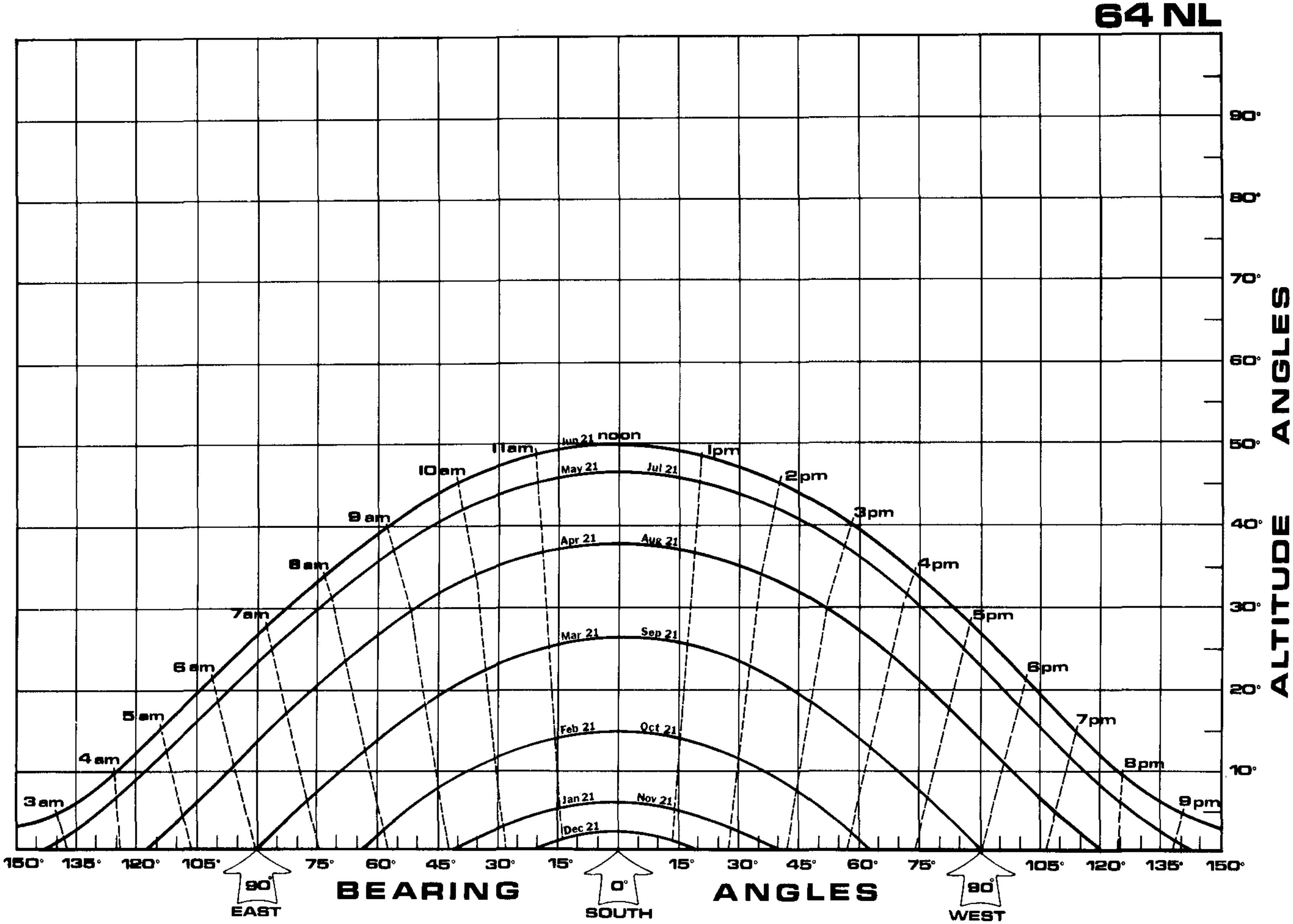


Figure 45. Sun path diagram for 64°N latitude.

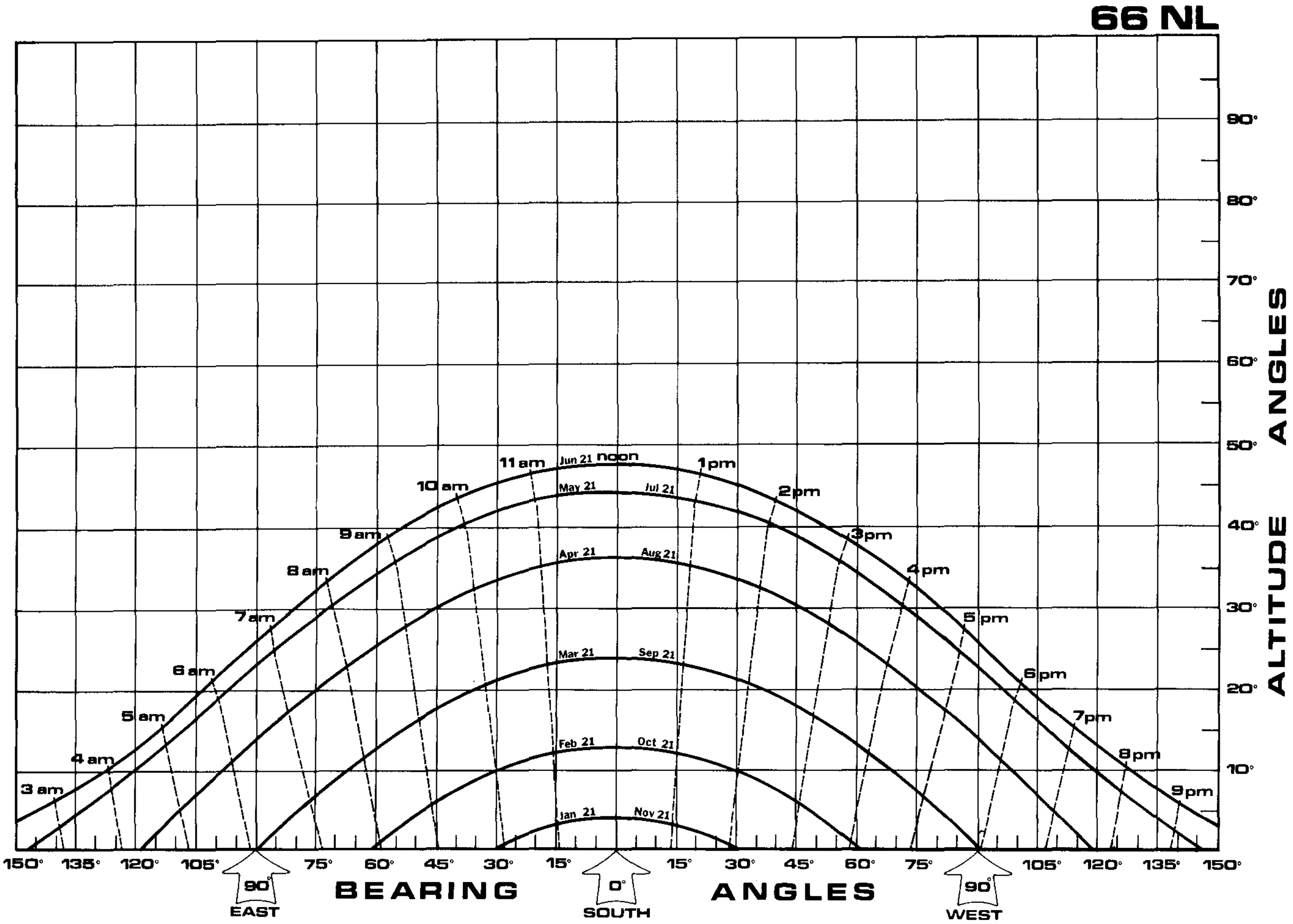


Figure 46. Sun path diagram for 66°N latitude.

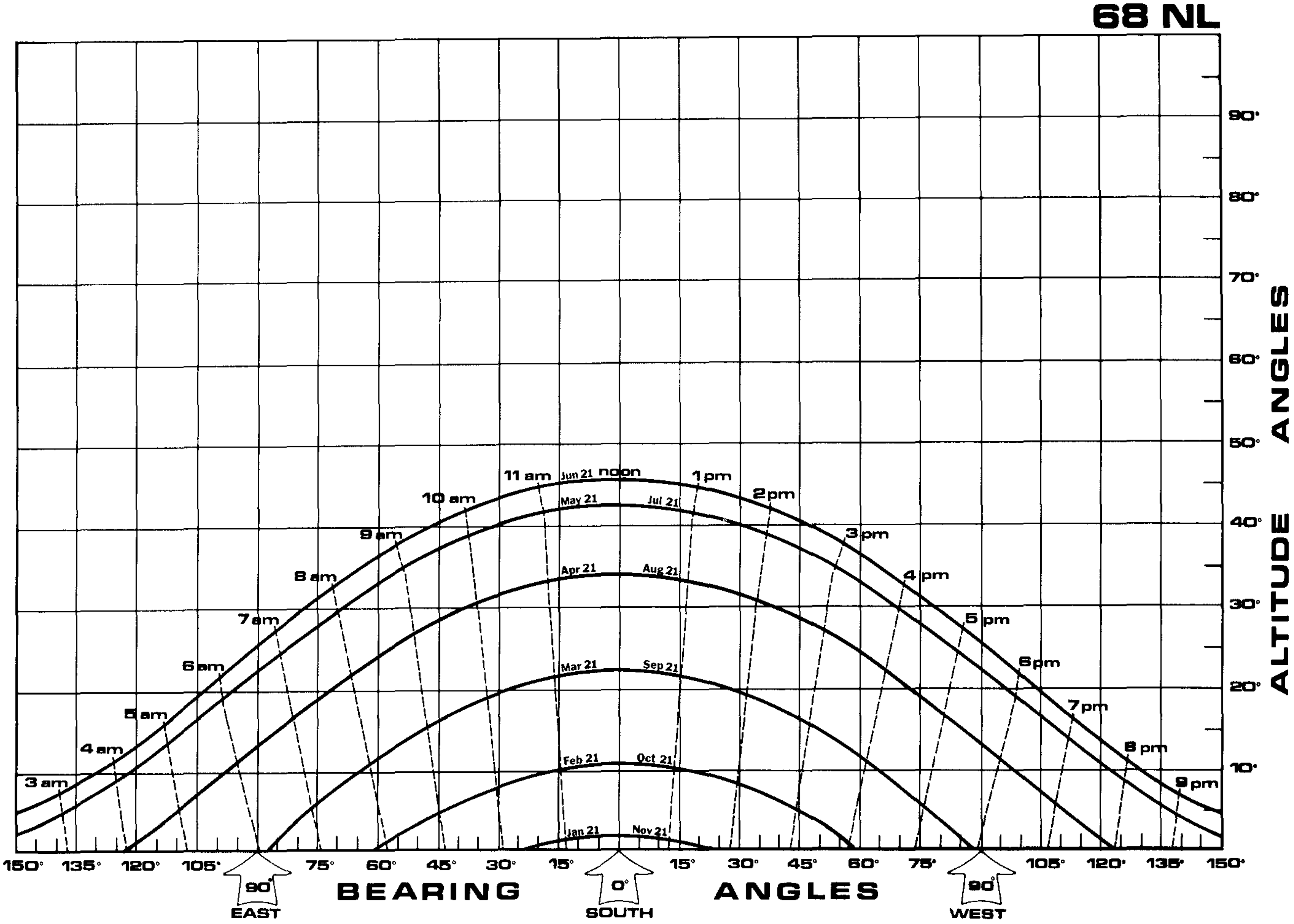


Figure 47. Sun path diagram for 68°N latitude.

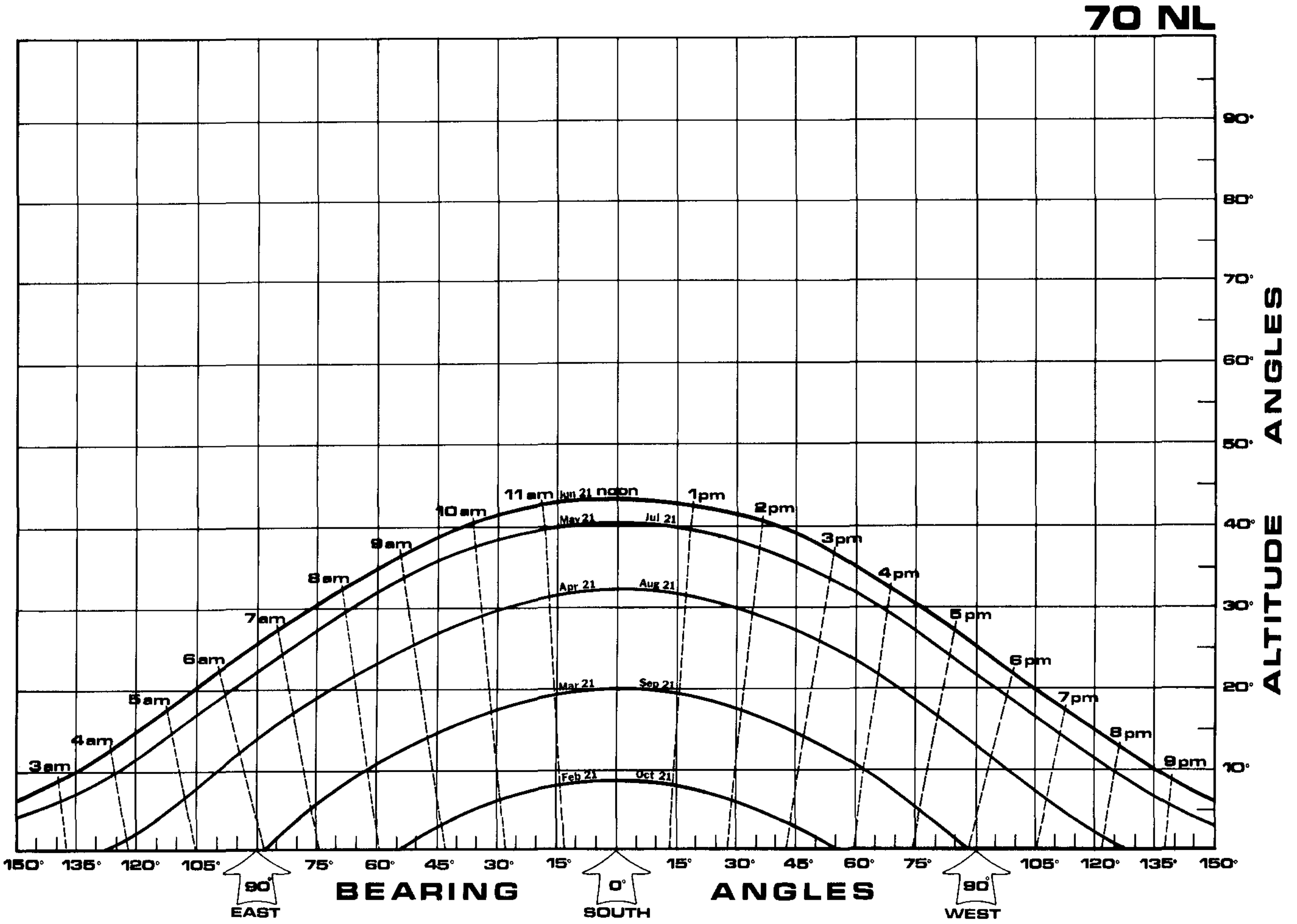


Figure 48. Sun path diagram for 70°N latitude.

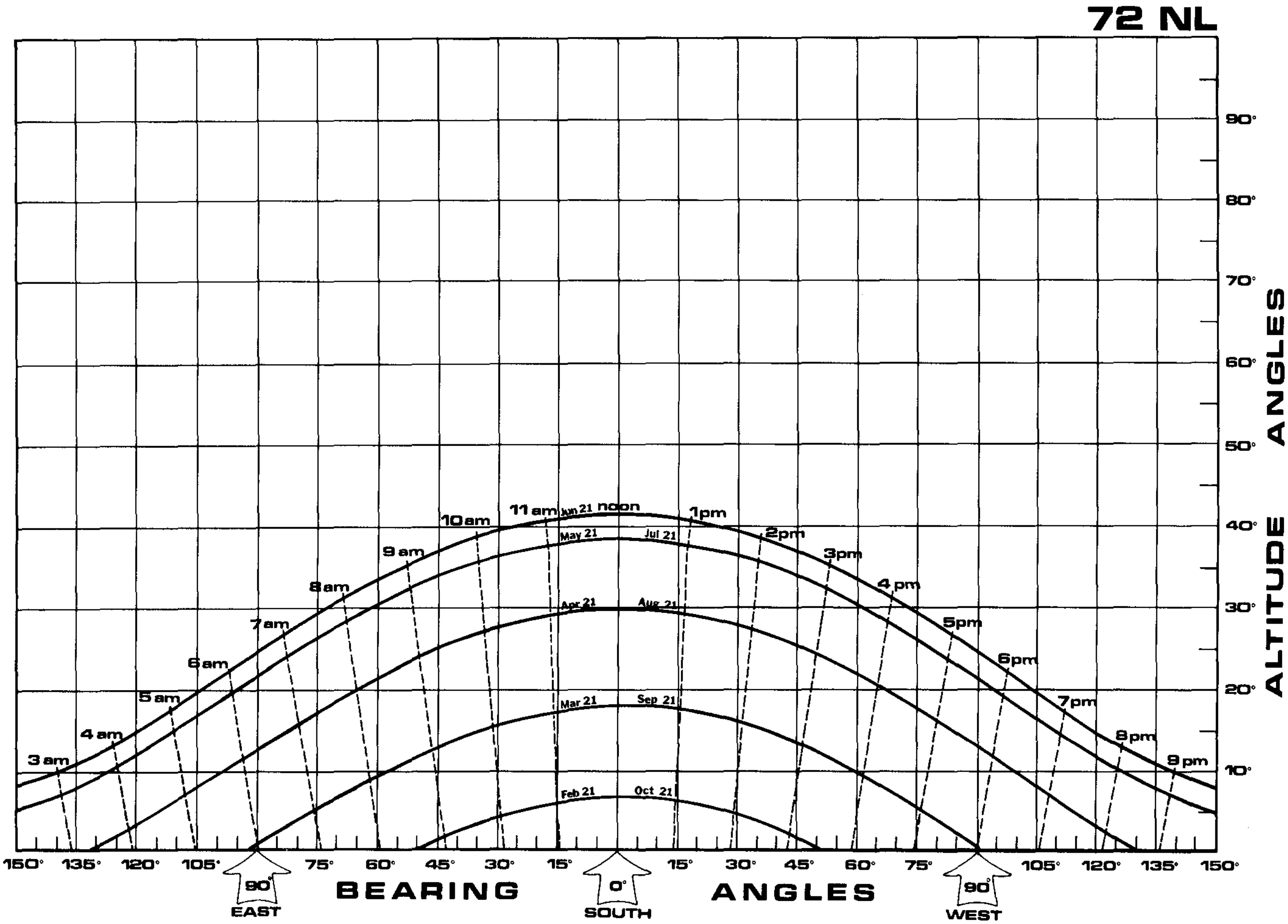


Figure 49. Sun path diagram for 72°N latitude.

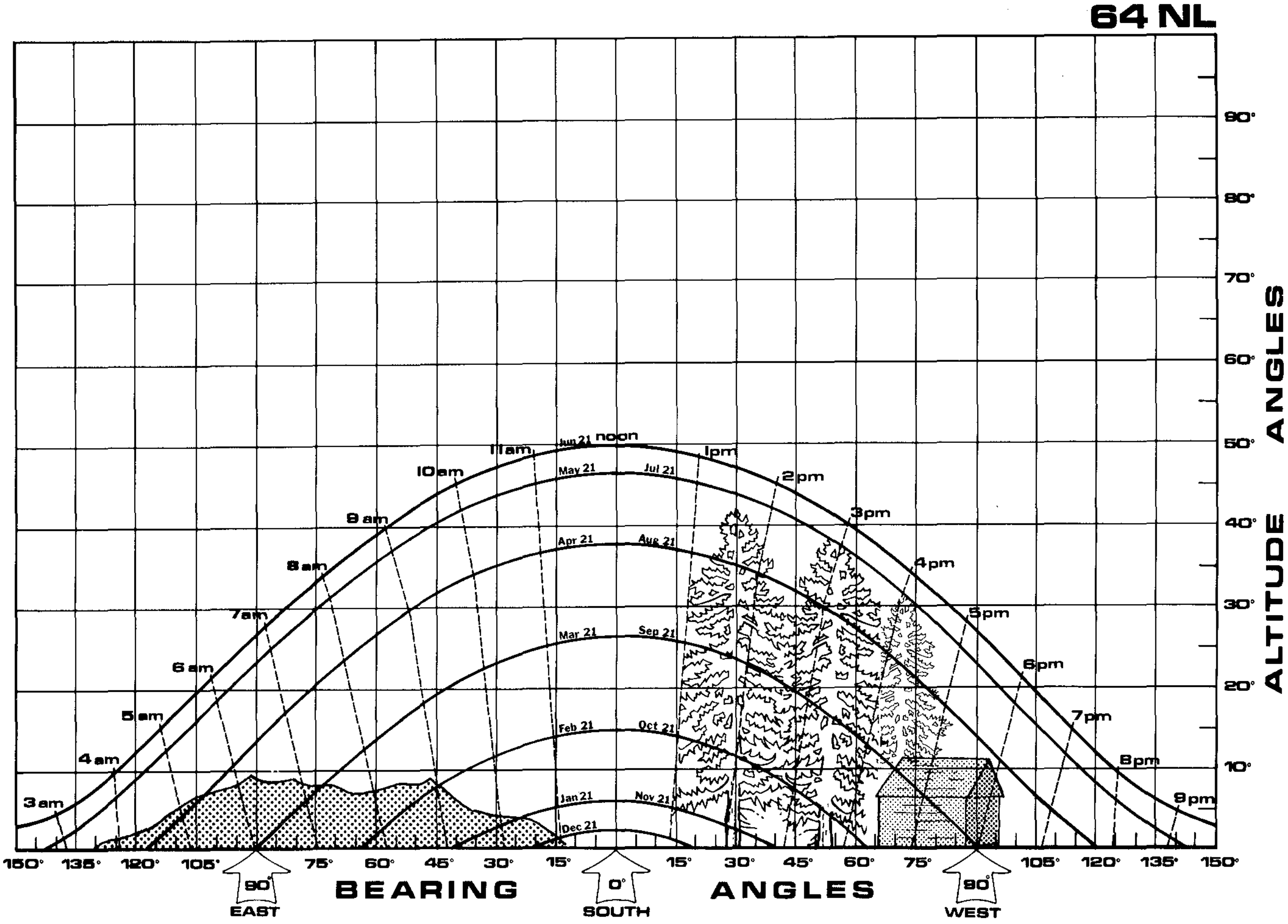


Figure 50. Example of horizon sketched on a sun path diagram.

the major obstructions that will shade the collector from the sun. In the example (Figure 50), 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 F. Using the chart for 64°N, the amount of solar radiation on a 64° tilted surface for March 21 can be determined for each hour. The hours of 2, 3, 4 and 5 p.m. receive 229, 172, 102 and 29 BTU/ft^2, respectively. This is a total of 534 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 534/1870 = 28.5 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).

active solar space heating

OVERVIEW

Designing active solar space heating systems is very similar to designing domestic hot water systems. Commercially available liquid-type collectors can be used to directly interface with both the domestic hot water supply and a hydronic heating system. Air-type collection systems can also be adapted to domestic water heating and hot-air space heating systems. Typical air and liquid systems are shown in Figures 51 and 52, respectively. The active solar space heating options are commercially mature in the lower 48 states. Active space heating systems function well with short-term storage (commonly water tanks in liquid-type systems and rock bed storage in air-type systems).

Because of the better match between the available winter solar energy at the latitudes between 30 and 45^{O}N, short-term storage enables a much larger portion of winter heating from solar energy. Thus, designs in the Lower 48 can obtain from 45-75 percent of the annual space heating load from active solar systems.

The seasonal distribution of solar energy in Alaska, however, makes it very difficult to match heating requirements to the available solar energy using a simple active system. The natural solar cycle is out of phase with the heating requirements. This is somewhat obvious, because the lack of solar heating is the natural reason for space heating systems. It is not possible to get more than a fraction of the total heating load for a building, because of the natural solar cycle. This is why 100 percent solar heating is very impractical using standard active solar collectors. The life cycle cost of an economic solar space heating system in Alaska also strongly precludes a 100 percent solar system. The inefficiency of the collectors during extreme cold further decreases collector efficiency and is the main cause of this inadequacy. The capital productivity of solar collectors is zero during these periods. This means that the investment in the collector is not paying any dividends. The collectors just don't yield any heat when it's extremely cold and the sun is faint.

Seasonal storage of solar energy may be an answer to this problem. If energy gained in the summer, when a surplus is available, could be stored and used in the winter, this would solve the major problem of solar energy in the North. Research is proceeding on this prospect for specific applications in Alaska, using zeolite minerals and active collectors. The technology is promising but it may be expensive.

Because of all these factors, the prospective solar user or designer should carefully weigh the investment in active solar energy with the investment in insulation and energy conservation. This is not a simple matter and has no single optimum. An optimum amount of insulation is specific to the construction type used in a building. **IT MAY BE BENEFICIAL TO INVEST PROPORTIONALLY MORE IN INSULATION AND CONSERVATION THAN IN ACTIVE SOLAR HEATING TECHNOLOGY.** The costs to weigh are the active solar system life cycle costs, the cost of auxiliary energy, including inflation, and the capital and construction costs of insulation and other conservation costs.

A printout of an f-chart simulation of a combined active solar air-type space heating system and domestic hot water system is included here as Tables 11 and 12. The results exemplify the estimated costs and the annual solar energy contribution of this type of system. This example uses data from Big Delta, Alaska. The air system employs a backup source of fuel oil which costs $1.31 per gallon and is inflated at 15 percent per year. Collector area costs are $25 per square foot. The entire system costs $9,600, consists of 344 square feet of collectors, and provides an estimated 30.8 percent of the annual heating and hot water loads of the building. The rate of return on the solar investment is 19.3 percent—a respectable return.

This is, however, only a simulated result. We lack actual experience with active space heating in Alaska, and the capital cost of such systems is high. These factors combine to inhibit investment in active space heating systems. More experience would make it possible to correlate actual performance of systems with that predicted by f-chart. Now, only the prediction is possible.

Active air-type and liquid-type space heating systems are in use in Alaska and some are being monitored for their performance. These systems will provide the essential performance information so badly needed to evaluate the active solar space heating option for Alaska. It is likely that a supplement to this manual will be developed to cover active solar space heating as experience is accumulated.

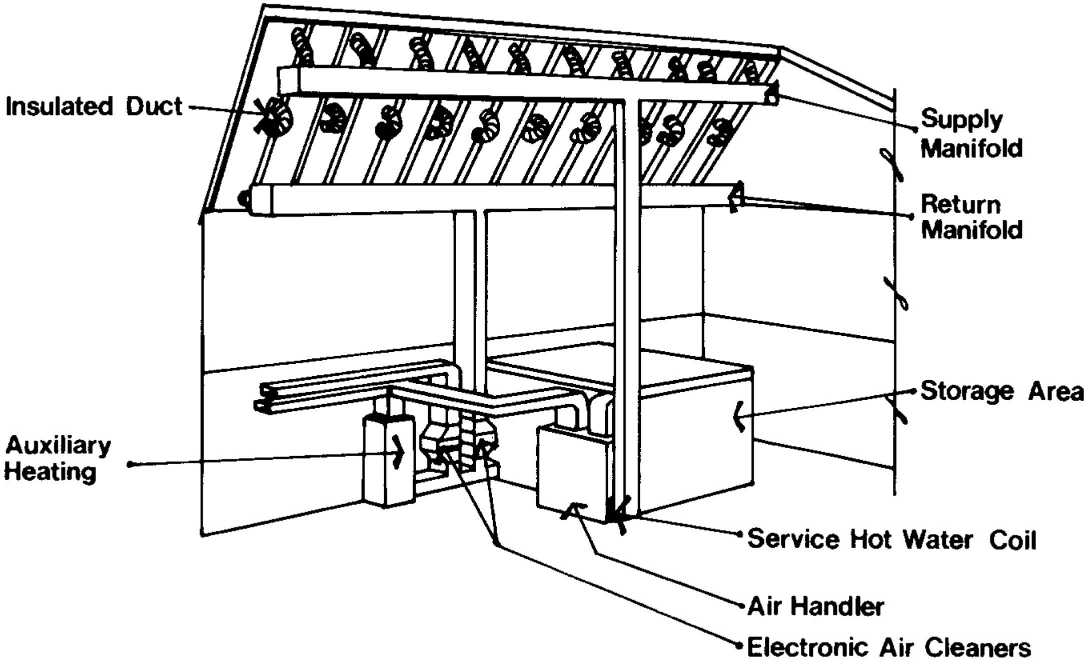


Figure 51. A typical air-type solar space heating system.

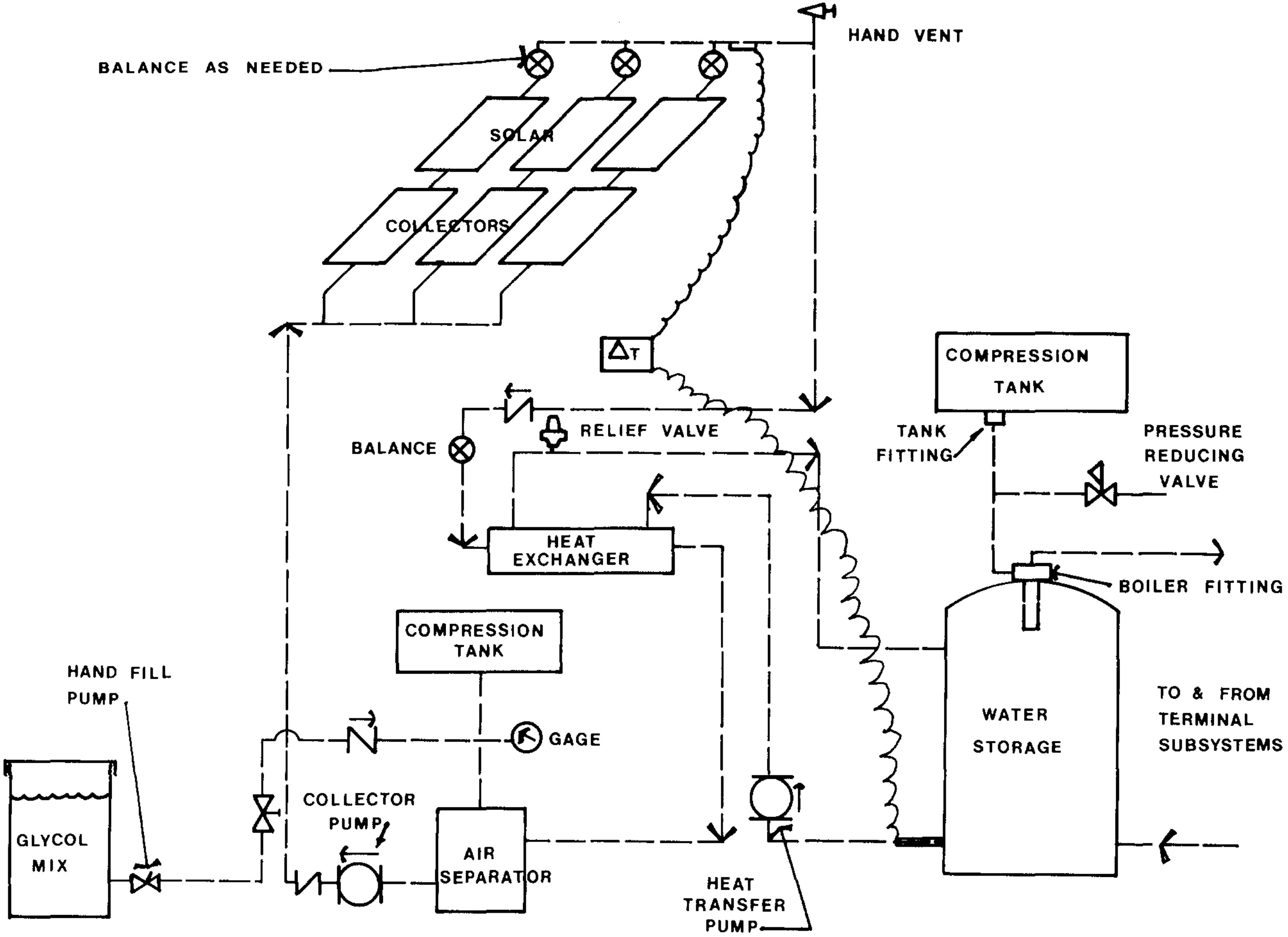


Figure 52. A schematic of a typical liquid-type, flat-plate solar space heating system.

TABLE 11: TYPICAL RESULTS OF AN F-CHART COMPUTER SIMULATION FOR AN AIR-TYPE ACTIVE SOLAR SPACE AND DOMESTIC HOT WATER HEATING SYSTEM IN BIG DELTA, ALASKA.

This structure has an integrated R-value of 15, with a 1,500 ft^2 floor area, and 10 percent of the area of the walls has shuttered windows. The infiltration rate is 0.5 air change per hour.

Thermal Analysis

Time	Percent Solar	Incident Solar (MMBTU)	Heating Load (MMBTU)	Water Load (MMBTU)	Degree Days (F-DAY)	Ambient Temp (F)
Jan	0	1.48	15.17	2.15	2167	-4.0
Feb	12.0	5.70	12.07	1.95	1724	3.2
Mar	46.7	14.08	11.44	2.15	1634	12.2
Apr	65.2	14.45	7.47	2.08	1067	30.2
May	93.6	15.81	4.06	2.15	580	46.4
Jun	100.0	14.96	1.80	2.08	257	57.2
Jul	100.0	14.33	1.27	2.15	182	59.0
Aug	93.7	12.35	2.26	2.15	322	55.4
Sep	57.9	9.72	4.50	2.08	643	42.8
Oct	18.0	6.13	8.64	2.15	1235	24.8
Nov	0.8	3.32	12.20	2.08	1742	6.8
Dec	0	0.17	15.02	2.15	2146	-4.0
Yr	30.8	112.50	95.90	25.36	13700	

Economic Analysis

Optimized collector area = 344 ft2
Initial cost of solar system = $9600
The annual mortgage payment for 20 years = $980
The rate of return on the solar investment (%) = 19.3
Years until undisc. fuel savings = investment 10
Years until undisc. solar savings = mortgage principal 14
Undiscounted cumulative solar savihgs = $27080
Present worth of yearly total costs with solar = $52647
Present worth of yearly total costs without solar = $58991
Present worth of cumulative solar savings = $6343

TABLE 12: LISTING OF THE VARIABLES USED IN THE F-CHART COMPUTER SIMULATIONS FOR AN AIR-TYPE ACTIVE SOLAR SPACE AND DOMESTIC HOT WATER HEATING SYSTEM IN BIG DELTA, ALASKA.

Code	Variable Description	Value	Units
1	AIR SH&WH=1,LIQ SH&WH=2,AIR OR LIQ WH ONLY=3	1.00	
2	IF 1, WHAT IS (FLOW RATE/COL.AREA)(SPEC. HEAT)?	2.15	BTU/H-F-F2
3	IF 2, WHAT IS (EPSILON)(CHIN)/(UA)?	2.00	
4	COLLECTOR AREA	344.00	FT2
5	FRPRIME-TAU-ALPHA PRODUCT (NORMAL INCIDENCE)	0.70	
6	FRPRIME-UL PRODUCT	0.83	BTU/H-F-F2
7	INCIDENCE ANGLE MODIFIER (ZERO IF NOT AVAIL.)	0.	
8	NUMBER OF TRANSPARENT COVERS	2.00	
9	COLLECTOR SLOPE	64.00	DEGREES
10	AZIMUTH ANGLE (E.G. SOUTH=0, WEST=90)	0.	DEGREES
11	STORAGE CAPACITY	30.00	BTU/F-FT2
12	EFFECTIVE BUILDING UA	7000.00	BTU/F-DAY
13	CONSTANT DAILY BLDG HEAT GENERATION	0.	BTU/DAY
14	HOT WATER USAGE	79.20	GAL/DAY
15	WATER SET TEMP. (TO VARY BY MONTH, INPUT NEG.\)	140.00	F
16	WATER MAIN TEMP. (TO VARY BY MONTH, INPUT NEG.\)	35.00	F
17	CITY CALL NUMBER	5.00	
18	THERMAL PRINT OUT BY MONTH=1, BY YEAR=2	1.00	
19	ECONOMIC ANALYSIS ? YES=1, NO=2	1.00	
20	USE OPTMZD. COLLECTOR AREA=1, SPECFD. AREA=2	1.00	
21	SOLAR SYSTEM THERMAL PERFORMANCE DEGRADATION	0.	/YR
22	PERIOD OF THE ECONOMIC ANALYSIS	20.00	YEARS
23	COLLECTOR AREA DEPENDENT SYSTEM COSTS	25.00	$/FT2 COLL
24	CONSTANT SOLAR COSTS	1000.00	$
25	DOWN PAYMENT (% OF ORIGINAL INVESTMENT)	10.00	
26	ANNUAL INTEREST RATE ON MORTGAGE	9.50	
27	TERM OF MORTGAGE	20.00	YEARS
28	ANNUAL NOMINAL (MARKET) DISCOUNT RATE	8.00	
29	EXTRA INSUR., MAINT. IN YEAR 1 (% OF ORIG. INV.)	1.00	
30	ANNUAL % INCREASE IN ABOVE EXPENSES	6.00	
31	PRESENT COST OF SOLAR BACKUP FUEL (BF)	13.56	$/MMBTU
32	BF RISE: %/YR=1, SEQUENCE OF VALUES=2	1.00	
33	IF 1, WHAT IS THE ANNUAL RATE OF BF RISE	15.00	
34	PRESENT COST OF CONVENTIONAL FUEL (CF)	13.56	$/MMBTU
35	CF RISE: %/RS=1, SEQUENCE OF VALUES=2	1.00	
36	IF 1, WHAT IS THE ANNUAL RATE OF CF RISE	15.00	
37	ECONOMIC PRINT OUT BY YEAR=1, CUMULATIVE=2	2.00	
38	EFFECTIVE FEDERAL-STATE INCOME TAX RATE	35.00	
39	TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST.	2.00	
40	ANNUAL % INCREASE IN PROPERTY TAX RATE	6.00	
41	CALC. RT. OF RETURN ON SOLAR INVTMT? YES=1, NO=2	1.00	
42	RESALE VALUE (% OF ORIGINAL INVESTMENT)	0.	
43	INCOME PRODUCING BUILDING? YES=1, NO=2	2.00	

SOURCES OF FURTHER INFORMATION

Three years and reviews of more than 150 commercial projects went into the making of a new Department of Energy publication for solar designers. *Active Solar Energy System Design Practice Manual,* by Stephen D. Weinstein of The Ehrenkrantz Group and Robert E. Hedden of Mueller Associates, is a collection of construction details focusing on components of solar installations rather than on full systems.

The process of turning a solar energy system concept into a final design requires a large degree of technical expertise and experience. This new manual has assembled selected design practices for commercial projects in the national solar demonstration program. Some practices were good, some bad. Emphasizing the successes and, in some cases, detailing the potential problems, the manual addresses the practical decisions required to construct active solar systems.

Divided into sections on air and liquid systems for active solar installations, the manual contains over 200 details on items such as roof penetrations, waterproofing, and pipe supports.

Active Solar Energy System Design Practice Manual was prepared for the U.S. Department of Energy, National Solar Data Network. To request a copy, send a postcard to: Design Manual, Technical Information Center, Department of Energy, P.O. Box 62, Oak Ridge, TN 37830.

Nearly every major company marketing solar collectors publishes its own design manual with recommended flow rates, connection sizing aids and technical details. Be sure to get this information if you intend to buy a commercial system. Consult the salesman or retail outlet.

More information on active solar energy applications can be obtained from the National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, MD 20856. The national center also has a toll free number from Alaska!! Call (800) 523-4700.

The Solar Home Book, by Bruce Anderson with Michael Riordan is available from Cheshire Books, Harrisville NH 03450 for $8.95. This 1976 standard-setting work is still one of the best all-around texts available for applying solar energy.

Two Canadian sources of information are especially useful for Alaska. *The Nicholson Solar Energy Catalogue and Building Manual,* by Nick Nicholson and Bruce Davidson (1977) is available from Renewable Energy Publications Ltd., P.O. Box 125, Ayers Cliff, Quebec, Canada JOB 1CO.

Information on the Saskatchewan Conservation House, which uses both active and passive applications, is available from the Department of Mechanical Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. There is also available an air-to-air heat exchanger design. Write to Department of Mineral Resources, 1404 Toronto Dominion Building, Regina, Saskatchewan, Canada S4P 3P5.

Hot Water from the Sun is a publication of the U.S. Department of Housing and Urban Development. While it has good general information, little is Alaska specific. This volume provides especially good background material. It is available through the National Solar Heating and Cooling Information Center.

A number of magazines also relate to solar technologies. *Solar Age*, P.O. Box 4394, Manchester, NH 03108. This is the official magazine of the American Section of the International Solar Energy Society, and provides a wide range of general interest articles on active and passive solar energy in the United States and Canada.

Solar Energy, Subscription Fulfillment Manager, Headington Hill Hall, Oxford, England OX3 0BW. This is the official research journal of the International Solar Energy Society.

Mother Earth News, P.O. Box 70, Hendersonville, NC 28739.

A report entitled *Building the Solar Home* should be consulted by all prospective solar homebuilders. It is a collection of experiences, warnings and mistakes assembled as a result of the U.S. Department of Housing and Urban Development's Residential Solar Demonstration Program. It contains valuable information for light construction applications, including rules of thumb, likely failure modes of solar equipment, and some unlikely ones. It includes sections on solar calculations, the manufacturer's role, collectors, storage, heat transfer fluids, components, and maintenance. It is available as Stock No. 023-000-00455-1, from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

passive solar space heating

In designing for passive solar energy use in Alaska, four major design elements must be considered:

1. South-facing windows.

2. Thermal mass.

3. Thermally insulating shutters (night insulation).

4. Building insulation (thermal performance of the structure).

Passive design implies that these building elements enable the *building itself* to function as a solar collector, instead of adding solar collectors to it. The thermal energy is transferred by natural energy flows (conduction, convection and radiation), rather than being pumped to a point of use. Passive design techniques, involving the four elements mentioned, were described briefly in the solar technology section. The value of using double, triple, or quadruple south-facing glazing was also described for Anchorage and Fairbanks in Figures 11-16. The study by Aspnes and Zarling (1979) shows that if R9 shutters (or shutters of a higher R-value) are used, then south-facing windows in Anchorage need only be double pane to yield a net energy gain every month of the year. Nearly the same result is true for Fairbanks, except that December is the only month during which a net loss of energy occurs. Windows of east or west orientation should either be shuttered or have at least triple-pane glazing. North windows should be avoided if possible, because of their net loss for six months of the year (with or without shutters). If they are present, they should be shuttered.

The usefulness of thermal storage in the far North has long been controversial. The changes in solar gain are rapid and dramatic throughout the year, so that the amount of storage cannot be appropriately sized for more than a small portion of the year. However, because of the everchanging, dynamic nature of solar energy and the effects it has on a building, we cannot easily separate out elements of the design to analyze them individually.

COMPUTER SIMULATION

The best way to analyze and optimize a passive solar design is to use a computer simulation of the entire building, and to vary the important elements: south-facing window area, shuttering, amount of building insulation, and internal and structural mass of the building.

Zarling and Seifert (1980) have done this for a house at 65°N latitude, where winter temperatures reach -50°F and the heating index is in excess of 14,000 °F-days. The TRNSYS program was used for the modeling process. Hourly solar radiation data required for the simulations were obtained from two different sources. One week of hourly solar radiation data for each month for September through May of 1975-76 was taken from the records of the National Weather Service station in Fairbanks. The second source was the SOLMET tape for Fairbanks using the year 1959-60. This year was chosen because the heating degree day accumulation for the season was within a few percent of the long-term average.

The building characteristics used in the computer study are listed in Table 13. These are the building characteristics of a well-built, well-sealed modern home. To determine the benefits of the four passive elements, their effect on building performance was tested via the computer model. The simulation was begun with the characteristics of the standard house. First, the south-facing glazing was varied and plotted as a ratio of the glazed area to the floor area. For instance, if the floor area is approximately 966 ft^2 (does not include second story), then 96 ft^2 of window area would be plotted as a ratio of 0.1 (10 percent) on the resulting figures (Figures 53 and 54).

NIGHT INSULATION (SHUTTERS)

The first result of interest is shown in Figure 53. This figure indicates clearly that **any increase in shuttered or unshuttered window area for the home is always going to result in worse thermal performance of the building in December.** December is, of course, the worst solar month at high latitudes. Since glazing (even if shuttered) is a poorer insulator than the standard house or superinsulated wall sections, the thermal performance of the building in December always gets worse with increasing window area. This demonstrates the worst case for an average year. **The only way to overcome such an effect would be to insure that the insulating value of the shuttering device is equal to that of the walls.** This, at present, is difficult to do, but it is a technical problem worth pursuing. It is also worth noting that thermal mass provided no benefits whatever during this simulation. Varying the amount of thermal mass by a factor of 4 did not affect the December heating load.

ANALYSIS OF PARAMETERS

Figure 54 shows the results of varying all the parameters in cumulative fashion to arrive at the best possible performance of a passive structure which combines superinsulation, added internal mass, and an area of south-glazing with shutters, for a heating season from September through May. The first curve, labelled "a", traces the performance of a typical house (as defined in Table 13) as unshuttered window area is increased. Thermal performance increases somewhat until the ratio of window area to floor area reaches 0.1; then the performance declines as the heat loss from the increasing window area gradually cancels the benefits from solar gain through those same unshuttered windows. Curve "b" is a case similar to curve "a" except that the internal mass is doubled. This results in an optimum performance for this house at a window area to floor area ratio of 0.2, or 20 percent. **The added mass, therefore, enables the performance of this house with south-facing, unshuttered windows to be improved by approximately 1 percent of the annual heating requirements (from 0.94 to 0.93 of the house's requirements).**

Curve "c" dramatically indicates the effect of shutters on a passive solar structure. With the shutters, the south-facing window area of a standard structure can be increased to 30 percent of the floor area before the heat loss of that shuttered area begins to cancel the solar gain. Shuttering the windows on a standard home can result in up to a 22 percent reduction in required heating, as indicated from this modeling process, and depending on the south-facing window area, as well as other window orientations and shuttering cycles. A shuttering cycle is the daily pattern of opening and closing the shutters on a structure. For example, open at 7 a.m., closed at 8 p.m., open at sunrise, closed at sunset, etc.

TABLE 13A: A LISTING OF PARAMETERS FOR THE TRNSYS COMPUTER MODELING USED TO FIND AN OPTIMUM PASSIVE SOLAR DESIGN FOR FAIRBANKS, ALASKA.

1. Window-triple pane: $U = 0.34$ BTU/hr·ft^{2}·°F, Area = 0 to 300 ft^{2}, $R = 2.94$
2. Infiltration: 0.15 air changes per hour
3. Thermal capacitance: $C = 4000$ to 16,000 BTU/°F
4. Insulation: As given in Table 15B
5. Ground reflectance: varied from 0.2 during fall and spring to 0.6 during winter
6. Thermal shutters: $U = 0.125$ BTU/hr·ft^{2}·°F, operated on an open cycle between 7:00 a.m. and 8:00 p.m., $R = 8$
7. Shading: Two-foot wing walls and overhang with one-foot perimeter gap
8. Allowable temperature swing: 65°F to 78°F
9. Ventilation fan turned on whenever interior temperature exceeded 78°F
10. Transmittance of windows: Assumes $KL = 0.0370$ yielding a transmittance of 0.70 at normal incidence
11. ASHRAE response factors for light and medium weight construction
12. Internal generation: 750 watts

Curve "d" shows the combined effect of shuttering the windows and doubling the interior mass. The effect of the additional mass is similar to that of curve "b"; it is a small, additive effect, totaling 4 percent of the total standard house heat load at a window area to floor area ratio of 0.30 (30 percent).

Curve "e" shows the performance of the unshuttered, superinsulated house. It is identical in shape to curve "a," but demonstrates the lower energy consumption afforded by the additional insulation. Otherwise, the unshuttered windows cause the same increase in heat loss as in case "a." Curve "f" is an example of an optimum passive solar design. It shows the results of the computer simulation of the superinsulated home (see Table 13) with shutters operated on a 7 a.m. open—8 p.m. closed daily cycle. **The best-performing structure is a house with a south-facing glazed area equal to 20 percent of the floor area, lightweight construction (no additional thermal mass), shutters, and superinsulation.** Several instructive conclusions for passive solar design of light construction buildings at subarctic latitudes can be drawn from the preceding study:

1. Triple-pane, south-facing windows yield a modest energy savings of 6-8 per-

TABLE 13B: SPECIFICATIONS FOR THE WALL AND ROOF SECTIONS USED TO COMPARE A STANDARD HOUSE TO A SUPERINSULATED HOUSE.

Standard House			Superinsulated House		
Wall Sections	**U-Value**	**R-Value**	**Wall Sections**	**U-Value**	**R-Value**
Inside air film 5/8 in gyp board 5-1/2 in fiberglass 1/2 in plywood 7/8 in cedar siding Outside air film	0.047	21.3	Inside air film 5/8 in gyp board 11 in fiberglass 1/2 in plywood 7/8 in cedar siding Outside air film	0.025	40
Inside air film 5/8 in gyp board 5-1/2 in Doug Fir 1/2 in plywood 7/8 in cedar siding Outside air film	0.100	10	Inside air film 5/8 in gyp board 7 in Doug Fir 4 in fiberglass 1/2 in plywood 7/8 in cedar siding Outside air film	0.040	25
Roof Sections	**U-Value**	**R-Value**	**Roof Sections**	**U-Value**	**R-Value**
Inside air film 5/8 in gyp board 11-1/4 in fiberglass 5/8 in plywood Felt paper Asphalt shingles Outside air film	0.025	40	Same as for standard house	0.025	40
Inside air film 7/8 in gyp board 1-1/4 in Doug Fir 5/8 in plywood Felt paper Asphalt shingles Outside air film	0.062	16.13	Same as for standard house	0.062	16.13

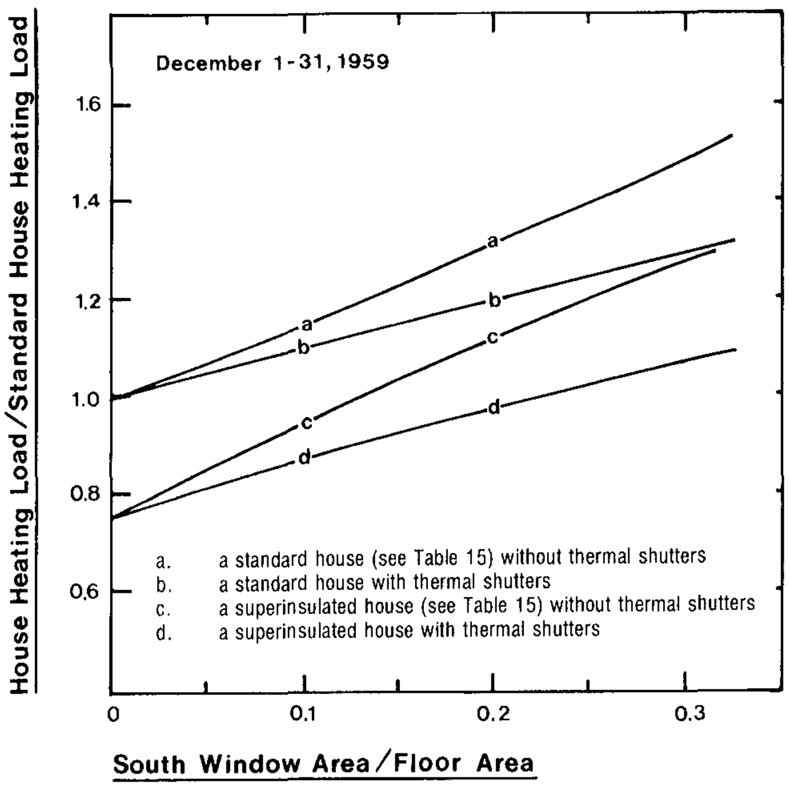


Figure 53. Increasing the window area of a structure to improve solar gain always results in increased heat loss for the month of December.

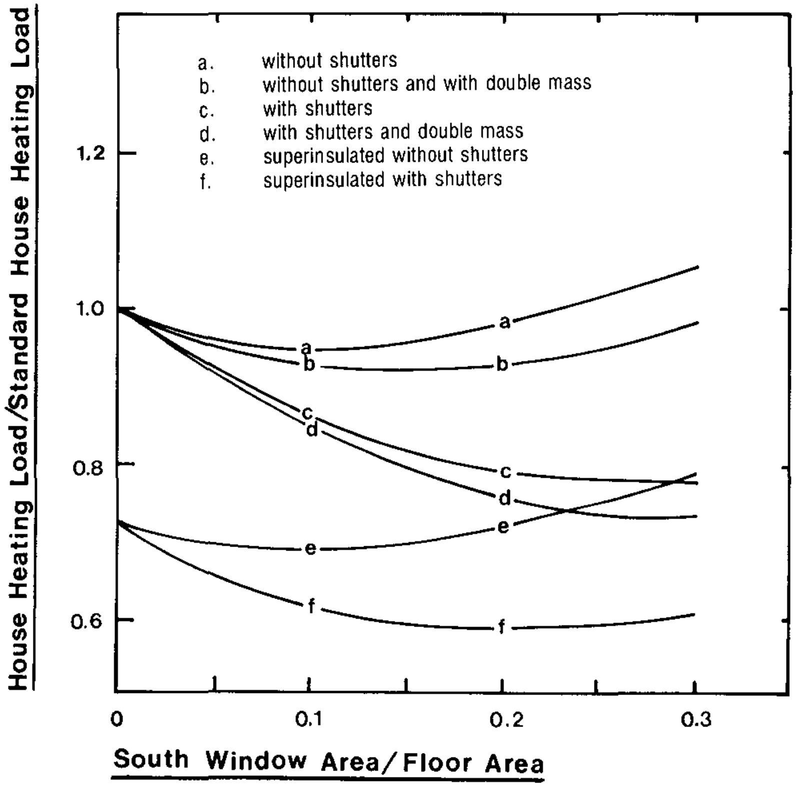


Figure 54. Annual heating requirements for houses with and without thermal shutters and various amounts of south-facing windows.

cent if the window to floor area ratio is in the range of 0.1 to 0.2. Windows facing any other direction will experience a net loss of thermal energy over the heating season.

2. Thermal shutters as modeled in this study on all south-facing windows of the structure can supply up to 22 percent of the space heating requirement. Of course, these savings are dependent on the open-close cycle and the insulating value of the shutters. If higher R-value shutters with a shorter open cycle are used, additional savings would be realized. One of the most attractive retrofits for existing homes is thermal shutters. A need exists for a well-designed, low-cost, semiautomatic shutter for old as well as new construction. Ideally, a shutter system would open only during periods of useful solar energy gain, but this is likely to be objectionable on aesthetic grounds. Also, the shutter would perform best if its insulating value were equal to that of the surrounding superinsulated wall. Size and mobility requirements for shutters preclude this.

3. Superinsulated construction combined with direct-gain, passive solar techniques have an additive effect resulting in a 25 to 40 percent reduction in the annual heating load.

4. Increased thermal mass in a structure can produce energy savings. However, at high northern latitudes with severe winters and little midwinter sun, these savings are not dramatic, and are unlikely to warrant the added expense of their inclusion in the structure.

Economics of the above measures have not been evaluated. Yet it appears that designing structures with south-facing windows while minimizing windows of other orientations could be easily accomplished. The incremental cost of this concept should be minimal. Adding thermal shutters to the structure will result in increased building costs.

Highly insulated structures are gaining popularity as the price of energy escalates, even though the extra wall thickness adds to the initial cost of the building. Often these structures are built with a 2x4 double stud wall so the cost of framing materials is slightly higher than conventional 2x6 construction. Insulation costs are directly proportional to thickness, labor costs for framing are increased, as are the costs of windows and doors with their required jam extensions. Doubling the wall thickness sacrifices usable floor space (about 100 ft^2 in the case of the house modeled for this study).

THE PROBLEM OF THERMAL SHUTTERS

Windows are notoriously poor thermal insulators, and usually are a major source of heat loss in structures. Insulating windows can significantly reduce this heat loss. A double-pane window with an R-value of 1.84 loses heat at the rate of 0.54 $BTU/hr/ft^2/^oF$. A wall with an R-value of 19 loses heat at a rate of 0.05 $BTU/hr/ft^2/^oF$. Thus the window loses about 10 times more heat per unit area than the wall under the same conditions. Obviously, when windows are not gaining useful heat during the dark period of the day, they are rapidly losing heat to the environment if it is colder outside than inside the structure. So windows need to be insulated at night if they are to perform optimally in a passive solar design.

What kind of shutter (also called movable insulation and night insulation) should you use? There are indoor shutters, outdoor types, shutters that fit into a wall pocket, shutters that fold away into a storage area, shutters that open and close automatically, and shutters that are controlled by photoperiod. There are R2 shutters and R15 shutters. But there are no ideal shutters. Every design has liabilities. They must open and close, be reliable in the most extreme conditions Alaska can offer, and—perhaps most important of all—they must be *used*. If shutters are bothersome, unaesthetic or unreliable in operation, they will be discarded or avoided. We do not yet have the technology for ideally coupling night insulation with south-facing glazing for passive solar design. Meanwhile, many Alaskans are working to find a better shutter design for our climate.

One of the questions often asked about shutters concerns their position relative to the window. Should the shutter be placed outside the window or inside? The answer is not simple, because neither solution is trouble-free. Placing the shutter mechanism outside exposes it to weather and reduces the ease of operation. The shuttering mechanism can become frozen open or shut from ice buildup, especially if it is a track or hinged mechanism. Any cranks or levers that penetrate the wall can also ice up due to freezing condensation; they also conduct valuable heat through the wall. If these types of mechanisms aren't used, then one must operate the shutters from outside, an unappealing option at -40°F.

Placing the shutter on the inside of the window *may* work, but it has similar problems. Interior shutters are convenient since they can be operated from inside the building, but this strategy causes the inside window surface to become colder. If the shutter is not sealed to exclude the passage of warm moist interior air to this cold window, water vapor will condense on the window, and one or all of the following will happen.

1. Water will drip down the sills of the window, along the wall, and onto the floor, discoloring and decaying the building materials.

2. Water will freeze behind the shutter, icing over the window and limiting its usefulness when unshuttered. When it *is* unshuttered, the ice will melt and repeat the events described above.

3. The shutter will freeze in place until a thaw comes.

Sealing the shutter from vapor problems is possible, but not simple, and most commercially available shutters do not have vapor seals.

Shutters deserve detailed attention, and there are presently two recommended books on the subject. Mainly, they review available commercial technologies and, in some instances, point out ideas for shutter improvement. *Movable Insulation* by William Langdon is available from Rodale Press, Emmaus, PA. *Thermal Shutters and Shades* by William Shurcliffe can be purchased from Brick House Publishing Co., 3 Main Street, Andover, MA.

EFFECTS OF CLIMATE

The Alaskan climate is typically characterized by long, cold winters and short, relatively warm summers. Solar radiation varies with the seasons, due to both the seasonal solar elevation angle and day length, as well as seasonally changing humidity. In Alaska, this can be seen by investigating the average solar radiation on a south-facing vertical surface. Figure 55 shows the comparison of two related quantities: the monthly average heating index, and the average daily solar radiation (BTU/ft^2) on a south-facing vertical surface in Fairbanks. Figure 56 shows the same comparison for the Matanuska Valley of Alaska, and Figure 57 for Bethel.

In the examples, an important and somewhat unexpected pattern is evident. Intuitively, the average solar radiation on a south-facing vertical surface (or any surface) should be symmetrical in magnitude about the summer solstice. One expects the average solar radiation in September to be very nearly equal to that in March. However at Bethel, Matanuska and Fairbanks, the solar radiation in March averages twice as much as that in September, on a vertical south-facing surface. The asymmetry is due to late summer and autumn cloudiness, and predominantly clearer weather during the period from February through May. The result is that solar radiation on a south-facing vertical surface (the most important consideration for passive solar design) is out of phase with heating degree days. Solar gain peaks in March and April, when the solar heat is still very useful. The solar geometry and climate provide an unexpected benefit for passive solar applications in the far North.

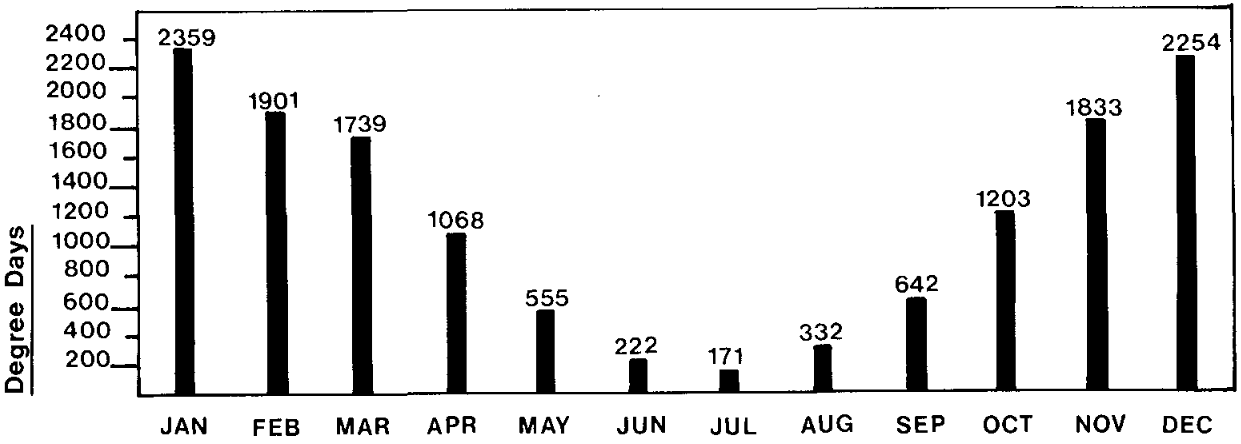
As in the case of active solar applications, the presence of snow cover for up to six months of the year is a positive factor improving the effectiveness of passive solar energy in Alaska.

PERFORMANCE OF "CLASSIC" PASSIVE DESIGNS IN ALASKA

As in many fields of design, passive solar technology has "classic" types. These are (1) direct gain systems, primarily using glazing and thermally efficient structures; (2) Trombe wall designs, described in Figure 17; (3) greenhouse options; and (4) direct gain with thermal shutters, also referred to as "direct gain with night insulation." These classic designs have been analyzed for their performance through a design project for a rural Alaskan school, sponsored by the Alaska Department of Transportation and Public Facilities and the U.S. Department of Energy.

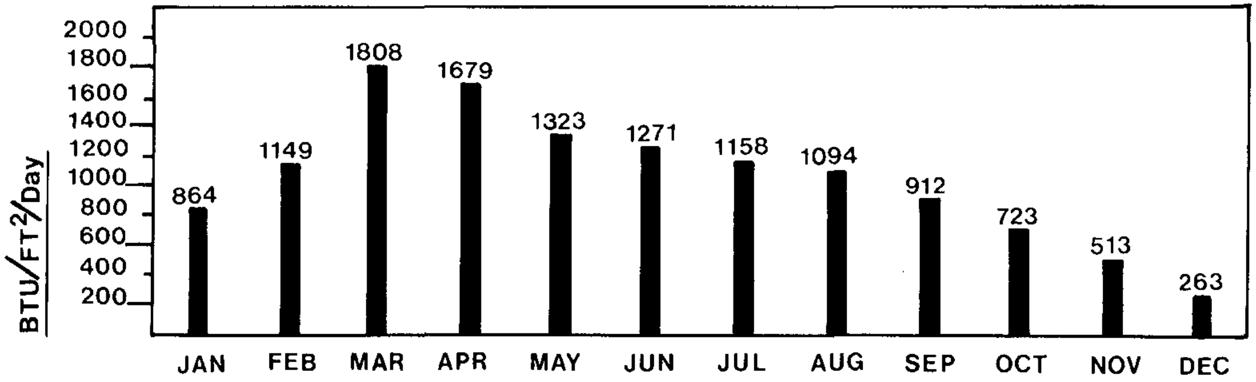
COMPUTER SIMULATION OF DESIGN OPTIONS

The performance of each passive solar design was evaluated for Alaska's climate. The design types include: direct-gain, south-facing windows without shutters (labelled Design Test 2 in Figure 58); a direct gain system with added thermal mass as a Trombe wall (labelled Design Test 3 in Figure 59); an attached south-facing solar greenhouse backed by a Trombe wall (labelled Design Test 4 in Figure 60); a direct gain application, superinsulated (3,095 BTU/°F-day), shuttered, with some mass added (labelled Design Test 5 in Figure 61); and the final design, which was selected for its thermal performance and daylighting possibilities (labelled Design Test 6 in Figure 62).



Average Monthly Heating Degree Days

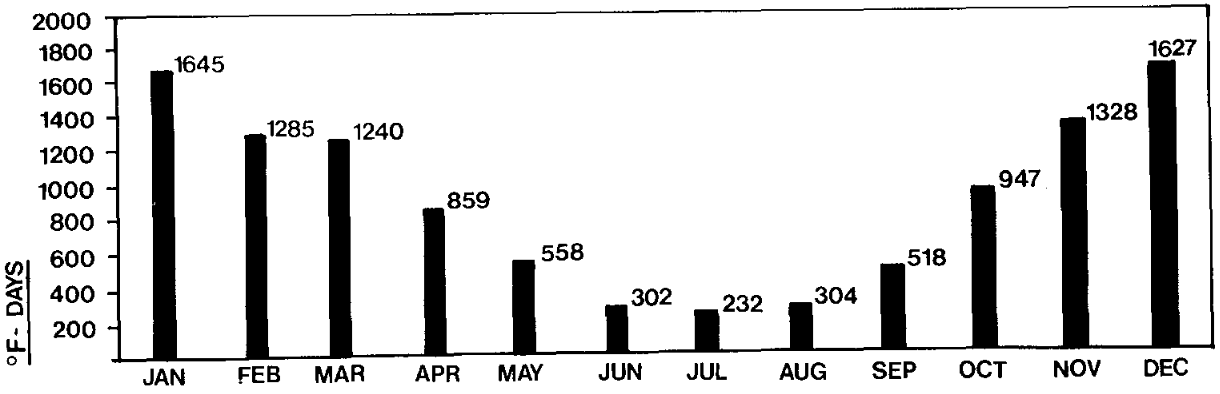
Fairbanks, Alaska



Average Solar Radiation on a Vertical South Facing Surface

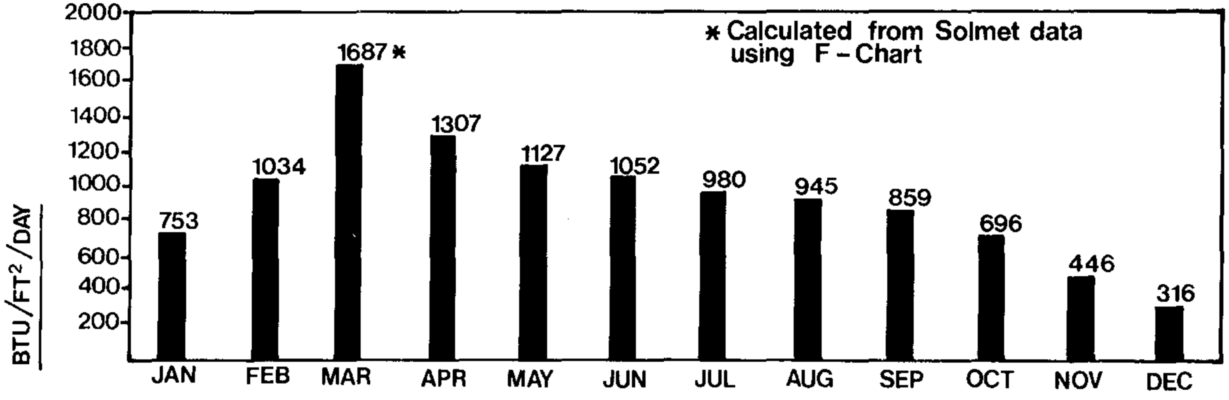
Fairbanks, Alaska

Figure 55. These graphs illustrate that the Fairbanks heating degree days and average solar radiation (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April when heating is needed. Data are from Kusuda and Ishii (1977).



Average Monthly Heating Degree Days

Matanuska, Alaska

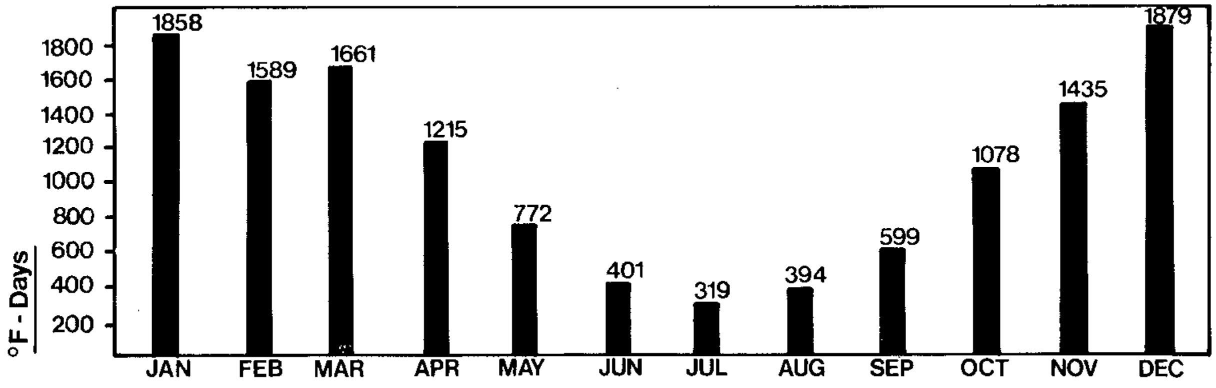


* Calculated from Solmet data using F-Chart

Average Solar Radiation on a Vertical South Facing Surface

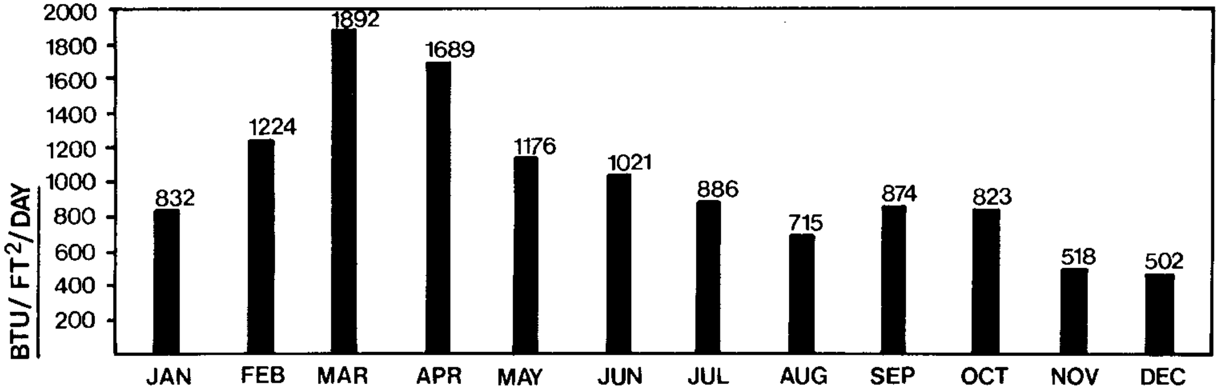
Matanuska, Alaska

Figure 56. Matanuska heating degree days and average solar radiation. These graphs illustrate that the annual heating degree days (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April when heating is needed. Data are from Kusuda and Ishii (1977).



Average Monthly Heating Degree Days

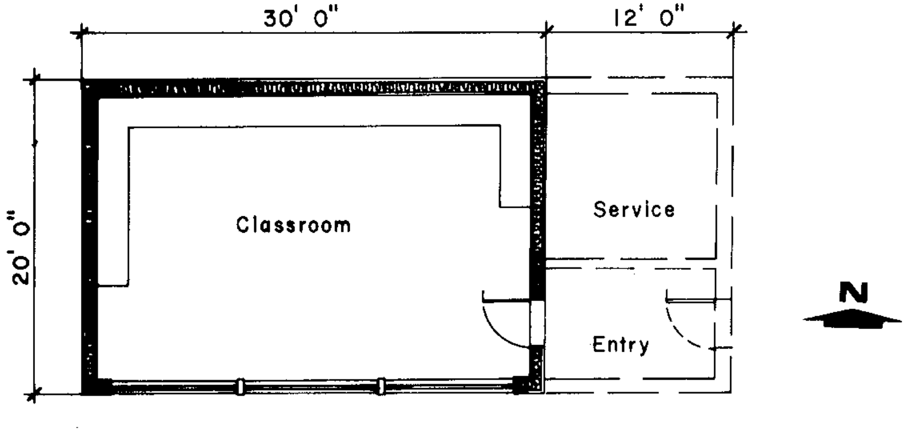
Bethel, Alaska



Average Solar Radiation on a Vertical South-Facing Surface

Bethel, Alaska

Figure 57. Bethel heating degree days and average solar radiation. These graphs illustrate that the annual heating degree days (which are an indication of a building's heating requirements) are not in phase with the solar radiation on a south-facing vertical surface. This has positive implications for passive solar heating. The solar gain is highest in March and April when heating is needed. Data are from Kusuda and Ishii (1977).



Floor Plan

Construction

Walls: 2 x 8 studs w/full batt fiberglass.

Roof: 12" fiberglass, metal roofing.

Floor: 12" fiberglass.

Foundation: piles or posts w/insulated floor.

Floor area: 600 ft^2.

Windows: double pane

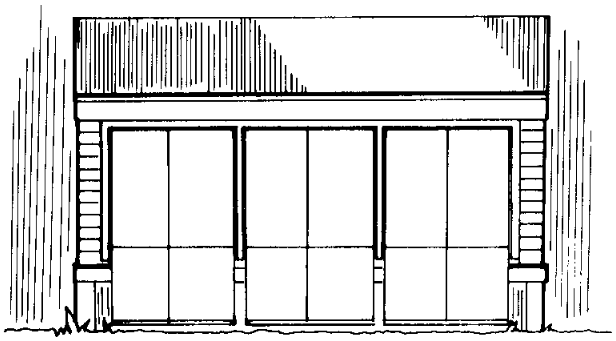
Window area: south 200 ft^2.

Building UA: 2011 BTU/DD.

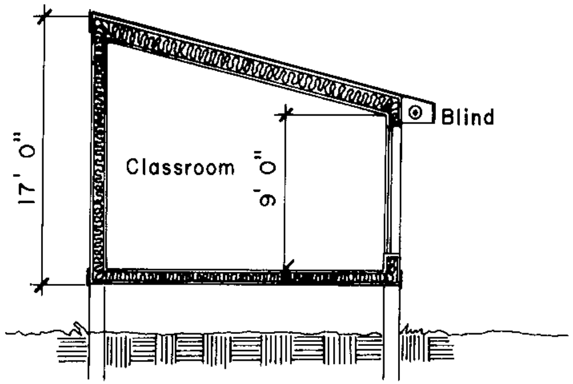
Vent reqmnt: 0.54 ACH.

Added thermal mass: none.

Shading mechanism: common exterior blind.

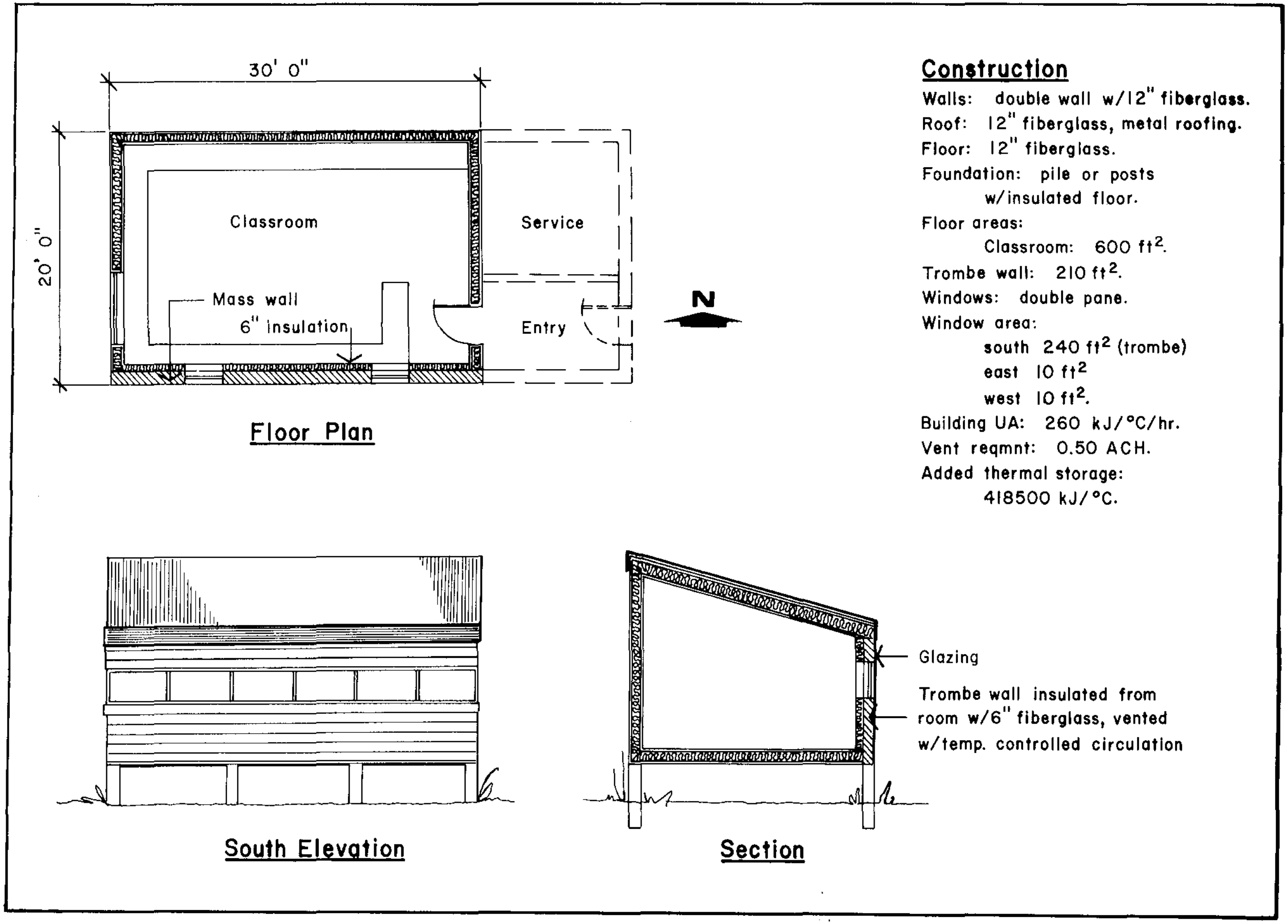


South Elevation



Section

Figure 58. Design Test 2, a direct gain passive solar design without shutters.



Floor Plan

South Elevation

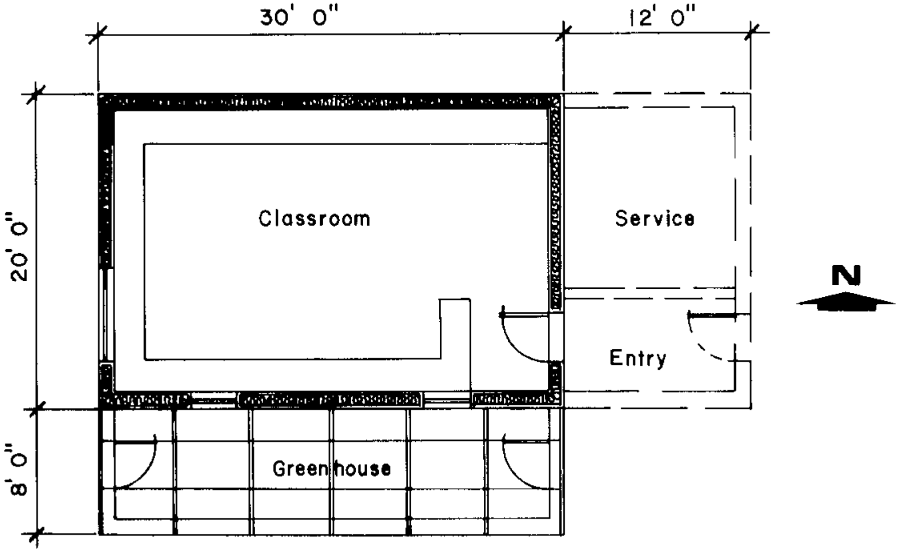
Section

Trombe wall insulated from room w/6" fiberglass, vented w/temp. controlled circulation

Construction

Walls: double wall w/12" fiberglass.
Roof: 12" fiberglass, metal roofing.
Floor: 12" fiberglass.
Foundation: pile or posts
w/insulated floor.
Floor areas:
Classroom: 600 ft^2.
Trombe wall: 210 ft^2.
Windows: double pane.
Window area:
south 240 ft^2 (trombe)
east 10 ft^2
west 10 ft^2.
Building UA: 260 kJ/°C/hr.
Vent reqmnt: 0.50 ACH.
Added thermal storage:
418500 kJ/°C.

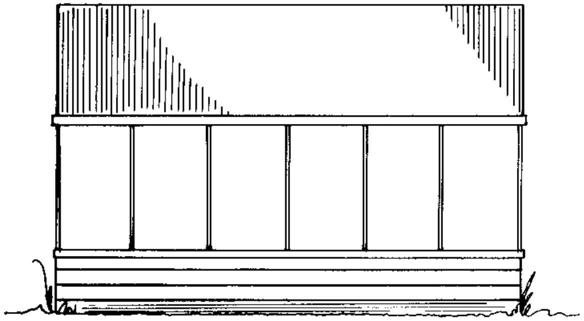
Figure 59. Design Test 3, a Trombe wall design with direct gain.



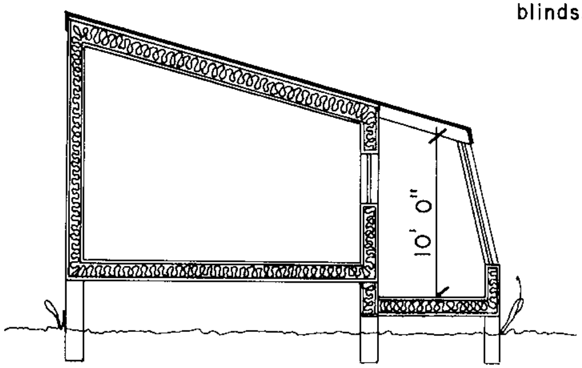
Floor Plan

Construction

Walls: 2 x 8 studs w/full batt
fiberglass.
Roof: 12" fiberglass, metal roofing.
Floor: 12" fiberglass.
Foundation: pile or posts
w/insulated floor.
Floor areas:
Classroom: 600 ft^2.
Greenhouse: 240 ft^2.
Windows: double pane.
Window area:
south (Greenhouse) 240 ft^2
east 10 ft^2
west 10 ft^2.
Building UA: 244 kJ/°C/hr.
Vent reqmnt: 0.5 ACH.
Added thermal mass:
418500 kJ/°C.
Shading mechanism: Greenhouse
blinds.

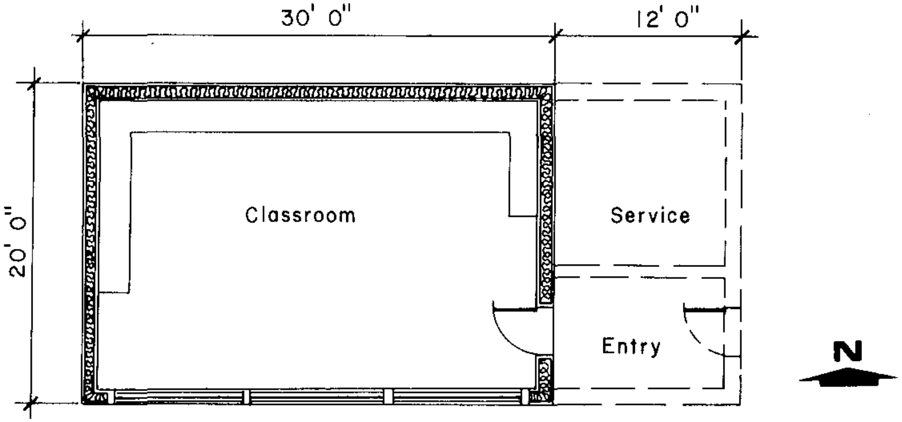


South Elevation



Section

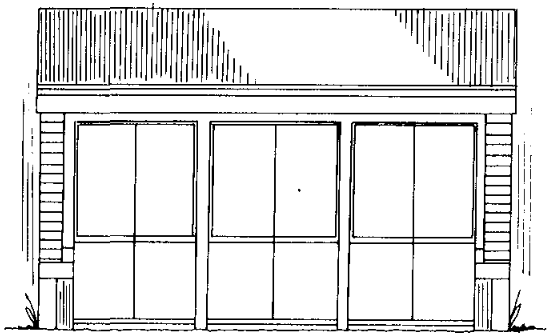
Figure 60. Design Test 4, a combination Trombe wall with attached greenhouse.



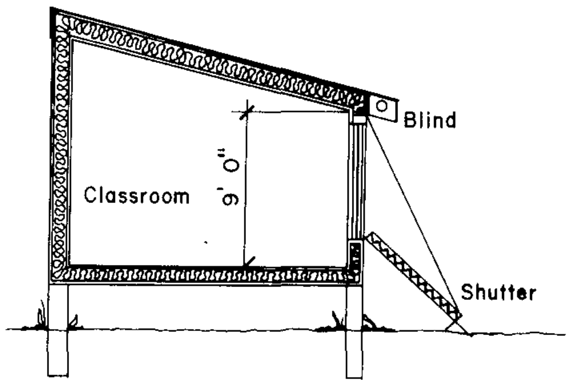
Floor Plan

Construction

Walls: 2x8 studs w/full batt fiberglass.
Roof: 12" fiberglass, metal roofing.
Floor: 12" fiberglass.
Foundation: piles or posts w/insulated floor.
Floor area: 600 ft^2.
Windows: double pane, shuttered.
Window area: south 200 ft^2.
Building UA: 244 kJ/°C/hr.
Vent reqmnt: 0.5 ACH.
Added thermal mass: 209000 kJ/°C.
Note: glazed south wall w/$\frac{1}{2}$ mass of trombe wall added to interior.

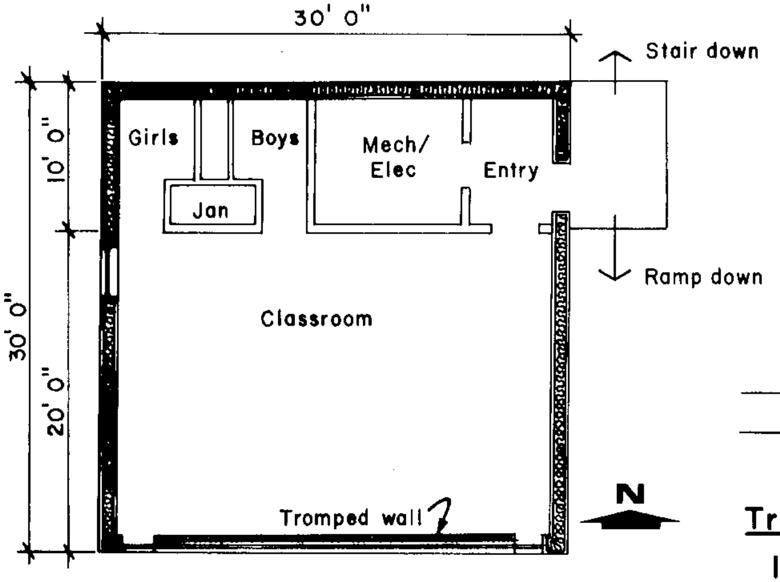


South Elevation

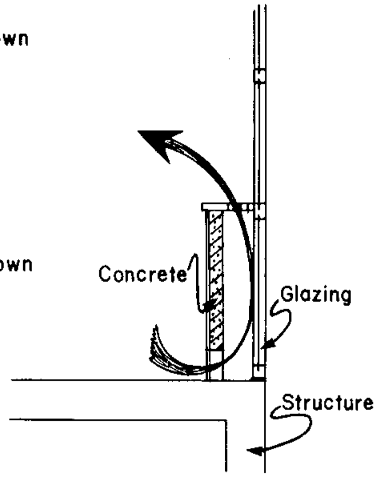


Section

Figure 61. Design Test 5, a simple direct gain design with night insulation.



Floor Plan

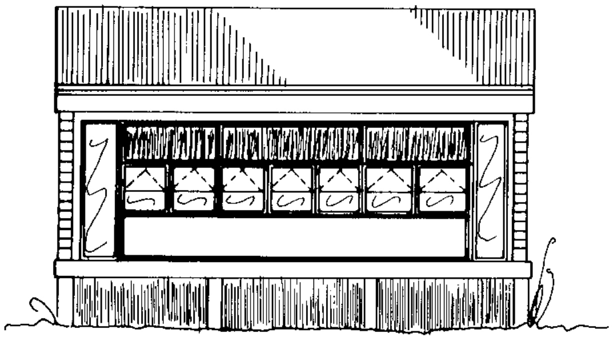


Tromped Wall

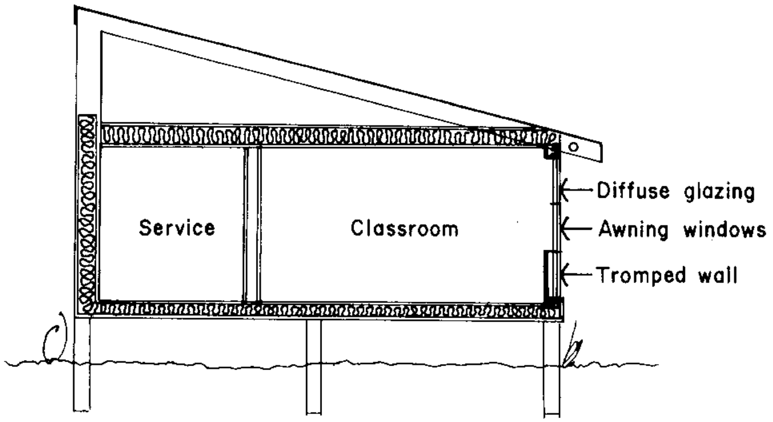
1/4" = 1' 0"

Construction

Walls: 2-2x4 studs w/full batt fiberglass.
Roof: 12" fiberglass, metal roofing.
Floor: 12" fiberglass.
Foundation: piles or posts w/insulated floor.
Floor area: 960 ft^2
School 660 ft^2
Service 300 ft^2.
Windows: double pane, shuttered to R-9.
Window area: south 200 ft^2.
"Tromped wall": south 78 ft^2.
Building UA: 3095 BTU/°FD.
Vent reqmnt: 0.5 ACH.



South Elevation



Section

Figure 62. Design Test 6, the final design recommended as the prototype. It includes a direct gain system with night insulation and a "tromped" wall (a hybrid low-mass Trombe-prompt wall), which provides some storage and an inducement to convective air circulation. Large windows on either side of the south facade provide daylighting.

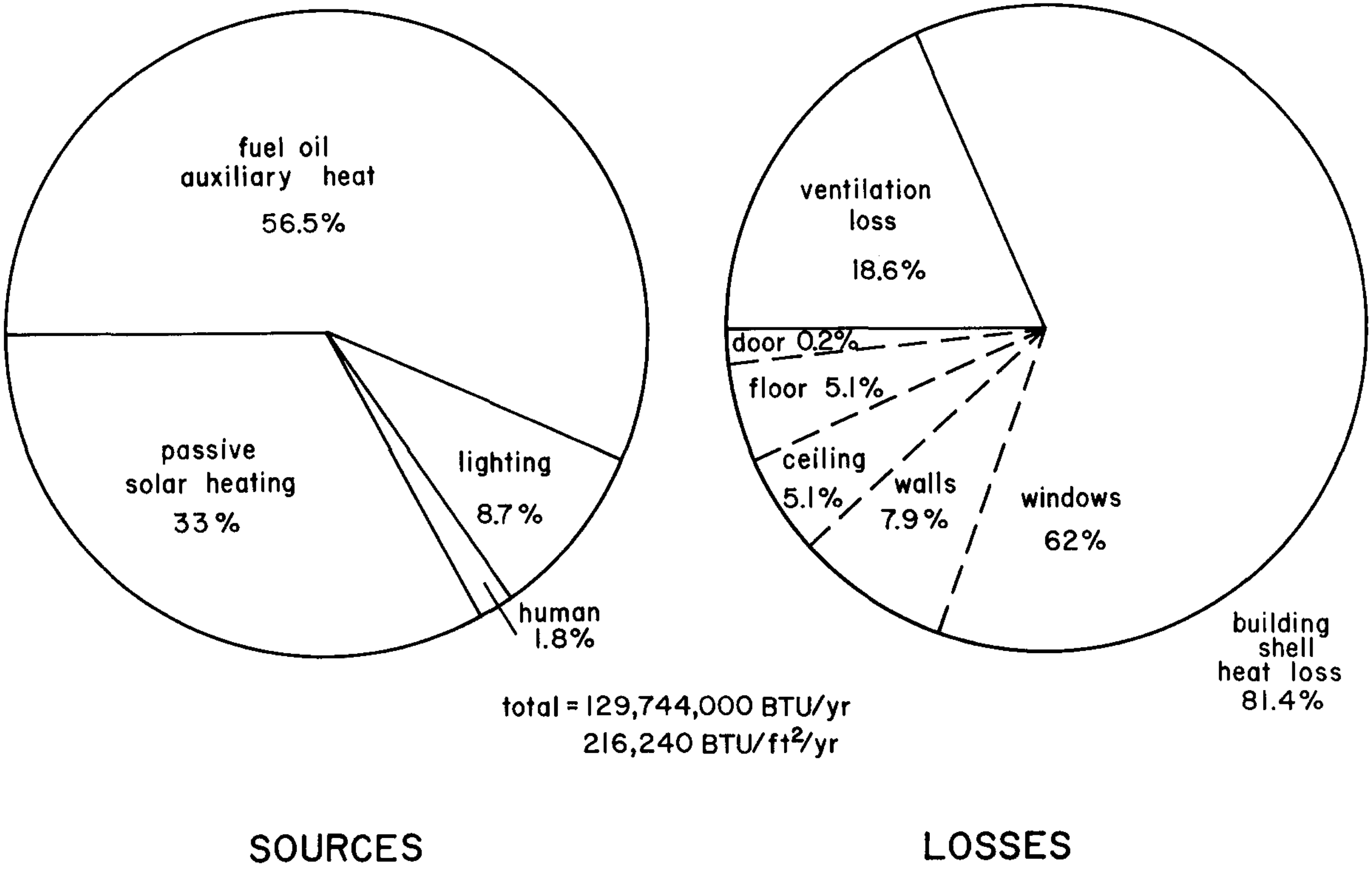
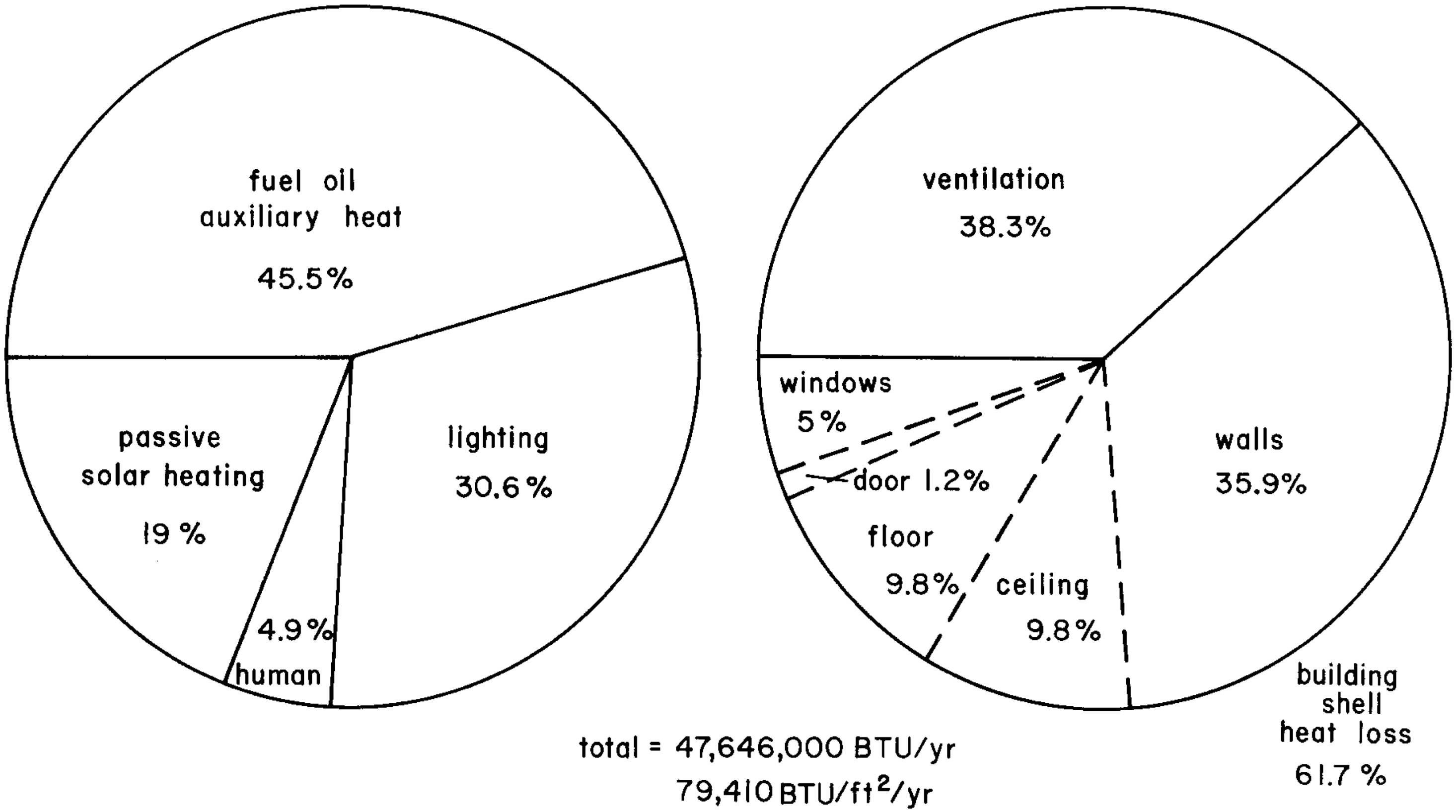


Figure 63. Thermal performance of Design Test 2, the direct gain system without night insulation. Notice the large percentage of heat loss due to uninsulated window area.



SOURCES

LOSSES

Figure 64. Thermal performance of Design Test 3, the Trombe wall design with direct gain.

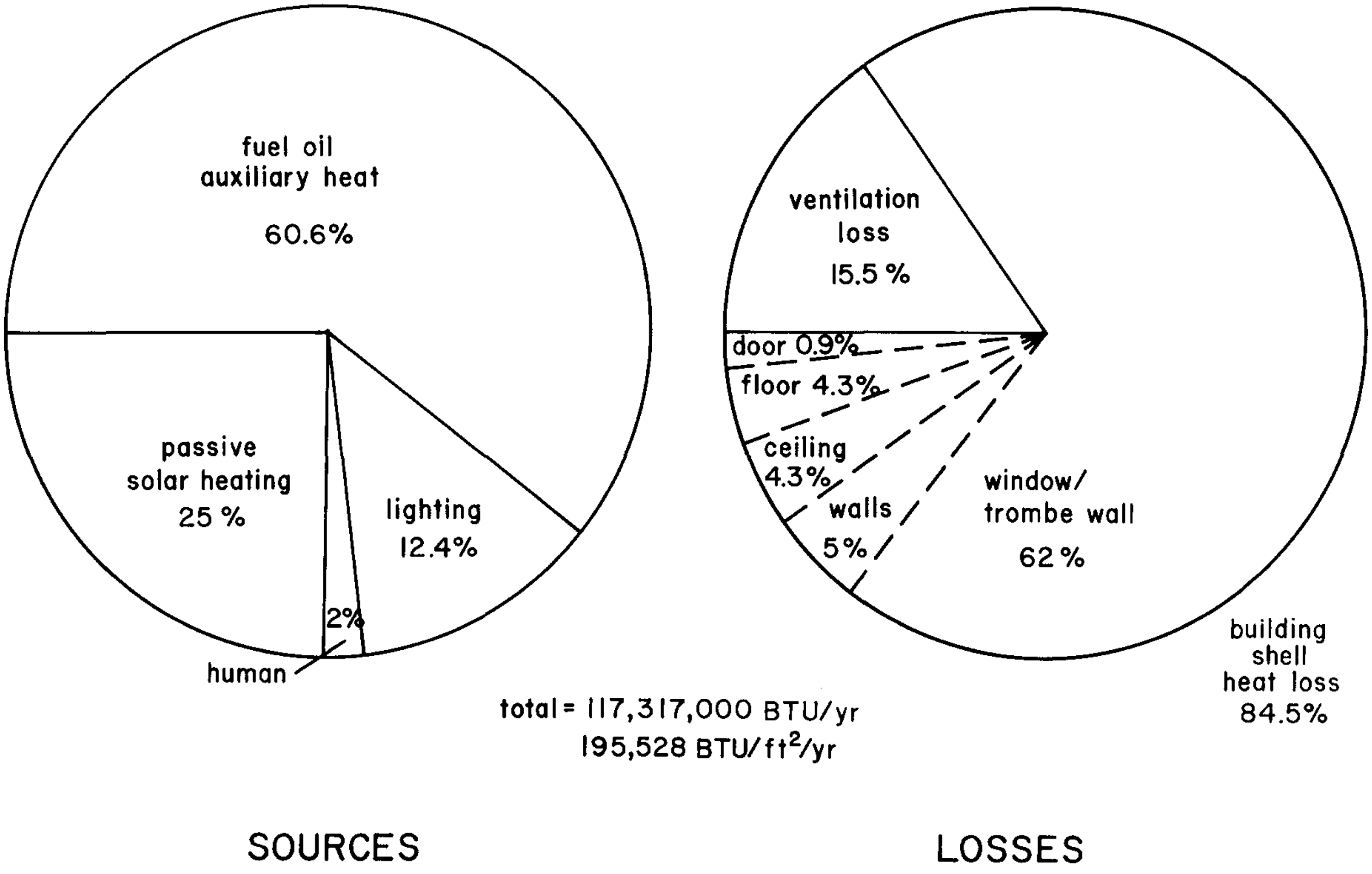


Figure 65. Thermal performance of Design Test 4, a combination Trombe wall and attached greenhouse.

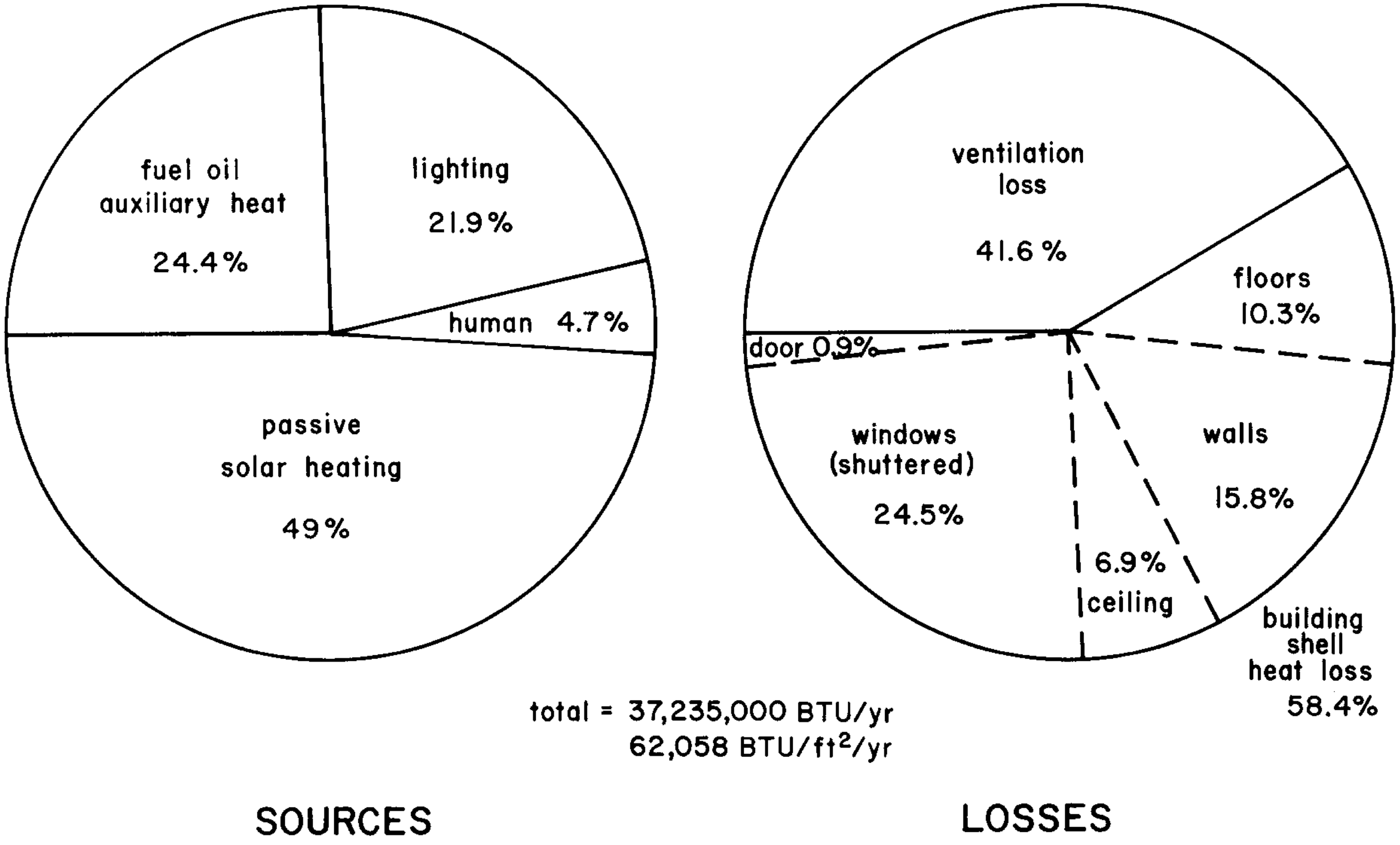


Figure 66. Thermal performance of Design Test 5, a direct gain with night insulation.

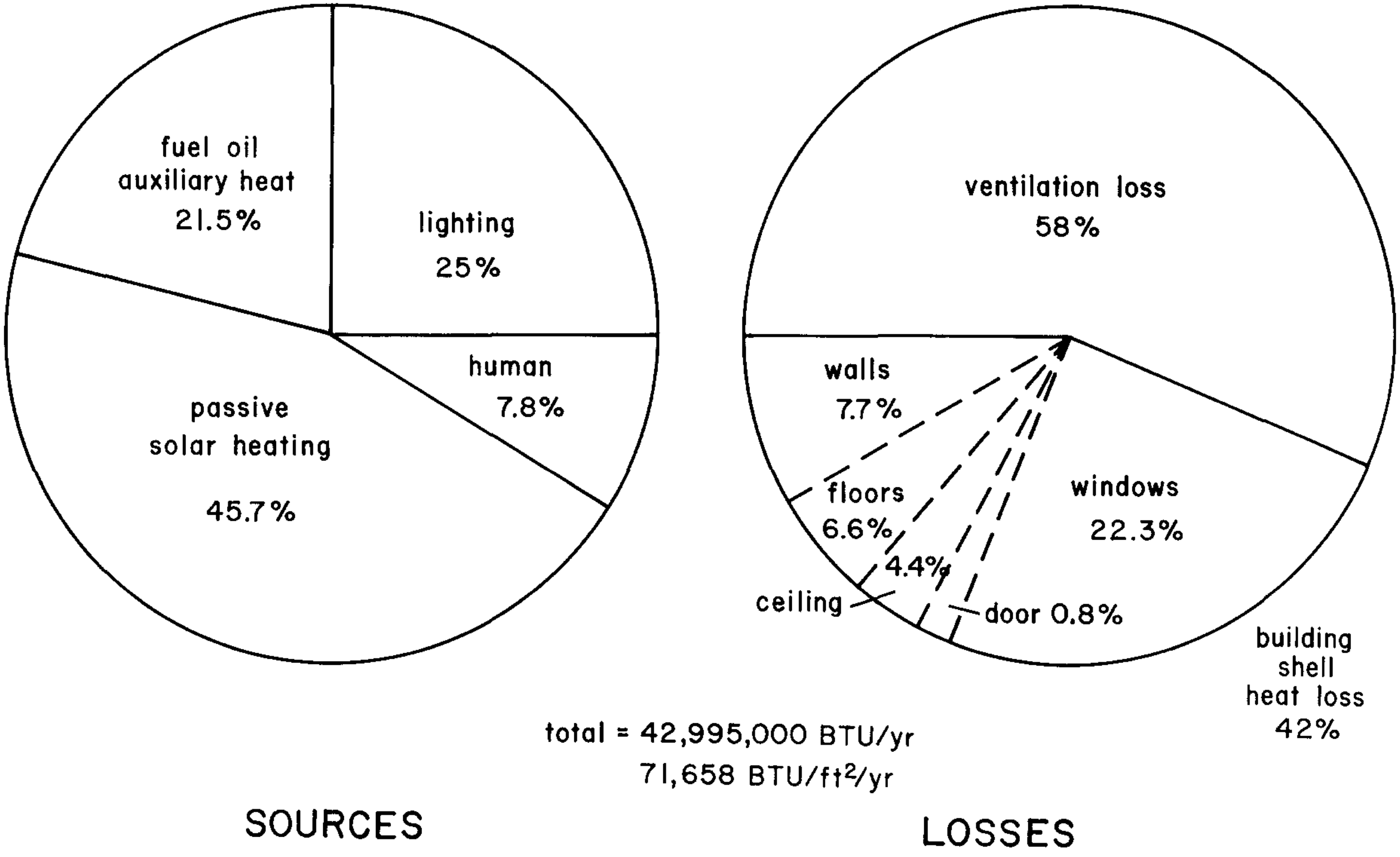


Figure 67. Thermal performance of the final recommended prototype, Design Test 6.

Comparisons among these examples (see the pie charts; Figures 63-67) show that the direct gain systems are the best performing systems from both the standpoint of solar gain and annual heating requirements, especially if they are shuttered when solar energy is not available.

The Trombe wall design (Design 3; Figure 64) in this case falls short of the performance of the direct gain system, mainly because it is not possible to insulate the wall efficiently and still transfer heat to the space where it is needed. This is achievable with shutters (they were not used in the Trombe wall test), but the system does not perform as well as a comparable direct gain system, and the Trombe wall severely limits the possibilities for daylighting at high latitudes.

The greenhouse-Trombe wall combination (Design 4; Figure 65) also does not perform as well as the direct gain system, but it would have many direct and indirect advantages since the greenhouse space can be used for growing food and decorative plants. It is, however, more difficult to shutter.

These design tests provide interesting case studies of the different classic passive solar design elements. This work indicates that the best combination of elements for high latitude applications of passive solar design are shuttering, direct-gain south-facing windows, and superinsulated construction.

INFORMATION FROM THE PASSIVE SOLAR DESIGN MANUAL

There are two design manuals that provide useful information about analytical techniques, passive solar performance measures, and graphic design aids. The *Passive Solar Design Manual, Vol. 2, Passive Solar Design Analysis* was prepared by J. D. Balcomb et al. for the U.S. Department of Energy. *The Passive Solar Design Manual* (PSDM) is available from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 ($14.00—printed, $3.00—microfiche). Ask for book code: DOE/CS-0127/S, Dist. Cat. UC-59. *The Passive Solar Energy Book,* by Edward Mazria, is available from: Rodale Press, Organic Park, Emmaus, PA 18049 ($24.00—hardcover, $10.95—paper cover).

One of the approaches used in the *Passive Solar Design Manual* is to discuss rules of thumb for passive design. Unfortunately for us in Alaska, these rules of thumb are not relevant because they do not consider Alaskan design situations. Many of the physical reasons for this lack of applicability are pointed out in the previous section, describing the passive design study of Zarling and Seifert (1980).

What is needed is a "recipe" book for the passive design process. The following four sections (from sizing procedures through building load coefficients) were adapted from the *Passive Solar Design Manual*. They are an attempt to enable the reader to go through a passive solar design process for Alaska.

Simplified Sizing Procedures for the Design Development Phase

The thermal balance characteristics of the building are determined during design development. Outside wall construction and insulating properties are decided, the location and gross amount of window area (including solar collection area) is selected, and the amount and type of thermal storage is determined and located relative to the solar collection area. These decisions are highly interdependent. Thus the numerical procedures must be simple enough to allow an iterative approach, adjusting and readjusting the preliminary design until all criteria are satisfied within reasonable bounds. If the procedure takes more than 10 or 15 minutes, then it simply won't be used. This phase is as critically important to the thermal design as to the physical design.

Detailed Estimates for the Construction Documents Phase

The main purpose of the thermal analysis in the construction documents phase is to confirm that the building will meet design criteria. Detailed account is taken of the building thermal loss and solar gain characteristics on a monthly basis, accounting with more precision for effects of angle, shading, and actual sizes and spatial relationships. The reduction in auxiliary heating due to solar heating is estimated for average weather and solar conditions at the building site.

The complexity of the design aids increases as one proceeds from schematic design through design development to construction documents. The only advantage in proceeding all the way through the construction documents procedures is to take account of some complexities of the design which are not accounted for in the simpler design aids.

Economic Analysis

Ideally, economic analysis should be included as an explicit part of the design process, but we lack enough information at the present time. It is assumed that the designer will factor in economic considerations as the design proceeds, trading off the cost of each proposed improvement against the performance benefit to be derived.

The most important economic consideration is to determine the "best" size of solar collection area and the "best" level of energy conservation for a particular application. This depends, of course, on the add-on cost of the solar features, the add-on cost of conservation and the future cost of fuel saved.

A methodology for determining the "best" values is described in this text. This procedure is probably most suitable for adjusting conservation levels and the solar aperture size (the effective "collector" area of glazing) early in the design phase.

Implicit in the solar design is a desire to minimize auxiliary energy requirements by substituting solar heat; i.e., we are interested in the maximum on-site energy generation.

DIRECT GAIN PASSIVE SOLAR DESIGN

This section reviews the physical features of a structure that can influence the performance of a direct gain system. It prepares the user for an actual Alaskan passive solar design calculation, which is covered in the next section.

Absorptance

The solar absorptance, α, of internal walls and furnishings may be a significant design feature in raising or decreasing the comfort level in a structure. Although darker colors are more absorptive, they also become very hot when exposed to direct solar radiation for extended periods of time. The use of a direct gain space must be carefully considered. A dark metal surface with a small amount of mass can reach temperatures in the range of 120-140°F. Substances with absorptivities of 0.5 to 0.7 will still get very warm when exposed to the sun, but they reflect more of the incident solar radiation, achieving more even heating of the space. Table 14 lists the absorptances of common materials.

The following suggestions are offered as a means of assuring that absorption levels on nonmassive surfaces be kept reasonably low in direct gain zones.

1. As a general rule, massive surfaces in a direct gain zone should be relatively dark in color, and low mass surfaces should be relatively light. This arrangement encourages absorption of sunlight on surfaces where the heat can be stored.

2. If dark objects with little thermal capacity are placed in a direct gain zone, they should be located out of direct sunlight as much as possible.

Adherence to these simple rules will help eliminate overheating problems in properly sized, direct gain structures.

Lightweight objects with low heat capacity (such as furniture) can diminish the performance of a direct gain building, especially if placed in direct sunlight. However, according to work done by Balcomb et al. (1980), the penalty for absorbing 20 percent of the transmitted solar radiation directly on nonmassive surfaces never exceeds 5 percent. This information is useful to an architect or designer who needs to make choices of furniture and wall coverings in a building, especially as it affects passive solar performance. The concern is that a large amount of low mass material in a direct gain sunspace might cause more frequent overheating and high levels of discomfort. An example of the worst case situation is described in the next paragraph, and helps to clarify that the interior design in passive solar structures is not severely constrained by the type, amount, and solar absorptance of the furnishings.

In order for half of the transmitted solar radiation to be transferred rapidly into the room air, it would be necessary for half of the exposed surface area to be a perfect absorber with no thermal storage capacity. Or, equivalently, if the surfaces lacking thermal storage capacity have a solar absorptance of 0.5, they must intercept all of the transmitted solar flux in order to transmit 50 percent of the absorbed radiation directly to the air (the air heating fraction). These two extreme cases seem to indicate that a designer would have to try very hard to design a structure that would rapidly overheat.

Yet rapid overheating may be a problem in Alaska. Since our computer simulations show that thermal mass storage is less useful for structures in Alaska, an optimum passive solar design for Alaska would more closely approach the extreme case of a perfect absorber with no thermal storage capacity. Thus Alaskan designs may require ventilation systems to remove this heat.

Two strategies may help avoid overheating problems. First, use interior paints and surface materials with absorptances of 0.5 or less. This would insure that the air heating fraction is 50 percent or less. Second, avoid using a surface material that is a good thermal insulator, such as carpeting, especially if its absorptance is greater than 0.5. Thus, for example, don't use carpets. Or if you do, use light-colored carpets.

Wind Speed and Spacing of Glazing

Most locations in continental Alaska have an average wind speed less than the 15 mph reference value that the American Society of Heating, Refrigerating and Airconditioning Engineers (ASHRAE) uses as a standard for reporting film coefficients on external building surfaces. The actual film coefficient should be based on one-half of the actual recorded wind speed at a given location. Using half of the hourly wind speed to compute film coefficients on the outside surface of direct gain glazing reduces the calculated amount of heat lost from the surface and yields higher performance predictions. **For night-insulated cases the improvement is small.** However, for designs without night insulation, the fractional decrease in effective conductance of the solar wall or glazing is significant.

A glazing air gap of 1/4 inch has been the traditional standard. It has been established that the air gap thickness affects the conductance of double-glazed windows but only recently has the effect on performance of direct gain buildings been studied. Figure 68 (after Balcomb et al., 1980) shows that increasing the air gap from 1/4 to 1/2 inch raises the solar savings by 12 to 15 percent depending on whether or not the effect of variable wind speed has already been accounted for. The direct gain design that was originally a 9 percent loser now shows a positive solar savings of 11.5 percent. Further increases in air gap thickness yield very little additional improvement in performance because convection

TABLE 14: SOLAR ABSORPTANCE OF VARIOUS MATERIALS[1,2]

Optical flat black paint	.98
Flat black paint	.95
Black lacquer	.92
Dark gray paint	.91
Black concrete	.91
Dark blue lacquer	.91
Black oil paint	.90
Stafford blue bricks	.89
Dark olive drab paint	.89
Dark brown paint	.88
Dark blue-gray paint	.88
Azure blue or dark green lacquer	.88
Brown concrete	.85
Medium brown paint	.84
Medium light brown paint	.80
Brown or green lacquer	.79
Medium rust paint	.78
Light gray oil paint	.75
Red oil paint	.74
Red bricks	.70
Uncolored concrete	.65
Moderately light buff bricks	.60
Medium dull green paint	.59
Medium orange paint	.58
Medium yellow paint	.57
Medium blue paint	.51
Medium kelly green paint	.51
Light green paint	.47
White semigloss paint	.30
White gloss paint	.25
Silver paint	.25
White lacquer	.21
Polished aluminum reflector sheet	.12
Aluminized mylar film	.10
Laboratory vapor deposited coatings	.02

[1] This table is meant to serve as a guide only. Variations in texture, tone, overcoats, pigments, binders, etc. can alter these values.

[2] A perfect absorber has an absorptance of 1.00; i.e., it absorbs 100 percent of the incident solar radiation. All normal materials absorb less.

currents between the glazings negate the insulating effect of the thicker air layer. Using a glazing air gap of at least 1/2 inch decreases heat loss from direct-gain buildings, especially if night insulation is not used.

Effect of Overhangs

Overhangs are normally used in most passive solar applications to reduce summer overheating. If the overhang is properly designed, there is no blockage of the sun for most of the heating season, but almost entire blockage of the midsummer sun. Figures 69 and 70 show a simple, convenient scheme for determining the sun angles at noon on the summer solstice, winter solstice, and equinoxes. **Overhangs are in some ways more critical in Alaska than they are elsewhere** because our lower solar angles require exaggerated overhangs to achieve the desired amount of shading. Without proper shading, overheating can begin in March and April and continue through the summer. Fortunately, however, overheating in most of Alaska can be avoided by opening windows or venting.

Note that the glazing should not extend to the bottom of the overhang because the top portion of the window would receive direct sun only in midwinter, but would lose as much heat as any other part of the window.

If the overhang is in place during all of the year (fixed overhang) then the design of the angles becomes a tradeoff between a sacrifice of solar heating during the spring months (when the sun angles are high but the weather is still cold) and overheating during summer (when the sun angles are higher and temperatures are warm).

TABLE 15: REFLECTANCE VALUES FOR FIFTEEN CHARACTERISTIC SURFACES (INTEGRATED OVER SOLAR SPECTRUM AND ANGLE OF INCIDENCE).

Surface	Reflectance
1. Snow (freshly fallen or with ice film)	.70
2. Water surfaces (relatively large incidence angles)	.07
3. Soils (clay, loam, etc.)	.14
4. Earth roads	.04
5. Coniferous forest (winter)	.07
6. Forests in autumn, ripe field crops, plants	.26
7. Weathered blacktop	.10
8. Weathered concrete	.22
9. Dead leaves	.30
10. Dry grass	.20
11. Green grass	.26
12. Bituminous and gravel roof	.13
13. Crushed rock surface	.20
14. Building surfaces, dark (red brick, dark paints, etc.)	.27
15. Building surfaces, light (light brick, light paints, etc.)	.60

IMPORTANT: MURPHY'S LAW OF OVERHANGS:

> "Any overhang which has a very significant effect on reducing the cooling load also has a very significant effect on reducing the solar heating contribution."

An alternative to fixed shading is movable shading (such as awnings). This is awkward and not much favored by designers, but it is quite effective. The shade can be left on until late in the fall, thus substantially reducing overheating. The shade can then be taken off and left off until late in the spring after the heating season is over.

Another option is to use night insulation as shading. It allows a very simple and effective means of accommodating to the weather; it markedly improves performance during the winter and is especially effective at reducing summer overheating. Types of night insulation which are located **outside** the window are particularly effective for summer shading. If they are located inside the window, the designer must be particularly careful to avoid material damage associated with buildup

TABLE 16: REFLECTANCE VALUES FOR TWELVE REPRESENTATIVE WINTER LANDSCAPES.

Rural Areas	Reflectance
Fields with Snow Cover	
1. Field with wooded area in background	0.66-0.73
2. Open field (soil and dry grass) new road	0.61-0.70
3. Trees dispersed in field	0.62
Wooded Areas	
1. Conifer forest (with heavy snow cover)	0.61
2. Deciduous forest (with heavy snow cover)	0.72
Water	
1. Open water	0.16
2. Water covered with ice and snow	0.68
3. Partially open waterway (trees and houses in background)	0.43-0.66
Urban Areas	**Reflectance**
1. Commercial and institutional areas	0.16-0.38
2. Residential areas (dwelling and roadway)	0.21-0.45
3. Educational institution	0.36-0.42
4. Recreational area (park)	0.49

of heat between the glazing and the insulation by using a light-colored or reflective outer surface. Thermal stress breakage of glazing can also be a problem. Use of tempered glass will help reduce the likelihood of this occurring.

Effect of Ground Reflectance

The effect of ground reflectance on the performance of solar energy systems was mentioned previously in this manual (see section on active solar hot water heating). There is little doubt that the increased ground reflectance due to snow cover contributes significantly to useful solar radiation during the winter season at high latitudes. Willcut et al. (1975), in a study of Canadian locations, found that ground-reflected solar radiation can contribute 8 percent of the total annual usable energy. In Alaska, this fraction may be even higher because of the longer duration of snowcover and lower sun angles, causing more solar radiation to be reflected onto solar collection surfaces. Tables 15 and 16 show the reflectivity values for 15 different surface characteristics and twelve representative winter landscapes, respectively.

ESTIMATING THE BUILDING LOAD COEFFICIENT

The first step in the process is potentially difficult: obtaining an estimate of the thermal load of the building, even before the design is final. Accepted procedures that predict the heating load of buildings are described in the 1977 *ASHRAE Handbook of Fundamentals.* Given detailed knowledge of the building geometry and construction, they provide comprehensive estimates of each element of the heating load. They are customarily used during the construction documents phase of the design, to accompany detailed drawings and specifications.

This procedure provides little help to the designer during the design development phase of a project. It has two failings.

1. Detailed specifications of the building are not known. Windows have not yet been precisely sized, wall construction details have not yet been firmed up, and exact wall areas and building volumes are not yet known. Thus the input information required for a detailed design load calculation are unknown.

2. Few designers would take the time to go through this involved calculation. Design development is an iterative process, and a much faster procedure is needed if it is to be used.

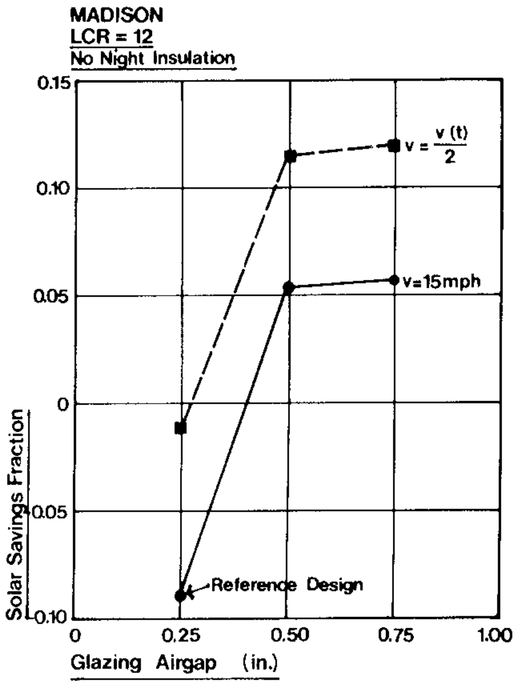


Figure 68. The effect of different values of air gaps between the double glazing layers and the effect of different assumptions of wind velocity on performance in Madison, Wisconsin (after Balcomb et al., 1980)

Quick and Dirty Heating Load Estimate

There is, therefore, a need for a "quick and dirty" method for estimating heating load. The procedure should take account of the important gross characteristics of the building that have been established prior to design development. These characteristics are: the building gross floor area and perimeter; the number of stories; the R-values of the walls and roof; whether the building is to be built with concrete slab on grade (i.e., no basement), over a basement, or over a crawl space; and a rough idea of the fraction of the wall area that will be allocated to windows.

The following procedure fills this need. It will give answers that are usually within 10 percent of the detailed ASHRAE heating load calculation, and it will show the relative contribution of the various important factors that make up the heating load.

In the process of calculating a heating load, a Building Load Coefficient (BLC) is determined. The primary use of the BLC is for estimating the solar savings of buildings heated by passive solar energy.

The procedure is not intended to be comprehensive, and it will not handle all situations. For example, it should not be used for underground structures. It is primarily intended for small buildings with skin-dominated loads (that is, dominated by heat loss by conduction and convection as opposed to loss dominated by air exchange, like large public buildings). It is not particularly appropriate for large buildings where the bulk of the heating energy is contributed from internal energy generation. It is by no means intended to substitute for a detailed ASHRAE heating load calculation, which should always be done during the construction documents phase. This procedure should only be used for rough thermal estimation during design development.

Calculating the Building Load Coefficient

The procedure consists of calculating several components of the Building Load Coefficient. It is based on Lower 48 experience and needs verification for Alaska. This coefficient is the additional heating that would be required to maintain a one degree Fahrenheit increase in the building inside temperature. For example, if the heat required to maintain the building at 70°F were determined to be 400,000 BTU/day, and the heat required to maintain the building at 71°F were determined to be 420,000 BTU/day, then the Building Load Coefficient is equal to the difference or 20,000 BTU/day for each °F (often expressed as 20,000 BTU/day·°F).

The procedure consists of adding together several estimated contributions of heat loss.

Start by making rough estimates of the combined area of all floors (ft^2) and the perimeter (the combined length in feet of all external walls at floor level). Then, either estimate the combined area of all east, west, and north windows, or use: nonsouth window area = (2/3) x (perimeter) x (ceiling height) x (nonsouth window fraction). The nonsouth window fraction will normally be between 0.05 (for a situation with minimum window area) and 0.10 for a case with standard window area.

Next, estimate the south (solar) window area being careful to *only include net exposed portion of the window.* (The rest doesn't contribute to solar gain!) The derivation of the following formulas is based on a simplified use of the ASHRAE-type heat loss approach. All

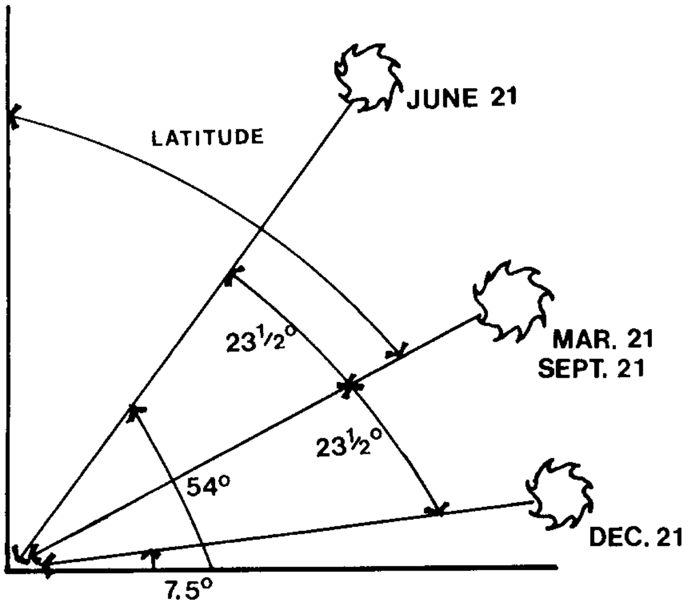


Figure 69a. The range of solar elevation angles at the latitude of Anchorage, Alaska (60°30'N). The maximum elevation is 56° on June 21, and the minimum is 7.5° on December 21.

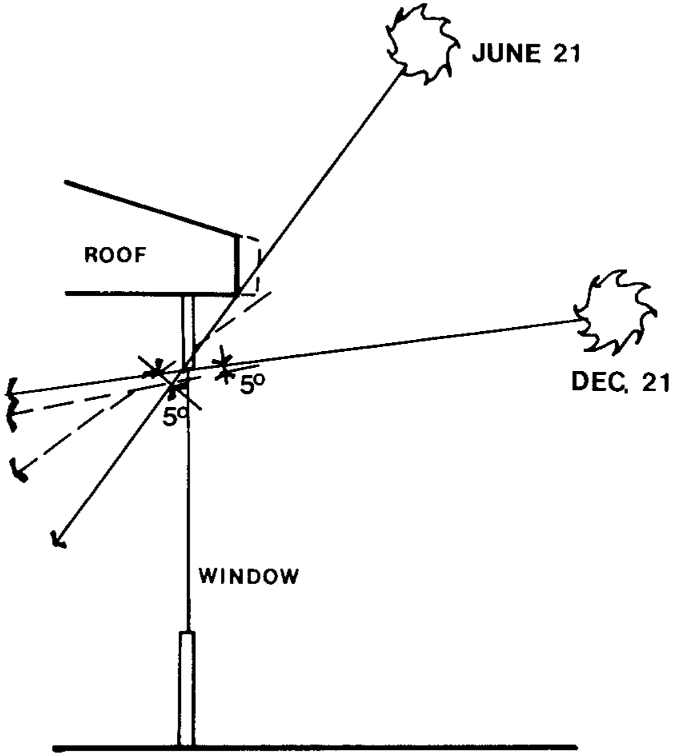


Figure 69b. Unlike the lower latitudes, a small overhang has little effect on shading the summer sun in Alaska. Larger overhangs are required in Alaska because of the lower solar elevation angles.

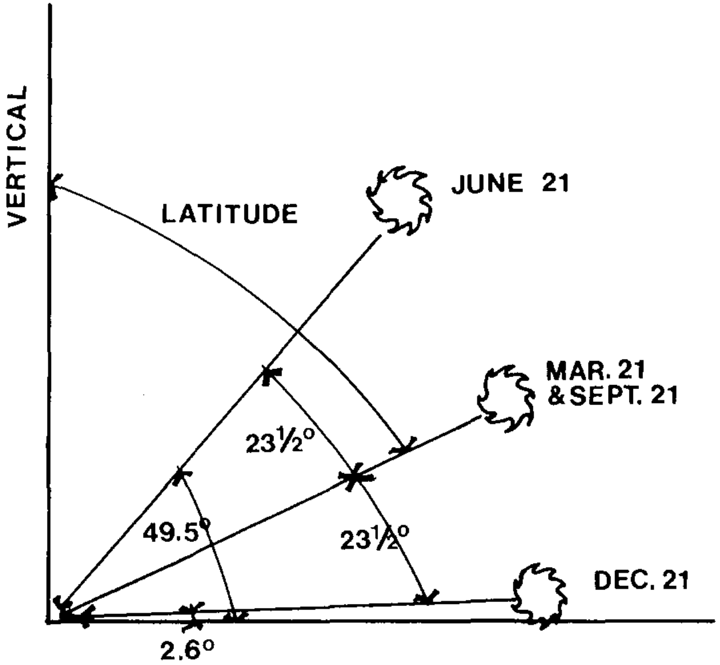


Figure 70a. The range of solar elevation angles at the latitude of Fairbanks (64°N). The maximum elevation is 49.5° on June 21, and the minimum is 2.6° on December 21.

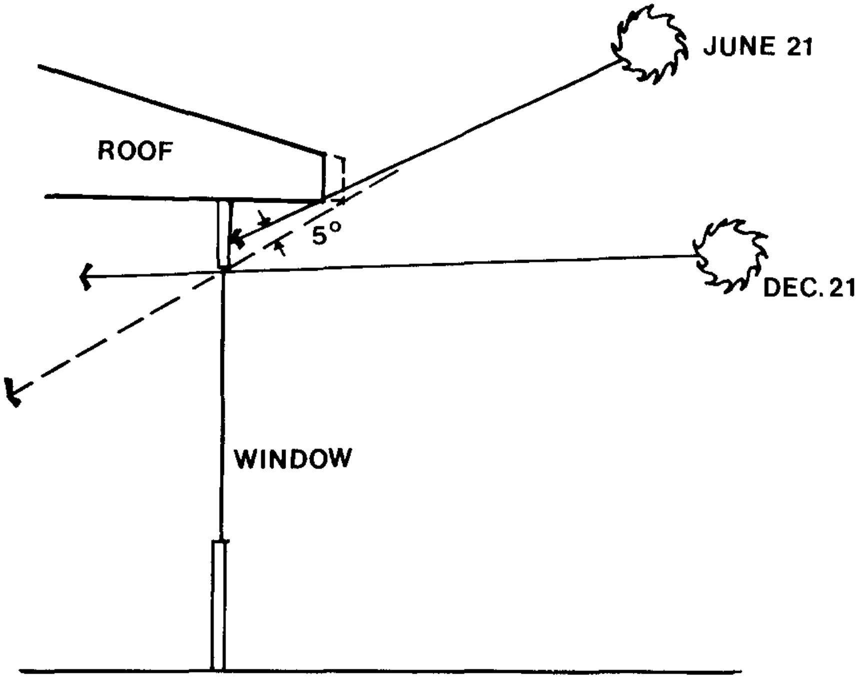


Figure 70b. Like Anchorage (Figure 69b), a small overhang in Fairbanks will not significantly alter summer solar gain on a window. A larger overhang is necessary because of the lower solar elevation angle.

terms contain a factor of 24 to convert from BTU/hr·^{o}F to BTU/day·^{o}F. The terms L_w, L_g, L_f, and L_r are simply 24 x U x A, where U is the U-value of the element (U is equal to 1/R) and A is the area of the element. For glazings, the approximation is made that U = 1.1/(number of glazings). For the perimeter and basement loss terms, the form is an approximation for rectangular slabs. So compute the following.

Walls

$$L_w = 24 \times \frac{\text{wall area}}{\text{R-value of walls}}$$

where wall area = (perimeter) x (ceiling height) - (nonsouth window area) - (south window area)

Nonsouth Window

$$L_g = 26 \times \frac{\text{nonsouth window area}}{\text{number of glazings}}$$

Perimeter (slab on grade)

$$L_p = 100 \times \frac{\text{length of foundation perimeter}}{\text{(R-value of perimeter insulation)} + 5}$$

Floor (over vented crawl space if present)

$$L_f = 24 \times \frac{\text{area of ground floor}}{\text{R-value of floor}}$$

Basement (heated basement or other fully earth-sheltered wall, including floor losses)

$$L_b = 256 \times \frac{\text{length of wall}}{\text{(R-value of wall insulation)} + 8}$$

Note: normally one of L_p, L_f, or L_b will apply.

Roof

$$L_r = 24 \times \frac{\text{roof area}}{\text{R-value of roof}}$$

Infiltration

L_i = (0.432) x (average air changes per hour) x (air density ratio) x (ceiling height) x (combined area of all floors) floors)

Add the appropriate components to obtain the final BLC estimate, for example:

$$BLC = L_w + L_g + L_r + L_p + L_i$$

Note that the solar glazing is not included in the calculation of the Building Load Coefficient. This is done for two reasons:

1. The solar glazing would not be present in a nonsolar building, which is the principal basis of comparison.

2. The solar wall is a net energy gainer (**with shutters!**), not a loser, and to represent it as part of the load would be misleading.

EXAMPLE: BUILDING LOAD COEFFICIENT

Here is an exemplary heat loss calculation using this method. The building is 1,000 square feet in floor area, well built (more insulation and better vapor barrier than average), 20 x 50 ft, slab on grade. The infiltration is 0.3 air changes per hour, and the walls have 7 inches of fiberglass in a 2 x 8 frame wall. The floor and perimeter are insulated with 2 inches of styrofoam. There are 60 ft^2 of nonsouth double-glazed windows, and the roof has 12-inch trusses with 11.0 inches of fiberglass. Ceilings are 8 feet high.

With this information, we can apply the previous equations. R-values are obtained from Appendix D.

Walls

$$L_w = \frac{24(1{,}120)}{24}$$

$$L_w = 1{,}120 \text{ BTU/}^{o}\text{F}\cdot\text{day}$$

Nonsouth window

$$L_g = \frac{(26 \times 60)}{1.24}$$

$$L_g = 848 \text{ BTU/}^{o}\text{F}\cdot\text{day}$$

Perimeter (slab on grade)

$$L_p = \frac{100 \times 140}{11.0 + 5} = 875$$

$$L_p = 875 \text{ BTU/}^{o}\text{F}\cdot\text{day}$$

(Only the perimeter heat loss applies since house is slab on grade.)

Roof

$$L_r = 24 \times \frac{1400}{37}$$

$$L_r = 908 \text{ BTU/}^{o}\text{F}\cdot\text{day}$$

Infiltration

$L_i = 0.432 \times 0.3 \times 8{,}000$

$L_i = 1{,}037 \text{ BTU}/^{\circ}\text{F}\cdot\text{day}$

Combining all these factors, we get the Building Load Coefficient estimate in units of BTUs per $^{\circ}$F·day.

L_w = 1,120
L_g = 848
L_p = 875
L_r = 908
L_i = 1,037

BLC = 4,788 BTU/$^{\circ}$F·day

This is a very good structure from a heat loss standpoint. Note, however, that this calculation neglects losses from south glazing. This assumption is critical for Alaskan applications because of the need for shuttering the south facade when heat from the sun is not available. Obviously, there will be some heat loss from the south glazing, and experience will further define its importance.

The contributions to the Building Load Coefficient from conduction through the walls, nonsouth glazing, and roof are all significant and roughly comparable in magnitude. A large contribution is associated with the heating of infiltration air. This deserves special comment.

INFILTRATION

During design development there is insufficient information available to estimate the building infiltration. The minimum value which might be selected will depend on one of two considerations.

1. The minimum air change rate recommended for small buildings is 1/2 air change per hour (ACH). Below this, the building becomes stuffy, odors build up, and humidity accumulation due to water use within the building may be a problem. Buildings with lower infiltration rates than this (for example the Saskatchewan House, the Phillips house in Aachen, Germany, and the Denmark Zero-Energy House) often employed forced ventilation with heat recovery units. Although this approach may be routinely used in large commercial buildings, it is only now being considered for smaller structures in Alaska (see Zarling, 1981).

2. The air infiltration rate associated with normal building construction is 1/2 ACH. To achieve a low infiltration rate requires meticulous attention to sealing all cracks where air might leak into or out of the building. Some applications may require much higher air exchange rates as a matter of building code requirements. For example, a restaurant or lounge might require 4 ACH during periods of occupancy, and many other commercial applications might also require high values. Fresh air must be provided in some manner. Tight structures, in particular, offer the occupant the benefit of minimal unwanted air infiltration; hence, one may control the amount of exhaust and makeup air required by ventilation. Ventilation is necessary for the following reasons.

a. To supply the proper amount of oxygen for the health of the occupants.

b. To supply the proper amount of oxygen necessary for combustion if open-flame furnaces, fireplaces, etc., are on the premises.

c. To dilute or eliminate excessive moisture in the air during the summer.

d. To dilute or eliminate odors generated in the lavatory, locker-room, and kitchen.

e. To dilute or remove the heat produced by internal sources during the summer.

In order to make energy-use projections for well-designed buildings, it is necessary to establish a reasonable level of ventilation. The level of ventilation will be determined for a 33 x 46 x 8.25 ft test house with a total volume of 12,557 ft^3. For example, assume that the house is a total-electric residence (no open flames) and is occupied by four people. This is the simplest example, and virtually all real situations are worse than this!

A primary concern is the respiratory requirement for the occupants of a house. Generally humans need 20 percent oxygen in the air. They can exist with 15 percent oxygen, but combustion will not occur. Death for humans will result with only 5 percent to 7 percent oxygen. Table 17 indicates human oxygen and air requirements for various activities.

If the four occupants are assumed to engage in activities of the 50 ft^3/min level for 16 hours per day and the 0.21 ft^3/min level for 8 hours per day, the minimum ventilation level for the house would be 2,343 ft^3/day. This requires a complete air change to the house only once every 5.5 days.

Yet energy codes state that the quantity of outdoor air introduced into spaces for normal respiratory and odor-control needs shall be no greater than 5 ft^3/min per person. With four occupants and 5 ft^3/min per occupant, the ventilation rate for a house is 29,240 ft^3 per day. This results in about 2.3 air changes per day.

Although data are unavailable for determining correct ventilation levels for odor and humidity control, some observations are useful. Data available for infiltration through window cracks and door openings indicate a ventilation level in a relatively tight house of approximately 2 air changes per day. Actual houses that fit these conditions show this is the minimal level for elimination of lingering odors, especially pungent cooking odors. The ventilation rate of 2 air changes per day is just below the code minimum of 2.33. A residence should have no less than 2 air changes per day. Until sufficient experience is gained in the ventilation of these houses, each should be analyzed before construction, and provisions should be made for increasing or decreasing ventilation as necessary.

Where open flames, including fireplaces, are present in well-sealed homes, increased ventilation must be provided. For purposes of energy conservation, combustion air should be ducted to furnaces or fireplaces from outside. As an alternate solution, delivery of heated makeup air (incoming fresh air) to the proximity of the fireplace may be considered. Ventilation may also be required for the removal of excess internal heat.

TABLE 17: OXYGEN AND AIR REQUIREMENTS OF HUMANS FOR VARIOUS ACTIVITIES.

Activity	Oxygen Consumed ft^3/min	Air Required ft^3/min
Sleeping	0.0075	0.188
Sitting	0.0094	0.219
Standing	0.0113	0.251
Walking - 2 mph	0.0204	0.439
Walking - 4 mph	0.0376	0.815
Jogging	0.063	1.348
Maximum exertion	0.094-0.125	2.04-3.13

ANALYSIS OF PASSIVE SOLAR GAIN

After the BLC is obtained, the passive solar gain must be calculated. We will use the method of Balcomb et al. (1980) as a guide for determining the monthly solar savings due to the passive design.

The calculations follow the format and tables included here. The method is laid out in a step-by-step fashion and requires two pages of work (Tables 18 and 20). First, we list the general steps which should be followed, in order to give the technique for general design. This general technique can be applied to most small structures (less than 3,000 ft^2). Structures larger than this are often more complex, and require a more detailed analysis. In order to more clearly show how a design performance calculation is done, a sample design problem is included in the next section.

This procedure takes into account actual unshaded solar window areas, orientations, tilts, and an estimate of building heat load. The principal values of the month-by-month method are that it provides explicit means of accounting for any effect that modifies the monthly profile of solar input (such as shading, etc.), and the effect of internal heat generation.

Here is the "recipe."

Monthly Solar Savings

STEP 1. Obtain the value of solar energy incident per square foot per day from Appendix B. Multiply it by the number of days in each month, and enter this result in column 1, Table 18.

TABLE 18: SOLAR RADIATION ABSORBED PER SQUARE FOOT BY MONTH.

Location ________

Aperture Type ______

Latitude ______

Collection Area (Ac) ______ ft^2

Column		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		VS x Days/Mon (VS Taken from Appendix B)	← **Factors** →						**Product of All Factors**	**S=(1)x(8)**
Mon	**L·D** (From) Table 22)	$\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2}$								$\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2}$
Sep										
Oct										
Nov										
Dec										
Jan										
Feb										
Mar										
Apr										
May										
Jun										

Many of the quantities used in this sequential calculation are given in Appendix E, where they are plotted as functions of latitude minus solar declination (L - D) at midmonth. Values of the latitude minus the solar declination are tabulated in Table 19 for Annette, Bethel, Fairbanks, and Matanuska. Enter the appropriate values in the column on Table 18.

STEP 2. Next apply those factors from the following list that pertain to the particular solar installation. Factors marked with a **superscript plus sign** should be considered for every solar heating system. Create additional factor columns in Table 18 if required. Label the headings of the columns used.

Orientation$^+$. From Figure E1 of Appendix E obtain the orientation factor for a vertical plane (tilt = 90°) at the appropriate azimuth. (South-facing glazing has azimuth = 0° and the factor is 1.00, so there would be little point in listing it.)

Tilt$^+$. Obtain the tilt factor from Appendix E. Tilt is the glazing angle measured from the horizontal. Vertical glazing has a tilt of 90° and the factor is 1.00.

Ground Reflectance. If the ground reflectance is known to be different from 0.3, obtain the **Ground Reflectance Factor** from Figure E7. This would be required, for example, when snow cover is present. See Tables 15 and 16 for reflectance values of different surface types.

Overhang. Figures E8 through E11 contain **Overhang Shadowing Factors.** The overhang is defined by two ratios. The overhang ratio (HR) is the horizontal projection of the overhang divided by the solar wall height. The separation ratio (SEPR) is the vertical spacing between the overhang and the top of the solar wall divided by the solar wall height. This is illustrated in Figure E15. Interpolation between figures will be necessary to obtain overhang factors for cases not calculated. All figures pertain only to south-facing vertical walls.

Transmittance$^+$. This is obtained for some geometries from Figures E12 through E15 of Appendix E. Figure E12 gives the **Transmittance Factor** for a vertical wall with various orientations from 0° (south facing) to 90° (east or west facing), while Figures E13, E14, and E15 have the wall tilted at 75°, 60°, and 45°, respectively, from horizontal and its azimuth varied from 0° to 90°.

Absorptance$^+$. Use an absorptance of 1.0 for a direct-gain room. This is the absorptance of the solar wall.

Site Shadowing. If the collection surface is shaded by trees or nearby build-

TABLE 19: MIDMONTH LATITUDE MINUS DECLINATION (L-D) AT FOUR ALASKAN SITES.

Location	Declination by Month Latitude	Jan -21.4°	Feb -14.0	Mar -2.8	Apr 9.1	May 18.6	Jun 23.1	Jul 21.4	Aug 14.0	Sep 2.8	Oct -9.1	Nov -18.6	Dec -23.1
Annette	55°2′N	76.4	69.0	57.8	45.9	36.4	31.9	33.6	41.0	52.2	64.1	73.6	78.1
Bethel	60°47′N	82.2	74.8	63.6	51.7	42.2	37.7	39.4	46.8	58.0	69.9	79.4	83.9
Fairbanks	64°49′N	86.2	78.8	67.6	55.7	46.2	41.7	43.4	50.8	62.0	73.9	83.4	87.9
Matanuska	61°34′N	82.9	75.6	64.4	52.5	42.9	38.5	40.2	47.6	58.8	70.7	80.2	84.7

TABLE 20: SOLAR SAVINGS FRACTION AND AUXILIARY ENERGY.

Column	(1) S	(2) DD	(3) S/DD	(4) Monthly SSF	(5) Q_{aux}
Source and Units / Month	From Column 9 of Table 18 $\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2}$	From Appendix B $\frac{\text{DD}}{\text{mon}}$	(1) ÷ (2) $\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2\cdot\text{DD}}$	From Figures 88 and 89 in Appendix E	[1-(4)] x(2) x BLC 10^6 BTU/mon
Sep					
Oct					
Nov					
Dec					
Jan					
Feb					
Mar					
Apr					
May					
Jun					
				Total	

Location ________

System ________

BLC ______ BTU/DD

DD ______ °F·day

LCR ______ BTU/DD·ft²

$$\text{Yearly SSF} = 1 - \frac{\Sigma(5)}{\text{BLC x DD}}$$

Yearly SSF = ______

Annual Auxiliary Heat

TABLE 21: SOLAR RADIATION ABSORBED PER SQUARE FOOT.

Location Anchorage

Aperture Type DGNI

Latitude 60°N

Collection Area (Ac) 200 ft^2

Column		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		VS x Days/Mon (VS Taken from Appendix B)	← Factors →						Product of All Factors	S=(1)x(8)
			Orientation	Ground Reflectance	Overhang	Trans-mittance				
Mon	L-D (From Table 22)	BTU mon·ft^2	Tilt=90° Azimuth=15°							BTU mon·ft^2
Sep	58	24,696	0.98	1.0	1.0	0.70			0.686	16,941
Oct	69.9	24,000	0.98	1.0	1.0	0.70			0.686	16,464
Nov	79.4	18,600	0.98	1.1	1.0	0.70			0.755	14,043
Dec	83.9	12,493	0.98	1.1	1.0	0.70			0.755	9,432
Jan	82.2	23,322	0.98	1.1	1.0	0.70			0.755	17,608
Feb	74.8	29,500	0.98	1.1	1.0	0.70			0.755	22,272
Mar	63.8	54,200	0.98	1.1	1.0	0.70			0.755	40,921
Apr	51.7	39,180	0.97	1.1	1.0	0.68			0.725	28,405
May	42.2	33,201	0.99	1.0	0.98	0.65			0.631	20,949
Jun	37.7	30,090	1.00	1.0	0.98	0.64			0.627	18,872

TABLE 22: SOLAR SAVINGS FRACTION AND AUXILIARY ENERGY.

Column	(1) S	(2) DD	(3) S/DD	(4) Monthly SSF	(5) Q_{aux}
Source and Units / Month	From Column 9 of Table 21 $\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2}$	From Appendix B $\frac{\text{DD}}{\text{mon}}$	(1) ÷ (2) $\frac{\text{BTU}}{\text{mon}\cdot\text{ft}^2\cdot\text{DD}}$	From Figures 88 and 89 in Appendix E	[1-(4)] x (2) x BLC 10^6 BTU/mon
Sep	16,941	518	32.7	0.53	1.165
Oct	16,464	947	17.4	0.26	3.355
Nov	14,043	1,328	10.6	0.11	5.659
Dec	9,432	1,627	5.8	0	7.790
Jan	17,608	1,645	10.7	0.11	7.009
Feb	22,272	1,285	17.3	0.27	4.491
Mar	40,921	1,240	33.0	0.54	2.731
Apr	28,405	859	33.0	0.54	1.891
May	20,949	558	37.5	0.55	1.202
Jun	18,872	302	62.5	0.82	0.260
				Total	35.553

Location Anchorage

System DGNI

BLC 4,788 BTU/DD

DD 11,000 °F·day

LCR 24 $\text{BTU/DD}\cdot\text{ft}^2$

$$\text{Yearly SSF} = 1 - \frac{\Sigma(5)}{\text{BLC} \times \text{DD}}$$

Yearly SSF = 32.5%

Annual Auxiliary Heat

ings, this factor is needed. See the discussion of solar geometry and shading in the section on active solar water heating.

STEP 3. Calculate the **Product of All Factors** and enter this in column 8.

STEP 4. Finally, calculate S, the **Solar Radiation Absorbed** per square foot of collection area per month. This number, placed in column 9, is the product of column 1 times column 8. The units are BTU/mo·ft^2. Check your values in Table 18 with those provided in Table 21, which is a worked example. These numbers should also be entered in column 1 of Table 20.

Annual Solar Savings Fraction

Using the results of the monthly solar heating contributions tabulated in Table 18, calculate the **Annual Solar Savings Fraction**, which is the annual percentage of the building's heating provided by the passive solar gain. Enter your work in Table 20.

STEP 1. Transcribe the **Solar Energy Absorbed per Square Foot per Month, S,** from Column 9 of Table 18 to Column 1 of Table 20.

STEP 2. Obtain from Appendix B the monthly heating **Degree Days for the Solar Building, DD**; place the values in Column 2. Note that both the yearly and monthly values of heating degree days are needed. Enter the yearly DD value in the second box on the right side of Table 20. Heating degree days can be found in the SOLMET data in Appendix B. Assume a base (inside) temperature of 65°F.

STEP 3. Form the quotients **S/DD** and enter these values in Column 3.

STEP 4. Calculate **LCR** and **Monthly SSF**. The **Load Collector Ratio, (LCR),** is calculated using this relationship: LCR = BLC/Ac, where Ac is the total collection area (i.e. south glazing). Enter LCR on Table 20.

Find the monthly **Solar Savings Fraction (SSF)** from Figures 70 or 71 for the appropriate type of solar system and LCR. In these figures, solar savings fraction is plotted against S/DD, with different curves for different values of the load collector ratio.

STEP 5. Calculate the monthly **Auxiliary Energy** required in the solar building. This is given by the following formula

$$Q_{aux} = (1 - SSF) \times (DD) \times (BLC)$$

With column numbers to represent the actual quantities, this equation is

$$Q_{aux} = [1 - (\text{column } 2)] \times (\text{column } 4) \times (BLC).$$

The 1 in the above equation is the numeral one; it does not refer to column numbers which are enclosed with parentheses. These figures should be divided by one million to produce convenient units of 10^6 BTU/mo. They are placed in Column 5.

STEP 6. Calculate the **Yearly Solar Savings Fraction (SSF)**. This is given by the following formula, which is located beside Table 20.

$$SSF = 1 - \frac{\Sigma Q_{aux}}{(BLC) \times (DD)}$$

This is the annual heating fraction provided to the structure by the direct gain passive system used in this example.

STEP 7. Check your values from Table 20 against those provided in Table 22.

EXAMPLE: DESIGN CALCULATIONS FOR A PASSIVE SOLAR BUILDING

Next, we do an example of the passive design process to help clarify any questions or uncertainties you may have about it. The example is the same building used in the calculation of the Building Load Coefficient (BLC). We simply work through this example and fill in the table as we go, so that you may better understand the process.

The structure for which we calculated the Building Load Coefficient is a 1,000 ft^2 structure with a BLC of 4,788 BTU/°F. Let us further assume that the solar aperture (glazed area on south wall) is 20 percent of the floor area (200 ft^2) and is insulated with R9 shutters at night. We wish to build the structure in Anchorage, where the average annual heating degree days are approximately 11,000. The south wall is vertical but faces south 15° west. If the window is one foot below the overhang, assuming an 8-foot window, this yields a separation ratio (Y/H) of 0.125. This result is obtained by referring to Figure E15 of Appendix E. The "overhang" is the ratio of the length of the overhang to its height, X/H, as in Figure E15, where x = 1 foot and H = 8 feet, so the overhang is 0.125. Tables 21 and 22 illustrate this example.

STEP 1. The first problem is that no listing of the L-D (latitude-declination) quantity is given in the text. But the latitude of Anchorage and Bethel are nearly identical. Since the quantity depends on the latitude only, the Bethel numbers can be used (Table 19).

Next, the solar radiation data are taken from Appendix B for Matanuska, which is the site closest to Anchorage for which data are available. Each month's value (Appendix B, column 2 - south) is multiplied by the number of days in that month. These values are entered in column 1 of Table 21. Note that the chart begins with September, but the solar data begin with January.

STEP 2. Next we note orientation. Since our solar aperture is a vertical south glazing, the tilt is 90°. The azimuth is south 15° west. Figure E1 in Appendix E gives us the values we need for this factor. Column 2 in Table 21 is labeled "Orientation" and the values from Figure E1 are entered in it.

STEP 3. The ground reflectance is assumed to be 0.6 for the months of November through April, and 0.3 for all other months. The difference is due to snow cover. Figure E6 in Appendix E gives the numbers as a function of latitude minus declination. These values are entered in column 3 of Table 21 and labeled "Ground Reflectance."

STEP 4. The overhang effects are small and the relevant chart is Figure E8 in Appendix E. These overhang effects are in column 4 of Table 21.

STEP 5. Transmittance values for this case are given in Figure E11 of Appendix E. Double glazing is assumed. The transmittance values are in column 5 of Table 21.

STEP 6. All the products are calculated, assuming an absorptance of 1.0 and no shadowing. The products are in column 8 of Table 21.

Next, the solar savings fraction and auxiliary energy requirements are calculated. First, the solar heat gain by month is transcribed from the first worksheet to Table 22. Then from Appendix B, the degree days for Anchorage (Matanuska is used) are entered in column 2 by month.

Column 3 in Table 22 is a simple division of the numbers in column 1 by those in column 2. Column 4 numbers are taken from Figure 71, for each monthly value of DD (column 3) and an LCR of 24 (LCR = 4,788/200 = 24).

For the final column, the monthly solar savings fractions are subtracted from 1.00 (not column 1!) and then multiplied by column 2 and the BLC (4,788 BTU/°F·day).

The yearly solar fraction is calculated by using 11,000 °F·day and 4,788 BTU/°F·day:

$$\text{SSF} = 1 - \frac{35.553}{52.668} = 1 - 0.675$$

$$\text{SSF} = 0.325 = 32.5\%$$

This analysis, therefore, shows that about 1/3 of the annual heating requirement of the structure in this example would be provided by passive solar heating. Blank worksheets like Tables 21 and 22 are included in Appendix G. They will be valuable for additional design problems and are provided so they may be photocopied.

ECONOMIC ANALYSIS OF PASSIVE SOLAR APPLICATIONS

This economic analysis is adapted from the discussion by Scott Noll and Dennis Barley in Balcomb et al. (1980).

Introduction

When someone who thought solar energy was free is discouraged from building a solar structure by the high initial expense, the subject of economics arises. There are two basic components to the cost of maintaining comfortable temperatures in any building.

1. Heat supply costs (fuel, for example).

2. Energy conservation costs (insulation, double-pane windows, etc.).

In a solar house, there are generally two sources of heat supply: the solar heating system, and a backup (or auxiliary) heating system. In this case there are three principal elements of the total cost.

1. Investment for solar heating system.

2. Investment for energy conservation.

3. Recurring cost of auxiliary heating.

These three cost elements are interrelated in such a way that any one of them can be decreased through an increase in one or both of the other two. The purpose of this chapter is to show how a designer can take the fullest possible advantage of this interrelationship.

Two aspects of this process are discussed: *cost evaluation* and *cost optimization*. Evaluation consists of determining the overall economic merit of a given design. In this chapter, life cycle cost (or life cycle savings) is used as a criterion. Optimization consists of manipulating the design variables to minimize the total cost.

It seems that most people associate the term "economics" with money. For an individual in the housing market, this may well be the predominant concern. The basic meaning of economics, however, pertains to the way in which resources are utilized. On a worldwide basis, the nature of the energy problem is physical—petroleum is in short supply, not dollar bills! The reason for raising this point is that we need to consider the resources that are consumed in constructing a solar heating system. If a particular system happens to consume more energy in construction than it subsequently saves in heating, no financial subsidy can alter the impact of the design on resource reserves. The methods presented in this chapter are given in two modes: *monetary* and *physical* economics.

Life Cycle Cost Equation

The total cost of supplying and conserving energy in a structure is expressed in the following equation. The three terms in this equation correspond to the three elements of cost previously listed (solar, conservation, and auxiliary), so that

$$LCC = (FC + A \cdot VC)E_1 + CC \cdot E_1 + L(1 - F)DD \cdot FP \cdot E_2/10^6$$

where LCC = uniform annual life cycle cost
FC = fixed cost of solar system (costs independent of collection area)
A = solar collection area (ft^2)
VC = variable cost of solar system per ft^2 of collection area
CC = conservation cost (insulation, etc.)
L = Building Load Coefficient (BTU/DD)
F = Solar Savings Fraction, SSF
DD = annual heating degree days
FP = auxiliary fuel price in the first year of operation

and E_1 and E_2 are economic parameters for converting initial costs and recurring costs to a common basis.

In considering monetary economics, LCC is expressed as a "uniform annual cost." This is the amount of an expenditure which, if repeated every year for a given number of years, is equivalent to a different nonuniform series of expenditures. Units for the various economic parameters are listed in Table 23. (For further explanation, see Appendices E, E1 and E2 of Balcomb et al. (1980).

In considering physical economics, we use the methodology presented by the Center for Advanced Computation at the University of Illinois. LCC has units of energy, corresponding to the energy resources embodied in an item. For example, about 4 BTU of energy are required to produce each BTU of electrical energy delivered to a heating load (includ-

TABLE 23: UNITS FOR MONETARY AND PHYSICAL ECONOMIC PARAMETERS.[1]

Parameter	Monetary	Physical
LC	\$/yr	MMBTU^p/yr
FC	\$	MMBTU^p
VC	\$/ft^2	MMBTU^p/ft^2
CC	\$	MMBTU^p
FP	\$/MMBTU	MMBTU^p/MMBTU
E_1 =	FCR (yr^{-1})	1/SL(yr^{-1})
E_2 =	FF	1

[1] SL = expected system life in years.

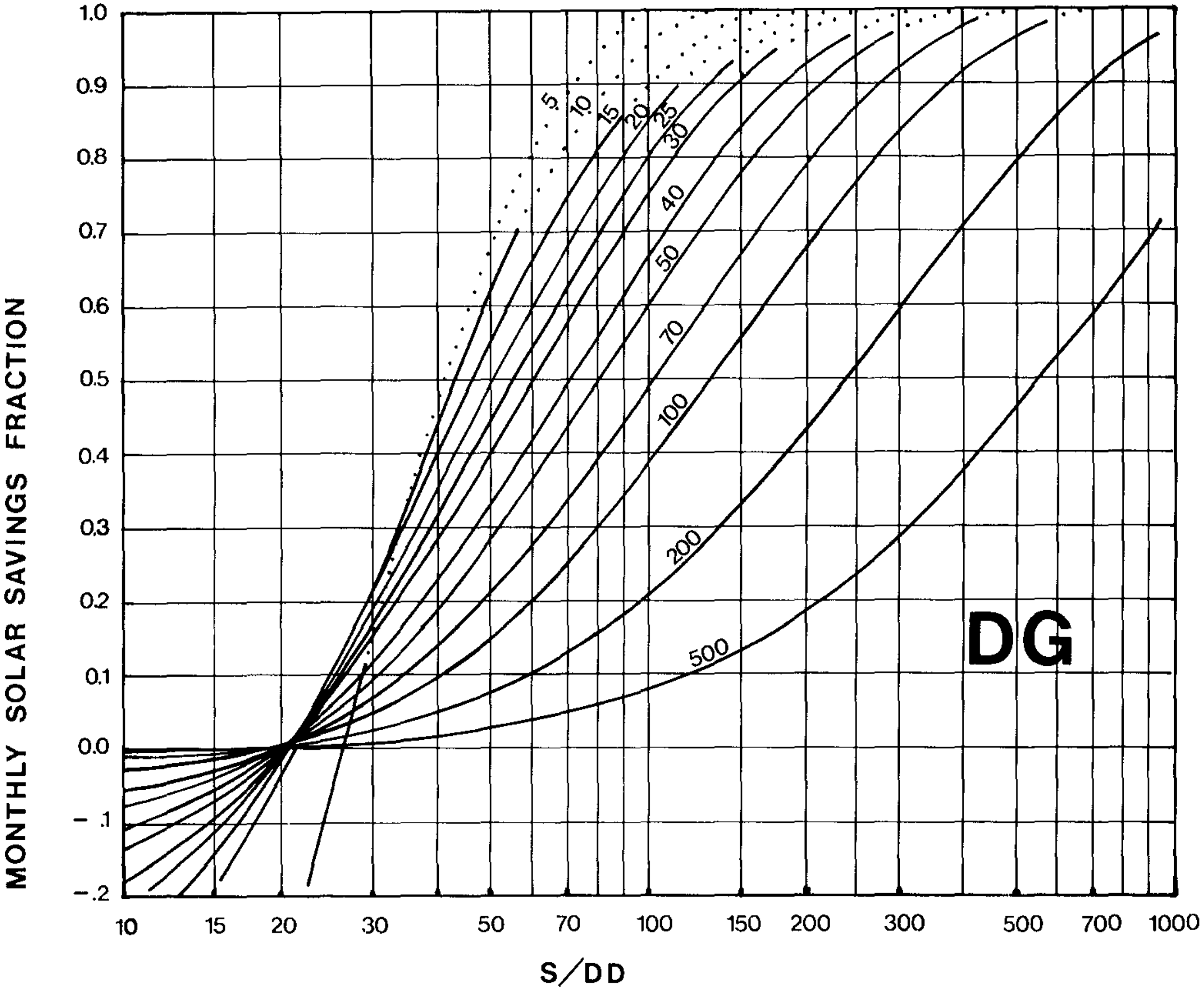


Figure 71. This figure enables the determination of the solar heating fraction for a direct gain (DG) passive solar building for a given load collector ratio (LCR). The LCRs are the numbers on the curves. The values of S/DD on the horizontal axis of the figure are determined in the passive solar design calculations, as in Table 20. These two values can then be used to determine the monthly solar heating fractions from this figure.

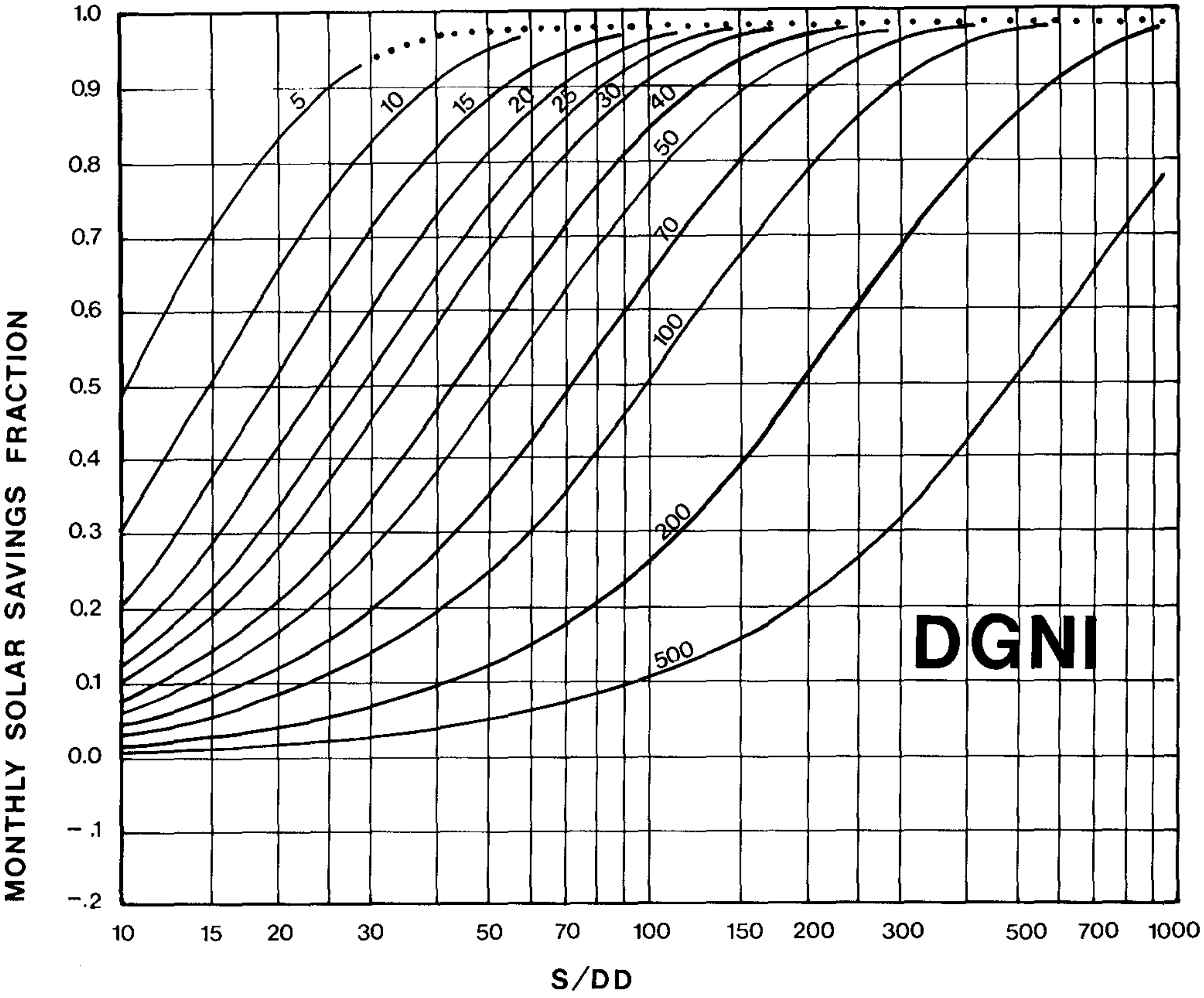


Figure 72. Similar to Figure 71, this curve is used if the passive solar building design is direct gain with night insulation (DGNI). The curves are labeled with the range of values for load collector ratio (LCR). The values of S/DD on the horizontal axis are determined from the design calculations, as in Table 20. These two values can then be used (find the point where they intersect) and the monthly solar savings fraction is read off the vertical axis.

ing power plant inefficiency, construction of transmission lines, etc.). So FP = 4 BTU^p/BTU, with BTU^p denoting primary energy resources.

Cost Evaluation

One component of a proper economic analysis is the accurate accounting or estimation of the initial costs of the design being evaluated. Where the physical components are easily separable and definable, standard procedures for estimating cost can be used with a fair degree of accuracy. With passive designs, it has been argued that separability is more difficult because many of the passive features are integral elements within the design of the building. In addition, collection and storage elements often provide a dual function which leads to confusion in terms of charges to be made and credits to be allowed.

To deal with these issues a simplified costing procedure is outlined below.

Categorization of costs. Costing is essentially a method of accounting, and the use of a consistent categorization scheme can help the designer/architect keep things organized. One such scheme, called the *functional elements approach*, assigns each item related to passive design to one of four functional categories: collection, storage, distribution, and controls. Two additional categories are called auxiliary heating equipment and building envelope construction (insulation features). Table 24 shows how various design elements fall into each of these categories.

Passive cost estimation. Once the design has been conceptualized, and the desired or

TABLE 24: FUNCTIONAL ELEMENTS OF PASSIVE SOLAR DESIGN.

Collection	Storage	Distribution	Controls	Auxiliary Heating Equipment	Envelope
1. Glazing	1. Containment	1. Ducting	1. Overhang	1. Ducted warm air a. Heat pump b. Resistance wire c. Furnace	1. Walls and ceiling
2. Framing	2. Material	2. Piping	2. Movable insulation	2. Hydronic radiators with boiler	2. Windows
3. Absorption	3. Support	3. Vents and dampers	3. Reflectors-glare control	3. Direct a. Zone electric resistance or radiant panels b. Combustion stove (wood, coal, oil, other) c. Fireplace	3. Doors
4. Reflectors		4. Blowers, pumps and fans	4. Mechanical/electrical a. Thermostats b. Timers c. Wiring		4. Infiltration
5. Support			5. Ancillary equipment		

available design options have been categorized by functional element as shown in Table 24, one must make or obtain cost estimates for each of the items. Common architectural practice is to state variable costs in unit terms: e.g., \$/linear foot (\$/ft), and \$/square foot of glazing or floor area ($\$/ft^2_g$ or $\$/ft^2_R$). In some instances, cost will be on a per-item basis and not vary with the size of the system. These are called fixed costs, and are stated in total terms. In addition, the unit or variable costs (VC) and fixed costs (FC) have both a materials and installation or labor component. Depending upon the circumstances, owner-builders may or may not want to account for their contributed labor.

Table 25 is a sample worksheet that can be used for costing purposes. The worksheet includes columns for the name of the item under consideration, a description of the item, the cost estimating unit (e.g., $\$/ft^2$), elements of cost, the amount desired, total cost, and additional notes.

Costing worksheets can be completed for each of the functional elements in the design. From these, the total cost of a variety of designs can be estimated and broken down into collector-area-dependent (variable) and collector-area-independent (fixed) cost components. In most passive applications, the majority of costs will depend upon collector area. In this way, active and passive costs are conceptually similar. This implies that one can design with either a small, moderate, or large amount of collector area (as a percent of floor area) and not be penalized with substantial fixed costs.

Envelope cost estimation. Increasing the levels of building insulation has the dual effect of increasing the building envelope construction costs while decreasing the annual heating requirements. In order to determine appropriate conservation construction measures, information is needed regarding the cost and thermal effectiveness of the various options available to the designer. For example, wall insulation options might include 3-1/2 inches (R11), 5-1/2 inches (R19), and 9-1/2 inches (R30) of fiberglass batt insulation at hypothetical costs of \$.57, \$.70, and \$.98 per square foot of wall area, respectively. Elements of the cost common to all conservation options need not be included in this accounting procedure (e.g., gypsum board, exterior sheathing, paint, etc., in the above example for walls). Cost information can be obtained from lumber yards, insulation contractors, and so forth.

Conventional cost estimation. In many instances, passive solar design elements (i.e., glazing) replace or augment various construction items that otherwise would have been installed. To arrive at the *add-on* costs attributable to the passive design, credit must be given for those items that were replaced or augmented. For instance, if "normal" construction practice were a 4-inch slab on grade, and a 6-inch slab were poured for direct gain thermal mass storage purposes, then only the additional 2 inches of slab should be counted as an *add-on* cost.

In the case of passive solar collection area, an allowance for the cost of the insulated wall displaced by the solar aperture should be deducted from the square-foot cost of the passive element. Table 26 lists some commonplace replacement credits that should be taken when estimating passive costs.

Final passive add-on cost estimates. Once the add-on costs and credits are specified (using Table 24 as one of many possible sample formats), a particular design can be selected and assigned cost parameters as follows:

VC = variable costs, in dollars per square foot of glazing ($\$/ft^2_g$), for passive solar add-on costs after allowance for replacement of conventional construction items.

FC = fixed costs (\$), after allowance for replacement of conventional construction items.

So, the net add-on construction cost for the passive design is calculated as

$$FC + (A \cdot VC).$$

Cost Optimization

The ability of individuals to optimize the three passive design considerations, the passive collection add-on costs, conservation costs, and backup auxiliary fuel costs is somewhat more limited in Alaska than elsewhere, due mainly to lack of experience in this optimization procedure, and the difficulty of obtaining realistic cost estimates and performance data. This cost optimization section is, therefore, terse and inadequate; ideally it should be a volume in itself. The reader is referred to Chapter H and Appendices E, E1, and E2 of Balcomb et al. (1980) for a treatment of the economics problem for passive systems. Several things should be emphasized

TABLE 25: COSTING WORKSHEET.

Project Number:
Design Description:
Location:
Calculated by:

Functional Element:

Sheet No. of
Date:

Item	Description	Cost Unit	Cost				Amount	Total Cost	Notes
			Mat.	Labor	O&P	Total			

TABLE 26: CONVENTIONAL CONSTRUCTION ITEMS COMMONLY REPLACED BY PASSIVE DESIGN ELEMENTS.

Functional Element	Passive Solar Feature	DISPLACED CONSTRUCTION FEATURES			
		Storage Wall	Storage Roof	Direct Gain	Attached Sunspace
Collection	Glazing and framing	Normal wood frame, concrete or masonry wall with insulation	None	Normal wood frame, concrete or masonry wall with insulation	None
Storage	Containment material	None	Roof structure replaced; interior and exterior walls replaced with load-bearing walls	Conventional slab on grade if augmented; interior walls replaced with mass	Adjoining exterior wall if made massive to provide storage
Distribution	Ducting, vents, dampers, blowers, pumps, and fans	None	None	None	None
Controls	Overhang, movable insulation, reflectors, mechanical/electrical	Replaced trim, drapes, etc.	None	Replaced trim, drapes, etc.	None
Auxiliary	Changes in the auxiliary heating system may allow changes in the conventional distribution and control items, in which case the extra costs or credits should be accounted for.				

TABLE 27: GEOGRAPHIC INDEX OF ENERGY AND CONSTRUCTION COSTS FOR ALASKA.

Geographic Area	Construction Cost Index	Fuel Cost Index
South Central		
Anchorage (base)	1.00	100.00
Anchorage zone	109.44	177.72
Village scenario (Cordova)	127.70	358.98
Kodiak Island	142.20	237.00
South Eastern		
Juneau	101.30	132.37
Juneau zone	109.74	175.70
Main center zone (Ketchikan, Wrangell, etc.)	129.05	166.35
Village scenario (Snettisham)	197.99	205.34
Sitka (Baranof Island)	142.00	153.05
Western		
Bethel	155.03	264.13
Large village scenario (Nome and Kotzebue)	176.40	297.23
Coastal village (Scammon Bay)	250.03	512.42
Southern Interior		
Fairbanks	102.13	135.33
Fairbanks zone	113.81	151.02
Village scenario (Galena)	214.70	361.54
Northern Interior		
Village scenario (Allakaket)	291.78	630.25
Arctic Slope		
Barrow	184.60	196.16
Coastal village (Point Lay)	255.65	338.94
Aleutian		
Village scenario (Cold Bay)	258.75	235.10

before leaving this subject.

As the fraction of the annual heating load provided by passive solar energy increases, the backup fuel cost decreases—but the relationship is not simple. Because the seasonal relationship between heating demand and available solar energy is not ideal, large increments of solar-collection area are needed to obtain increasingly smaller increments of the total building heat load. This is especially true in Alaska where the seasonal variation is so great.

Auxiliary heating costs are a continuing problem. Prices are so volatile that any projections of fuel cost escalation and future prices are subject to considerable uncertainty. Costs in Alaska were stable until the U.S. Department of Energy eliminated the cost advantage previously given to refineries utilizing North Slope crude oil. At that point (July 1980), costs rose 7 to 9¢ per gallon in most of the state. Although Alaska has its own supply of petroleum heating fuels, in 1981 they will all be tied to the world price directly, and will not be in the control of the state or its consumers. This has worrisome implications for future fuel cost estimates, and is especially foreboding to the rural areas of Alaska where fuel costs are already among the highest in the nation.

The cost of conservation additions to a structure (such as increasing the wall and insulation thickness from 6 to 9 inches) is dependent on both the cost of additional insulation *and* the cost of the *type* of construction used. Conservation costs are specific to the construction type. For this reason, they are analyzed by construction type for each insulation type in Appendix D.

Table 27 is a series of cost indices that enable the estimation of cost increments for fuels and electricity as well as estimated construction costs for many sites throughout Alaska. The index of comparison is based on the construction costs of a 7,500 ft^2 school. These costs include camp establishment and transportation costs for that school, so that *individuals* should note that their costs may be significantly lower. The relative comparisons are likely to be quite realistic for commercial construction.

If the cost of a structure or fuel at one of the main sites is known (Anchorage is the base with an index = 100, Fairbanks = 102.13, Juneau = 101.30), the index yields an estimate of the costs at the site of interest. The calculations were accurate for November 1980 and were done by James Strandberg, P.E., for the research section of the Alaska Department of Transportation and Public Facilities.

For example, we know the cost of gasoline in Fairbanks (say, $1.00 per gallon). We wish to know the cost of gas in Cold Bay. Since all fuel costs are indexed to Anchorage, we must convert the cost using the index for Fairbanks (135.33). To find the cost in Anchorage, multiply $1.00 by the ratio, 100.00/135.33, which yields $0.74 per gallon. To find the cost of gas in Cold Bay, multiply the Cold Bay index (235.10) times the calculated Anchorage base ($0.74), which equals $1.74 per gallon.

EXAMPLE: PASSIVE SOLAR COST ESTIMATION

This economic evaluation of passive solar and conservation design will focus on the (final) passive solar rural school design (a 900 ft^2 modular classroom) that was discussed earlier. The incremental cost of the passive solar design elements totalled $7,000 (windows and prompt wall). This cost must be prorated over the life of the building to obtain an annual cost for passive solar heating during the first year of operation.

The **annual cost method** is used to determine solar cost per year based on a capital recovery factor. The annual cost method is one common technique for estimating the amount of money needed each year to amortize an investment. It is determined by summing the total principal and interest to be paid during the term of amortization (mortgage term), and dividing that sum by the number of years over which the amortization is spread (commonly 10 to 30 years), yielding an annual cost. The capital recovery factor is obtained from engineering economics texts or amortization tables (see Grant, Ireson, and Leavenworth, 1976, for such amortization tables). By multiplying the initial investment by the appropriate factor, the annual cost can be easily obtained for any investment. The capital recovery factor is different for each interest rate and term of amortization. In this example, the capital recovery factor (CR) assumes a 12 percent interest rate over 20 years, so that

$$\begin{aligned}\text{Annual cost of solar heating} &= \$7{,}000 \times (\text{CR}) \\ &= \$7{,}000 \times (0.1339) \\ &= \$937/\text{year.}\end{aligned}$$

This structure should require 42,995,000 BTU during the first year. Contributions to this total would come from: fuel oil (21.5 percent); artificial lighting (25 percent); passive solar heating (45.7 percent); and human body heat (7.8 percent). Fuel oil burned at 65 percent efficiency would cost

$$\text{Oil heating cost} = \frac{9{,}243{,}925 \text{ BTU/year}}{89{,}700 \text{ BTU/gal}} \times \$1.50\text{/gal}$$

$$= 103 \text{ gal/year} \times \$1.50\text{/gal}$$

$$= \$155\text{/year}.$$

Electricity (produced at 15 percent efficiency from fuel oil) would provide 25 percent of the space heating from lighting and mechanical equipment at a cost of

$$\text{Electrical heating cost} = \frac{10{,}748{,}750 \text{ BTU/yr}}{138{,}000 \text{ BTU/gal}} \times (100\%/15\%) \times \$1.50\text{/gal}$$

$$= \$779\text{/year}.$$

Solar energy provides 19,648,715 heating BTU/year at an average annualized cost of $937 based on a 20-year lifetime. Thus in the first year, solar heating costs $47 per million BTU, oil heating costs $17 per million BTU, and electrical heating costs $72 per million BTU.

Solar space heating is conspicuously more expensive than oil heating in the first year, even if you include savings from the reduced need for electric lights. Solar heating has the equivalent cost of oil at $4.21 per gallon. Yet solar heating compares favorably with fuel oil over a 20-year building life. Table 28 shows that the cost of $4.21 per gallon of fuel oil equivalent is exceeded in the eighth year of the building's life. Table 29 demonstrates that this passive solar design will save $14,868 by initially investing $7,000. This illustrates the importance of looking at the entire life cycle costs of a structure, not only the first year operating costs. It appears at first glance that the passive solar design is very costly. But over the life of the building, fuel costs will inflate while the cost of passive solar energy will not. Thus, the passive solar design is a sound investment.

TABLE 28: INCREASES OF FUEL OIL COST OVER A 20-YEAR BUILDING LIFE BASED ON AN INITIAL COST OF $1.50 PER GALLON INFLATED AT 15 PERCENT PER YEAR.

Year	**Fuel Cost** (dollars per gallon)	**Cost Per Million BTUs (at 65 Percent Burning Efficiency)** (dollars per million BTUs)
1	1.50	16.72
2	1.73	19.28
3	1.98	22.07
4	2.28	25.41
5	2.62	29.20
6	3.01	33.55
7	3.46	38.57
8	3.99	44.48
9	4.58	51.05
10	5.25	58.52
11	6.06	67.55
12	6.97	77.70
13	8.02	89.40
14	9.22	102.78
15	10.61	118.28
16	12.20	136.00
17	14.03	156.41
18	16.14	179.93
19	18.56	206.91
20	21.34	237.90

TABLE 29: HEATING COSTS (IN DOLLARS) WITH AND WITHOUT PASSIVE SOLAR HEATING OVER A 20-YEAR BUILDING LIFE. COSTS ARE SEPARATED BY HEATING SOURCE, AND RELATIVE CONTRIBUTIONS ARE GIVEN IN PERCENT.

Heating Source	**Passive Solar 45.7%**	**Fuel Oil 21.5%**	**Lighting 25%**	**Body Heat 7.8%**	**Additional Fuel Oil Needed Without Passive Solar 45.7%**	**Grand Total Heating Costs over 20 Years**
Calculation	Calculated by multiplying annualized cost times term of mortgage. Thus 937 x 20 = 18,740.	Calculated by multiplying the fuel costs from Table 29 times the amount of oil needed to supply 21.5% of annual heating needs (103 gallons). This is calculated for each year, and these costs are totalled for the term of the mortgage.	Calculated by taking the ratio of electrical to fuel oil heating costs from first year and multiplying by the total cost of fuel oil for 20 years. Thus 779/155 x 14,829 = 74,522.	Free	Calculated by multiplying the fuel costs from Table 28 times the amount of oil needed to supply 45.7% of annual heating needs (520 gallons). This is calculated for each year, and the costs are totalled for the term of the mortgage.	
Cost with Passive Solar	18,740	14,829	74,522	0	–	**108,091**
Cost without Passive Solar	–	14,829	74,522	0	33,602	**122,953**

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appendices

APPENDIX A : ANALYSIS METHODS FOR SOLAR HEATING AND COOLING APPLICATIONS

The following table describes solar heating and cooling manual design methods. This table does not give all of the design methods applicable to SHAC analysis, but it does contain the most currently used and best known methods. These methods do not require access to a computer although some (e.g., F-CHART) have been implemented on computers. They vary in degree of sophistication from the simple, almost rule-of-thumb type to methods requiring programmable calculators. Some of the latter type methods are available from the source indicated as prerecorded programs on magnetic cards.

Description	Author	Availability			Applications									Tools Required					Output			
					Active				Passive													
		Cost ($)	Date	Reference/Source	Space Heating	Domestic Hot Water	Liquid Collector	Air Collector	Direct Gain	Thermal Storage Wall	Attached Sunspace	Thermal Storage Roof	Convective Loop	Tables/ Graphs	4 Function Calculator	Scientific Calculator	Programmable Calculator		Solar Fraction	Optimum Area	Economic Analysis	Other
A Simplified Method for Calculating Solar Collector Array Size for Space Heating	J. D. Balcomb J. C. Hedstrom		1976	Sharing the Sun: Solar Technology in the Seventies Vol 4. American Section, International Solar Energy Society. 1976. pp 281-284.	●	●	●	●						●	●					●		
Passive Solar Design Handbook SLR Method	J. D Balcomb Bruce Anderson	14	1980	NTIS 5285 Port Royal Road Springfield, VA 22161					●	●	△			●	●				●	●	●	
Predicting the performance of Solar Energy Systems	U.S Army Construction Engineering Research Lab		1977	Rept No AD-A035 608/9 ST (NTIS)	●	●	●	●						●	●				●	●	●	
Copper Brass Bronze Design Handbook —Solar Energy Systems	Copper Development Association	3	1978	Copper Development Association, Inc 1011 High Ridge Road Stamford, CN 06905	●		●	●						●	●				●			
Copper Brass Bronze Technical Report: How to Design and Build a Swimming Pool Heater	Cooper Development Association	Free	1978	Copper Development Association, Inc			●							●	●				●		●	
PEGFIX and PEGFLOAT	W Glennie	75 both	1978	Princeton Energy Group 729 Alexander Road Princeton, NJ 08540 (609) 452-8235					●		●						●					●
IMPSLR interactive SLR	PEG	250	1980	Princeton Energy Group					●	●								●	●			
NEATWORK thermal network	PEG	250	1980	Princeton Energy Group					●	●								●	●			●
PEGSOL two-zone	PEG	400	1980	Princeton Energy Group					●	●	●							●	●			●
Solarcon Programs for Comprehensive Active System Design (5 programs & 5 sets, weather data) (5 Insolation models)	R W Graeff	383 data	1977	Solarcon, Inc 607 Church Street Ann Arbor, MI 48104 (313) 769-6588	●	●	●	●								●	●	●	●		●	
Solarcon Programs for Passive System Design (5 programs & 5 sets, weather data)	R W Graeff	495	1979	Solarcon, Inc					●	●							●	●	●			
Solar Heating Systems Design Manual	ITT Corporation Fluid Handling Division	2 50	1977	Bulletin TESE-576, Rev 1 ITT Training & Education Dept Fluid Handling Division Morton Grove, IL 60053	●	●	●	●						●	●				●			
A General Design Method for Closed-Loop Solar Energy Systems	S. A. Klein W. A. Beckman		1977	Proceedings of the 1977 Annual Meeting, Vol 1, American Section, International Solar Energy Society, 1977, pp 8.1-8.5			●							●		●			●			
Solar Heating Design by the F-CHART Method	S. A. Klein, W. A. Beckman, J. A Duffie	10	1977	John Wiley and Sons, New York, N.Y., 1977 (Publisher)	●	●	●	●						●	●				●		●	
TEANET thermal network model	J T Kohler P. W. Sullivan	95	1978	Total Environmental Action, Inc Church Hill Harrisville, NH 03450 (603) 827-3374					●	●	●	●	●				●					●
The GFL Method for Sizing Solar Energy Space and Water Heating Systems	G F Lameiro P Bendt		1978	Rept No SERI-30 Solar Energy Research Institute 1617 Cole Boulevard Golden, CO 80401	●	●	●	●						●		●			●			
A Rational Procedure for Predicting the Long-Term Average Performance of Flat-Plate Solar Energy Collectors	B Y H Liu R C Jordan		1963	Solar Energy, Vol 7, No 2, 1963, pp. 53-70	●	●	●	●						●		●			●			
Pacific Regional Solar Heating Handbook	Los Alamos Scientific Lab		1976	Rept No TID-27630 (NTIS)	●	●	●	●						●		●			●			

McClintock Corp	R McClintock	195 Therm alone, 175, econ anal alone, 75	1977	McClintock Corp P O Box 430980 Miami, FL 33143 (305) 666-1300	●	●	●	●									●	●	●	●	●	
Minimum Cost Sizing of Solar Heating Systems	J C Ward		1976	Sharing the Sun. Vol 4 1976 pp 336-348	●	●	●	●						●		●			●	●	●	
Designing and Building a Solar House Your Place in the Sun	D Watson	9	1977	Garden Way Publishing Charlotte, VT 05445	●	●	●	●						●	●				●		●	
Optimal Sizing of Solar Collectors by the Method of Relative Areas	C D Barley C B Winn	95	1978	Solar Environmental Engr Co Inc	●	●	●	●						●		●				●	●	
SEEC I--Heat Load, Monthly Solar Fraction, Economics (F-CHART)	C B Winn	125	1976	Solar Environmental Engineering Co., Inc. 2524 East Vine Drive Fort Collins, CO 80524 (303) 221-5166	●	●	●	●									●	●	●		●	
SEEC II--Collector Optimization, Annual Solar Fraction, Economics	C B Winn D Barley G Johnson J Leflar	95	1978	Solar Environmental Engineering Co., Inc.	●	●	●	●									●		●	●	●	
SEEC III-SEEC II Plus Insulation Optimization	C B Winn D Barley G Johnson J Leflar	125 (Calculator version)	1978	Solar Environmental Engineering Co., Inc	●	●	●	●									●		●	●	●	
SEEC IV--Collector Heat Exchanger Sizing and Analysis	C Byron Winn J Leflar	95	1978	Solar Environmental Engineering Co., Inc	●	●	●										●					●
SEEC V--Duct design and Air Flow Analysis	J Leflar	95	1978	Solar Environmental Engineering Co., Inc	●			●									●					●
SEEC VI--Passive Solar Heating	K. Sharp	125	1978	Solar Environmental Engineering Co., Inc					●	●							●	●	●	●	●	
SEEC VII--Sun Angles and Shading	K. Sharp	75	1979	Solar Environmental Engineering Co., Inc													●					●
SEEC VIII Swimming Pools	P. Jacobs K Sharp	125	1980	Solar Environmental Engineering Co., Inc			●										●		●	●	●	●
Sunshine Power Programs for Modeling Solar Energy Components and Systems Solar Energy Library (9 programs)	G [illegible]		1977	Sunshine Power Co 1018 Lancer Drive San Jose CA 95129 (408) 446-2446	●	●	●	●									●		●			
Mazria Design Patterns (Rule-of-Thumb) in The Passive Solar Energy Book	Edward Mazria	11	1979	Rodale Press Emmaus PA 18049					●	●	●	●	●	●					●	●		
PASCALC Los Alamos SLR	[illegible]	PASCALC therm., 75 econ., 20	1979	Total Environmental Action, Inc Church Hill Harrisville NH 03450					●	●	●						●		●	●	●	
SOLARGRAF/DHW nomographs	W Wright	10	1980	Northeast Solar Energy Center 470 Atlantic Ave. Boston, MA 02110		●	●	●						●	●				●			
SOLARGRAF/SLR nomographs	W. Wright	10	1980	Northeast Solar Energy Center					●	●				●	●				●			
SUN-PULSE II	G. Tully	100	1980	McGraw-Hill Book Company P O Box 400 Hightstown, NJ 08520	●	●	●	●	●	●							●		●			●
G-CHART	SEDCLA	25 + tax	1979	Solar Energy Design Corp of America	●	●	●	●						●		●			●		●	
P-CHART SLR nomograph	SEDCLA	20 + tax	1980	Solar Energy Design Corp of America					●	●				●	●				●	●	●	
Solar Energy Programs	S A Klein W A Beckman	40	1980	F-CHART P O Box 5562 Madison, WI 53705	●	●	●	●	●								●		●		●	●
PASODEI SLR	L-P-M	300	1980	Londe-Parker-Michels Inc Mr Steve Andes 7438 Forsyth, Suite 202 St Louis, MO (314) 725-5501					●	●	●							●	●	●	●	
OVERHANG shading	L-P-M	350	1980	Londe-Parker-Michels Inc														●				●
EXFIND hour sim. Trombe	L-P-M	300	1980	Londe-Parker-Michels, Inc						●	●							●				●
INSULATE econ. optimized	L-P-M	300	1980	Londe-Parker-Michels Inc														●				●
LPMTZ two-zone passive	L-P-M	1500	1980	Londe-Parker-Michels Inc					●	●	●							●	●			

Δ McFarland, R. D. and Jones, R. W., "Performance Estimates for Attached-Sunspace Passive Solar Heated Buildings." Proc. 1980 AS/ISES, Vol. 3.2, pp. 784-788, Phoenix, AZ, June 1980.

Program Name	Latest Version	Availability				Application							Intended Users			Computation Interval		Computer Versions Available	Economic Analysis	Sponsor
		Purchase ($)	Time Share	Special Arrangements	Comments	User Manual	Service Hot Water	Space Heating	Space Cooling	Process Heat	Active System	Passive System	Research Engineers	Architect/Engineers	Builders	Hour	Month			
BLAST*	1980	Nom.	●		Training available	●	●	●	●		●	●	●	●		●		CDC	●	USAF, USA, GSA
DEROB	1979	200				●		●	●			●	●	●		●		CDC		NSF, ERDA, DOE
DOE-2*	1980	400	●			●	●	●	●		●	●	●	●		●		CDC	●	LASL, DOE
EMPSS	1978	500		●	Consulting with ADL	●	●	●	●		●	△	●	●		●		IBM	●	EPRI
F-CHART	1978	100	●		Training available	●	●	●			●			●	●		●	CDC, IBM UNIVAC †	●	DOE
FREHEAT	1979	150			Limited documentation			●				●	●			●		CDC	●	DOE
HISPER	1978	Avail. on request			Limited documentation	△	●	●	●		●		●			●		UNIVAC PDP		NASA, MSFC
HUD-RSVP/2	1979	175	●		Based on F-CHART	●	●	●			●			●	●		●	CDC UNIVAC	●	HUD
PACE	1980	100	●		Based on F-CHART, SLR	●	●	●			●	●		●	●		●	CDC UNIVAC	●	DOE, SERI
SHASP	1978	Avail. on request				●	●	●	●		●		●			●		UNIVAC	●	DOE
SOLAR-5	1979		●		Not Distributed			●	●			●		●	●	●	●	CDC		UCLA, DOE
SOLCOST	1979	300	●			●	●	●			●	●	●	●	●		●	CDC, IBM UNIVAC	●	DOE
SOLFIN 2	1980	Nom.		●	Documentation Cost $6.	●	●	●	●	●	●	●	●	●	●	Annual		IBM, CDC	●	California Energy Commission
SOLOPT	1978	20				●	●	●			●		●				●	AMDAHL	●	Texas A&M Univ.
SOLTES	1979	175			No Cost for DOE	●	●	●	●	●	●		●			●		CDC		DOE, Sandia
SUNCAT	1979	Nom.			Limited documentation	●		●				●	●	●		●		Data General Eclipse	●	NCAT
SUNSYM®	1979		●	●	Offered as service only	●	●	●	●		●			●		●		IBM	●	Sunworks Comp. Systems
SYRSOL	1978	Nom.			Avail. but not actively marketed		●	●	●		●		●	●	●	●		IBM	●	ERDA, NSF, DOE
TRACE SOLAR*	1980		●	●	Offered as service only	●	●	●	●	●	●		●	●		●	●	IBM	●	The Trane Co.
TRNSYS	1979	200	●		Training required	●	●	●	●	●	●	●	●			●		CDC, IBM UNIVAC †	△	DOE
TWO ZONE	1977	No Charge		●		●		●	●		●	●	●			●		CDC	●	LBL
UWENSOL	1980	200				●		●				●	●			●		CDC		State of Wash.
WATSUN II, III	1980	Contact Author				●	●	●			●		●			●		IBM	●	Nat'l Research Center of Can.

*Programs are primarily developed for large-scale, multi-zone applications

△ Being added

† ANSI 1966 Std. Fortran

APPENDIX B : 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 $langleys/BTU/ft^2$.

TABLE B1: ANNETTE SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days $^{\circ}$F·day	Mean Temperature $^{\circ}$F
	Horizontal Surface	Vertical Surface South	Vertical Surface East/West	Vertical Surface 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 $^{\circ}$F·day	Mean Temperature $^{\circ}$F
	Horizontal Surface	Vertical Surface South	Vertical Surface East/West	Vertical Surface 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 $^{\circ}$F·day	Mean Temperature $^{\circ}$F
	Horizontal Surface	Vertical Surface South	Vertical Surface East/West	Vertical Surface 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 $^{\circ}$F·day	Mean Temperature $^{\circ}$F
	Horizontal Surface	Vertical Surface South	Vertical Surface East/West	Vertical Surface 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.

TABLE B5: FAIRBANKS 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	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·ft^2				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·ft^2				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·ft^2				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.

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	Vertical Surface East/West	Vertical Surface 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	Vertical Surface East/West	Vertical Surface 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	Vertical Surface East/West	Vertical Surface 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	Vertical Surface East/West	Vertical Surface 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	346.5	261.9	20.9	10,847	35.0

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

TABLE B13: McGRATH SOLMET DATA.

Month	Incident Solar Radiation, BTU/day·ft^2				Degree Days	Mean Temperature
	Horizontal Surface	Vertical Surface			°F·day	°F
		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·ft^2				Degree Days	Mean Temperature
	Horizontal Surface	Vertical Surface			°F·day	°F
		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·ft^2				Degree Days	Mean Temperature
	Horizontal Surface	Vertical Surface			°F·day	°F
		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.

APPENDIX C : A GLOSSARY OF SOLAR ENERGY TERMS

absorbent – the less volatile of the two working fluids in an absorption cooling device.

absorber – the surface in a collector that absorbs solar radiation and converts it to heat energy; generally a matte black metallic surface is best.

absorption chiller – air conditioning device which uses heat at 190°F or higher to generate cooling; it may be powered by solar-heated water.

absorptivity – the ratio of the energy absorbed by a surface to the energy absorbed by a black body at the same temperature.

active solar energy systems – in contrast to passive solar energy approaches, an active solar energy system utilizes outside energy to operate the system, to transfer the collected solar energy from the collector to storage, and to distribute it throughout the living unit. Active systems can provide space heating and cooling and domestic hot water.

airlock entry – a vestibule enclosed with two airtight doors; it reduces heat loss by limiting the movement of heated air.

air-type collector – a collector that uses air for heat transfer.

altitude – the angular distance from the horizon to the sun.

ambient temperature – the natural temperature surrounding an object; it usually refers to outdoor temperature.

atrium – a closed interior court to which other rooms open; it is often used for passive solar collection.

auxiliary energy – auxiliary heat plus the energy required to operate pumps, blowers, or other devices.

auxiliary heat – the heat provided by a conventional heating system for periods of cloudiness or intense cold, when a solar heating system cannot provide enough heat.

azimuth – the angular distance from true south to the point on the horizon directly below the sun.

backup energy system – a backup energy system using conventional fuels should be provided for heating and domestic hot water. This system should be capable of providing all of the energy demand during any period when the solar energy system is not operating. Components and subsystems may be used as parts of both systems where the component or subsystem is a recognized, acceptable product in the conventional building industry.

berm – see earth berm.

British thermal unit (BTU) – a unit of heat; the quantity needed to raise the temperature of one pound of water one degree Fahrenheit.

building envelope – the elements (walls, roof, floors) of a building which enclose conditioned spaces.

clerestory – a window located high in a wall near the eaves, used for light, heat gain, and ventilation.

coefficient of heat transmission – the rate of heat transmission measured per degree of temperature difference per hour, through a square foot of wall or other building surface. It is usually called the U-value.

collection – the process of trapping solar radiation and converting it to heat.

collector – a device which collects solar radiation and converts it to heat.

collector aperture – the glazed opening in a collector which admits solar radiation.

collector efficiency – the ratio of the heat energy extracted from a collector to the solar energy striking it.

collector tilt – the angle between the horizontal plane and the solar collector plane, designed to maximize the collection of solar radiation.

comfort zone – the range of temperature and humidity in which most people feel comfortable.

concentrating collector – a collector with a lens or a reflector that concentrates the sun's rays on a relatively small absorber surface.

conduction – the flow of heat between a hotter material and a colder material that are in direct physical contact.

conductivity – the property of a material indicating the quantity of heat that will flow through one foot of a material for each degree of temperature difference.

convection, forced – commonly, the transfer of heat by the forced flow of air or water.

convection, natural – the motion of a gas or liquid, caused by temperature or density difference, by which heat is transported.

cooling pond – a large body of water that loses heat from its surface, largely by evaporation but also by convection and radiation.

cooling tower – a device for cooling water by evaporation.

cover plate – a layer of glass or transparent plastic placed above the absorber plate in a flat-plate collector to reduce heat losses.

damper – a control which permits, prevents, or controls the passage of air through a duct.

degree day – a unit of measurement for outside temperature; it is the difference between a fixed temperature (usually 65°F [18°C]) and the average temperature for the day.

design heating load — the total heat loss from a building under the most severe winter conditions likely to occur.

design outside temperature — the lowest outdoor temperature expected during a heating season.

diffuse radiation — indirect scattered sunlight which casts no shadow.

direct radiation — sunlight which casts shadows, also called beam radiation.

direct solar gain — a type of passive solar heating system in which solar radiation passes through the south-facing living space before being stored in the thermal mass for long-term heating.

distribution — the movement of collected heat to the living areas from collectors or storage.

diurnal temperature range — the variation in outdoor temperature between day and night.

double-glazed — covered by two layers of glazing material (commonly, glass or plastic).

double-walled heat exchanger — a heat exchanger which separates the collector fluid from the potable water by two surfaces; it is required if the collector fluid is non-potable.

drainback — a type of liquid heating system which is designed to drain into a tank when the pump is off.

draindown — a type of liquid heating system which protects collectors from freezing by automatically draining when the pump is turned off.

earth berm — a mound of dirt that abuts a building wall to stabilize interior temperature or to deflect the wind.

emissivity — the ratio of the energy radiated by a body to the energy radiated by a black body at the same temperature.

energy audit — an accounting of the forms of energy used during a designated period, such as monthly.

eutectic salts — a mixture of two or more pure materials which melts at a constant temperature; a material which stores large amounts of latent heat.

evaporative cooling — a method of space conditioning which requires the addition of bodies of water or of moisture for cooling the living spaces.

fan coil — a unit consisting of a fan and a heat exchanger which transfers heat from liquid to air (or vice versa); usually located in a duct.

flat-plate collector — a solar collection device in which sunlight is converted to heat on a flat surface; air or liquid flows through the collector to remove the heat.

flywheel effect — the damping of interior temperature fluctuations by massive construction. (See diurnal.)

forced-air heat — a conventional heating distribution system which uses a blower to circulate heated air.

galvanic corrosion — the deterioration of tanks, pipes, or pumps, which occurs when a conducting liquid permits electrical contact between two different metals, causing the more active metal to corrode.

Glauber's salts — a term for sodium sulfate decahydrate, which melts at 90°F; a component of eutectic salts.

glazing — a material which is translucent or transparent to solar radiation.

greenhouse — in passive solar design, an attached glazed area from which heat is withdrawn to the living space during the day.

heat capacity (specific heat) — the quantity of heat required to raise the temperature of a given mass of a substance one degree F.

heat exchanger — a device which transfers heat from one fluid to another.

heat gain — as applied to heating or cooling load, that amount of heat gained by a space from all sources (including people, lights, machines, sunshine, etc.).

heat pump — an electrically operated machine for heating and cooling; when heating, it transfers heat from one medium at a lower temperature (called the heat source) to a medium at a higher temperature (called the heat sink), thereby cooling the source (outside air) and warming the sink (the house); when cooling, the heat pump functions much like an air conditioner—taking unwanted heat from the heat source (a building) and dumping it to the heat sink (the outside).

heat sink — a medium (water, earth, or air) capable of accepting heat.

heat source — a medium (water, earth, or air) from which heat is extracted.

heat transfer — conduction, convection, or radiation (or a combination of these).

heating load — the rate of heat flow required to maintain indoor comfort; measured in BTU per hour.

heating season — the period from early fall to late spring during which heat is needed to keep a house comfortable.

heliostat — an instrument consisting of a mirror mounted on an axis moved by clockwork; the heliostat reflects sunbeams in one direction, usually to a central absorber located in a tower.

hybrid solar energy system – a hybrid system is one incorporating a major passive aspect, where at least one of the significant thermal energy flows is by natural means and at least one is by forced means.

hydronic system – a conventional heating system which circulates hot water, usually 160°F to 180°F, through baseboard finned pipes or radiators.

indirect gain solar – a type of passive solar heating system in which the storage is interposed between the collecting and the distributing surfaces (e.g., Trombe wall, water wall, or roof pond).

infiltration – the uncontrolled movement of outdoor air into a building through leaks, cracks, windows, and doors.

infrared radiation – the invisible rays just beyond the red of the visible spectrum; their wavelengths are longer than those of the spectrum colors (.7 to 400 microns), and they have a penetrating heating effect.

insolation – the amount of solar radiation (direct, diffuse, or reflected) striking a surface exposed to the sky; measured in BTU per square foot per hour (or in watts per square meter).

insulation – a material which increases resistance to heat flow.

isolated solar gain – a type of passive solar heating system in which heat is collected in one area to be used in another (e.g., greenhouse or attic collector).

kilowatt – a measure of power or heat flow rate; it equals 3,413 BTU per hour.

kilowatt-hour (kwh) – the amount of energy equivalent to one kilowatt of power being used for one hour; 3,413 BTU.

langley – a measure of solar radiation; it equals one calorie per square centimeter, or 3.69 BTU per square foot.

latent heat – the change in heat content that occurs with a change in phase and without change in temperature; the heat stored in the material during melting or vaporization. Latent heat is recovered by freezing a liquid or by condensing a gas.

life-cycle cost analysis – the accounting of capital, interest, and operating costs over the useful life of the solar system compared to those costs without the solar system.

liquid-type collector – a collector that uses a liquid as the heat transfer fluid.

microclimate – the variation in regional climate at a specific site; caused by topography, vegetation, soil, water conditions, and construction.

movable insulation – a device which reduces heat loss at night or during cloudy periods and permits heat gain in sunny periods (e.g., Beadwall ®, insulated draperies, automatic shutters); it may also be used to reduce heat gains in summer.

nocturnal cooling – a method of cooling through radiation of heat from warm surfaces to a night sky.

nonpotable – water that is not suitable for drinking or cooking purposes.

nonrenewable energy source – a mineral energy source which is in limited supply, such as fossil (gas, oil, and coal) and nuclear fuels.

passive solar energy systems and concepts – passive solar heating applications generally involve: energy collection through south-facing glazed areas; energy storage in the building mass or in special storage elements; energy distribution by natural means such as convection, conduction, or radiation with only minimal use of low-power fans or pumps; and a method controlling both high and low temperatures and energy flows. Passive cooling applications usually include methods of shading collector areas from exposure to the summer sun and provisions to induce ventilation to reduce internal temperatures and humidity.

payback – the time needed to recover the investment in a solar energy system.

peak load – the maximum instantaneous demand for electrical power which determines the generating capacity required by a public utility.

percent possible sunshine – the amount of radiation available compared to the amount which would be present if there were no cloud cover; usually measured on a monthly basis.

phase-change – see latent heat.

photovoltaic cell – a device without any moving parts that converts light directly into electricity by the excitement of electrons.

potable – water that is suitable for drinking or cooking purposes.

preheat – the use of solar energy to partially heat a substance, such as domestic potable water, prior to heating it to a higher desired temperature with auxiliary fuel.

prompt wall – a thin, low mass wall similar to a Trombe wall, but designed to respond more rapidly to solar gain.

pyranometer – an instrument for measuring direct and diffuse solar radiation.

pyrheliometer — an instrument that measures the intensity of the direct radiation from the sun; the diffuse component is not measured.

radiation — the process by which energy flows from one body to another when the bodies are separated by a space, even when a vacuum exists between them.

refrigerant — fluid, such as Freon ®, that is used in heating or cooling devices, such as heat pumps, air conditioners, or solar collectors.

renewable energy source — solar energy and certain forms derived from it, such as wind, biomass, and hydro.

reradiation — the emission of previously absorbed radiation.

retrofit — to modify an existing building by adding a solar heating system or insulation.

rock bin or rock bed — a heat storage container filled with rocks or pebbles, used in air-type solar heating/cooling systems.

R-value — see thermal resistance.

seasonal efficiency — the ratio of the solar energy collected and used to the solar energy striking the collector, measured over an entire heating season.

selective surface — a surface that is a good absorber of sunlight but a poor emitter of thermal radiation, used as a coating for absorbers to increase collector efficiency.

sensible heat — heat which, when gained or lost, results in a change in temperature.

shading coefficient — the ratio of the amount of sunlight transmitted through a window under specific conditions to the amount of sunlight transmitted through a single layer of common window glass under the same conditions.

solar access or solar rights — the ability to receive direct sunlight which has passed over land located to the south; the protection of solar access is a legal issue.

solar cell — see photovoltaic cell.

solar collector — a device which collects solar radiation and converts it to heat.

solar constant — the average intensity of solar radiation reaching the earth outside the atmosphere; 429.2 BTU per square foot per hour (or 1,354 watts per square meter).

solar fraction — the percentage of a building's seasonal heating requirement provided by a solar system.

solar furnace — a solar concentrator used to produce very high temperatures; also a trade name for a modular air heating system, usually ground mounted, with rock storage.

solar gain — the part of a building's heating or an additional cooling load, which is provided by solar radiation striking the building or passing into the building through windows.

solar noon — the time of day when the sun is due south; halfway between sunrise and sunset.

solar radiation — energy radiated from the sun in the electromagnetic spectrum; visible light and infrared light are used by solar energy systems.

solar thermal electric power — the indirect conversion of solar energy into electricity by solar collectors, a heat engine, and electrical generators.

solarium — a living space enclosed by glazing; a greenhouse.

specific heat capacity — the quantity of heat needed to change the temperature of one pound of a material by one degree Fahrenheit (or one kilogram of a material by one degree Centigrade).

stack effect — the rising of heated air over a dark surface by natural convection to create a draft, used to provide summer ventilation in some passive houses.

stagnation — a high temperature condition obtained in a solar collector when the sun is shining and no fluid is flowing through the collector; temperatures range from 250°F to 400°F, depending on collector design. Any condition under which a collector is losing as much heat as it gains.

storage — the device or medium that absorbs collected solar heat and stores it for later use.

storage capacity — the quantity of heat that can be contained in a storage device.

sunspace — a living space enclosed by glazing; a solarium or greenhouse.

sun tempering — a method that involves a significant daytime solar gain and an effective distribution system but generally lacks a storage system.

therm — a quantity of heat equal to 100,000 BTU; approximately 100 cubic feet of natural gas.

thermal lag — in an indirect gain system, the time delay for heat to move from the outer collecting surface to the inner radiating surface.

thermal mass — the heat capacity of a building material (brick, concrete, adobe, or water containers).

thermal radiation — see infrared radiation.

thermal resistance (R-value) — the tendency of a material to retard the flow of heat; the reciprocal of the coefficient of heat transmission.

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

tilt angle — see collector tilt.

tracking — for a collector, a device which causes the panel to follow the sun.

transfer medium — the substance that carries heat from the solar collector to storage or from storage to the living areas.

trickle-type collector — a collector in which the heat transfer fluid flows in open channels on the absorber.

Trombe wall — masonry, typically 8 to 16 inches thick, blackened and exposed to the sun behind glazing; a passive solar heating system in which a masonry wall collects, stores, and distributes heat.

tromped wall — a fanciful name for a hybrid low-mass wall that is useful as a convector of solar heating. It is similar in effect to a prompt wall yet it has more mass and is conceptually similar to a Trombe wall, so the term "tromped" wall (Trombe + prompt = tromped) was coined.

U-value — see coefficient of heat transmission.

vapor barrier — a waterproof liner used to prevent passage of moisture through the building structure. Vapor barriers in walls and ceilings should be located on the heated side of the building.

wet-bulb temperature — the lowest temperature attainable by evaporating water in the air; a measure of humidity.

zoned heating — the control of the temperature in a room or a group of rooms independently of other rooms.

APPENDIX D : INSULATION VALUES FOR VARIOUS TYPES OF CONSTRUCTION

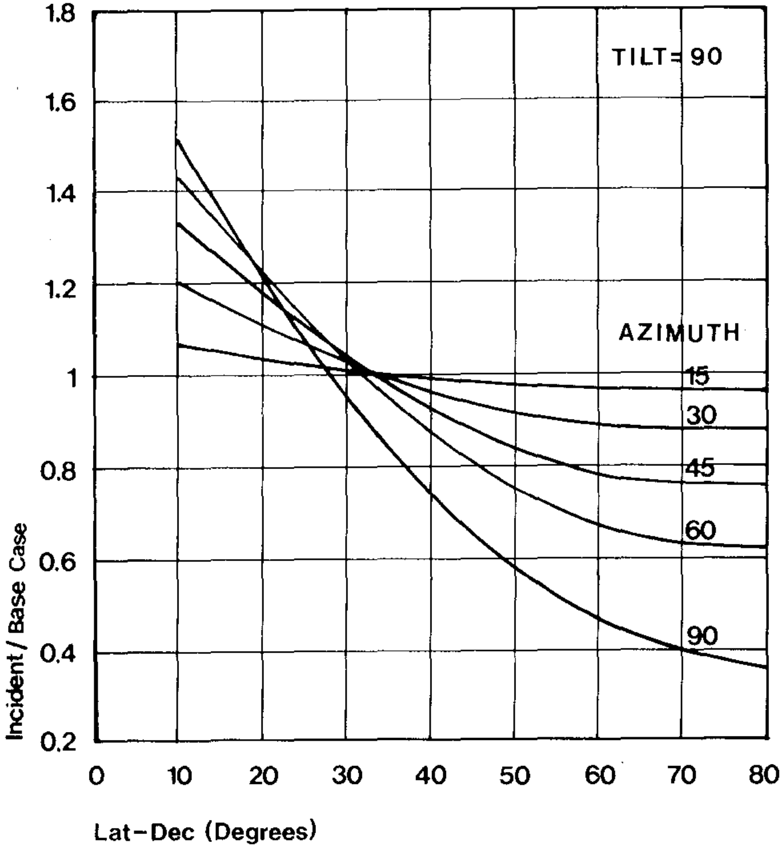
TABLE D1: TYPICAL HOUSE SECTIONS WITH AVERAGE R-VALUES.

Floor on Grade (on ground surface)	
Concrete 0" insulation	6.10
Concrete 4" styrofoam	28.10
Floor 12" Below Grade (ground level)	
Concrete 0" insulation	7.50
Concrete 2" styrofoam	18.50
Floor 24" Below Grade	
Concrete 0" insulation	14.30
Concrete 2" styrofoam	25.50
Floor 36" Below Grade	
Concrete 0" insulation	20.80
Concrete 2" styrofoam	31.80
Floor 48" Below Grade	
Concrete 0" insulation	27.00
Concrete 2" styrofoam	38.00
Floor 60" Below Grade	
Concrete 0" insulation	34.50
Concrete 2" styrofoam	48.00
Floor 72" Below Grade	
Concrete 0" insulation	37.00
Concrete 2" styrofoam	59.00
Floor 84" Below Grade	
Concrete 0" insulation	38.50
Concrete 2" styrofoam	59.00
Wall Foundation 12" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	12.22
Masonry 0" insulation	2.44
Masonry 2" styrofoam	13.44
Stud 2x6 treated all-weather wood foundation 6" fiberglass	19.29
Cavity 2/12 treated all-weather wood foundation 12" fiberglass	38.44
Wall Foundation 24" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	12.95
Masonry 0" insulation	3.17
Masonry 2" styrofoam	14.17
Stud 2x6 treated all-weather wood foundation 6" fiberglass	20.02
Wall Foundation 36" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	13.59
Masonry 0" insulation	3.81
Masonry 2" styrofoam	14.81
Stud 2x6 treated all-weather wood foundation 6" fiberglass	20.66
Wall Foundation 48" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	16.77
Masonry 0" insulation	4.42
Masonry 2" styrofoam	15.42
Stud 2x6 treated all-weather wood foundation 6" fiberglass	21.42
Wall Foundation 60" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	17.34
Masonry 0" insulation	4.99
Masonry 2" styrofoam	15.99
Stud 2x6 treated all-weather wood foundation 6" fiberglass	21.99
Wall Foundation 72" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	17.90
Masonry 0" insulation	5.55
Masonry 2" styrofoam	16.55
Stud 2x6 treated all-weather wood foundation 6" fiberglass	22.55
Wall Foundation 84" Below Grade	
Masonry 2x4 and 3-1/2" fiberglass	18.71
Masonry 0" insulation	6.27
Masonry 2" styrofoam	17.27
Stud 2x6 treated all-weather wood foundation 6" fiberglass	23.27
Cavity 2/12 treated all-weather wood foundation 12" fiberglass	42.27
Window	
Triple glazed	2.79
Single glazed	0.89
Double glazed	1.84
Double with drapery	2.35
Double with screen	3.74
Shutter	
Double 1" styrofoam closed 16 hr	5.23
Double 1" styrofoam closed 24 hr	6.94
Double 1-1/2" styrofoam closed 16 hr	6.92
Double 1-1/2" styrofoam closed 24 hr	9.46
Wall Foundation Above Grade	
Stud 2x6 (8" on center) avg 6" fiberglass	16.15
Masonry 0" insulation	2.00
Stud 2x4 (8" on center) avg 0" insulation	3.42
Stud 2x4 (8" on center) avg 2-1/4" fiberglass	8.89
Stud 2x4 (8" on center) avg 3-1/2" fiberglass	10.62
Stud 2x4 (8" on center) 2x2 16" on center 7" fiberglass[1]	15.05
Stud 2x6 (24" on center) 6" fiberglass	18.74
Stud 2x6 (24" on center) 2x2 7.5" fiberglass[1]	22.23
First Floor	
Joist 2x10 (24" on center) 6" fiberglass	18.86
Joist 2x10 (24" on center) 0" insulation	3.07
Joist 2x10 (24" on center) 3-1/2" fiberglass	14.62
Joist 2x10 (24" on center) 9-1/2" fiberglass	29.87
Joist 2x12 (24" on center) 12" fiberglass	36.98
First Floor with Super Insulation	
Truss 2x16 (24" on center) 14" fiberglass	44.00
Truss 2x20 (24" on center) 18" fiberglass	57.00
Door	
1-3/4" styrofoam core	11.17
1-3/4" solid wood	3.04
1-3/4" solid wood with storm door	3.99
Wall Section	
Stud 3x6 8" on center avg 6" fiberglass	16.15
Stud 2x4 8" on center avg 0" insulation	3.42
Log 6" 3-sided	10.16
Stud 2x4 8" on center avg 3-1/2" fiberglass	10.62
Log 8" milled	11.84
Stud 2x4 8" on center avg 3.5" urea formaldehyde	12.36
Stud 2x4 8" on center (16" on center) 2x2 5" fiberglass[1]	15.05
Log 12" turned	15.46
Stud 2x6 24" on center 6" fiberglass	18.74
Stud 2x4 (16" on center) 2x2 5" urea formaldehyde[1]	18.76
Stud 2x6 (24" on center) 2x2 7.5" fiberglass[1]	22.23
Rafter Roof	
Rafter 1x12 24" on center 12" fiberglass	38.61
Rafter 2x6 24" on center 0" insulation	2.77
Rafter 2x6 24" on center 2-1/4" fiberglass	7.73
Rafter 2x6 24" on center 3-1/2 fiberglass	10.32
Rafter 2x8 24" on center 6" fiberglass	18.99
Rafter 2x12 24" on center 12" fiberglass	30.49
Truss 2x16 24" on center 12.5 fiberglass	40.59
Truss 2x20 24" on center 18" fiberglass	55.06
Truss Roof	
Truss 24" on center 12" fiberglass	38.61
Truss 24" on center 0" insulation	1.67
Truss 24" on center 2-1/4" fiberglass	7.73
Truss 24" on center 3-1/2" fiberglass	11.39
Truss 24" on center 6" fiberglass	18.99
Truss 24" on center 9-1/2" fiberglass	30.49
Truss 24" on center 15-1/2" fiberglass	49.61
Truss 24" on center 18" fiberglass	57.61

[1] These walls have crosshatching of the studs with 2x2 nailers to provide a cavity inside the vapor barrier for plumbing and wiring. For further construction information, see *How to Build a Superinsulated House*, which is available from Project 2020, Box 80707, Fairbanks, AK 99708.

APPENDIX E : PASSIVE SOLAR DESIGN CORRECTION FACTORS

These charts indicate correlations among tilt, azimuth, transmittance, reflectance and overhangs, and their various effects on passive solar designs. Further instructions on their use are contained in the passive design section. The calculations presented in graphical form represent many (but not all) possible solar collection geometrics. Therefore, for some cases it will be necessary to interpolate (estimate) desired quantities. The zenith angle is L-D (0 minus the elevation angle) of the sun at noon at midmonth. The values of this quantity for several locations in Alaska by month are given in Table 19.



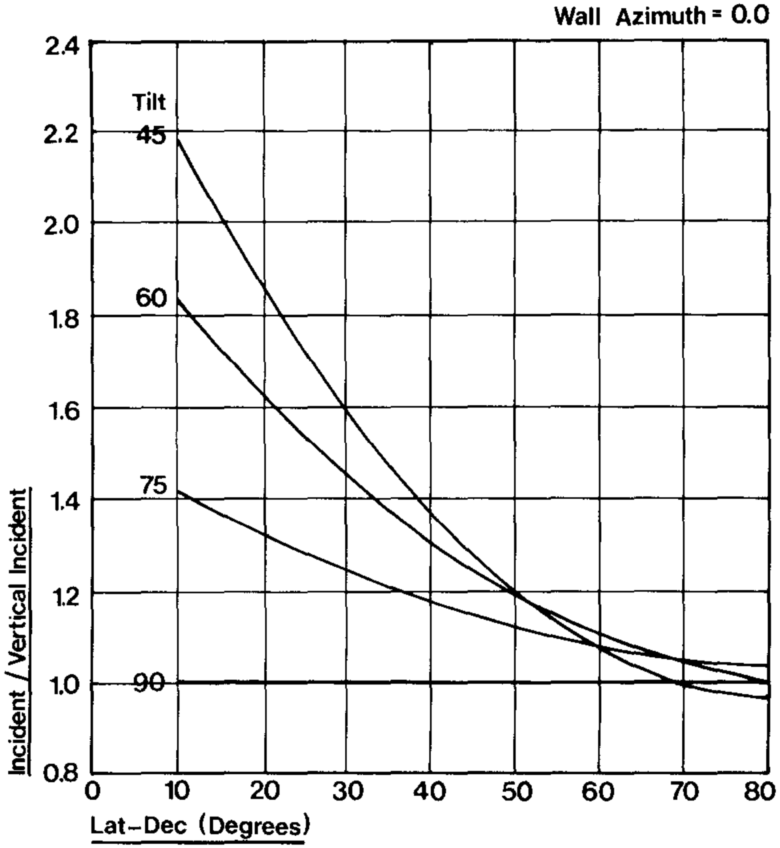


Figure E1. Effect of azimuth for a vertical wall (orientation factor).

Figure E2. Effect of tilt, for wall azimuth = 0° (south-facing).

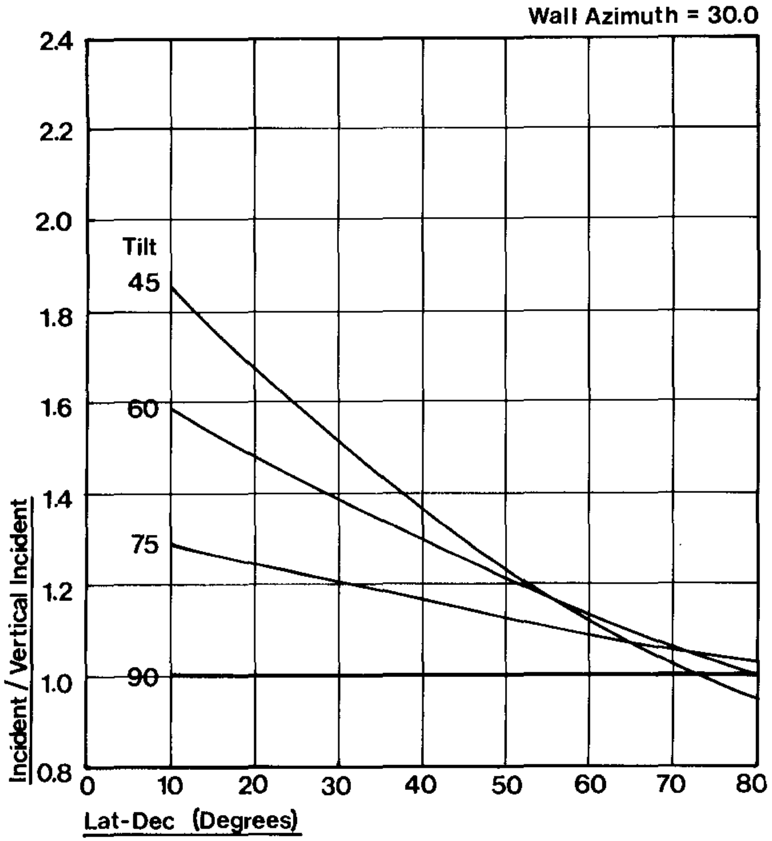


Figure E3. Effect of tilt, for wall azimuth = 30° from south.

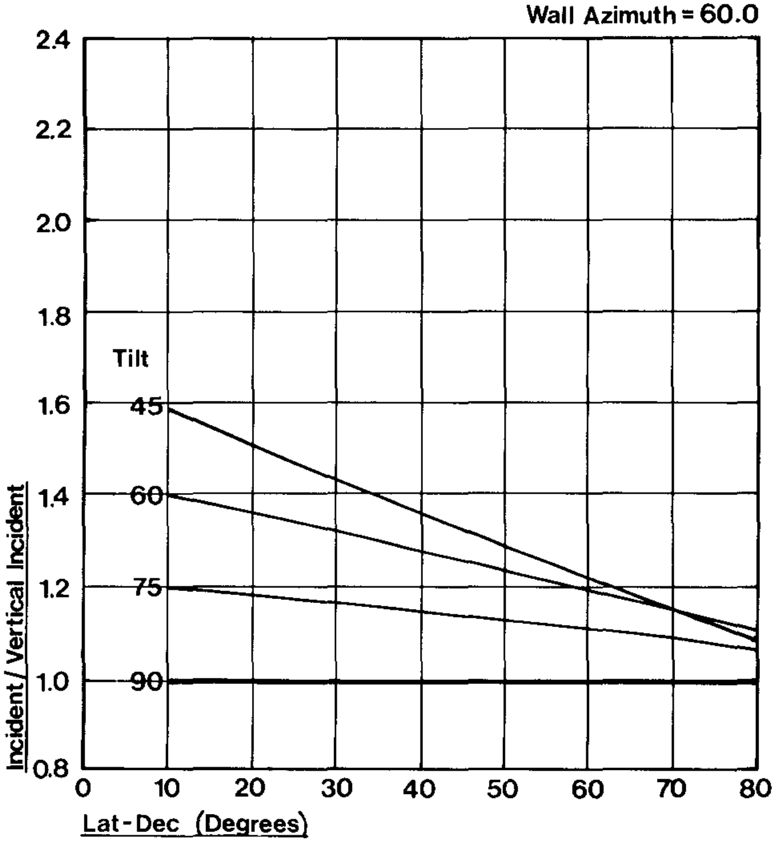


Figure E4. Effect of tilt, for wall azimuth = 60° from south.

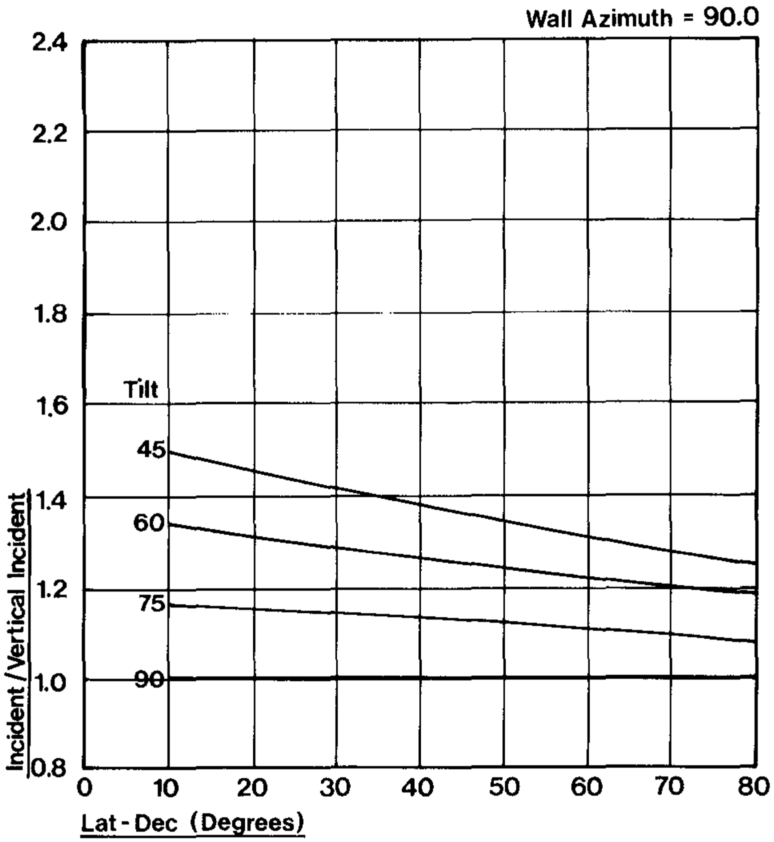


Figure E5. Effect of tilt, for wall azimuth = 90° from south.

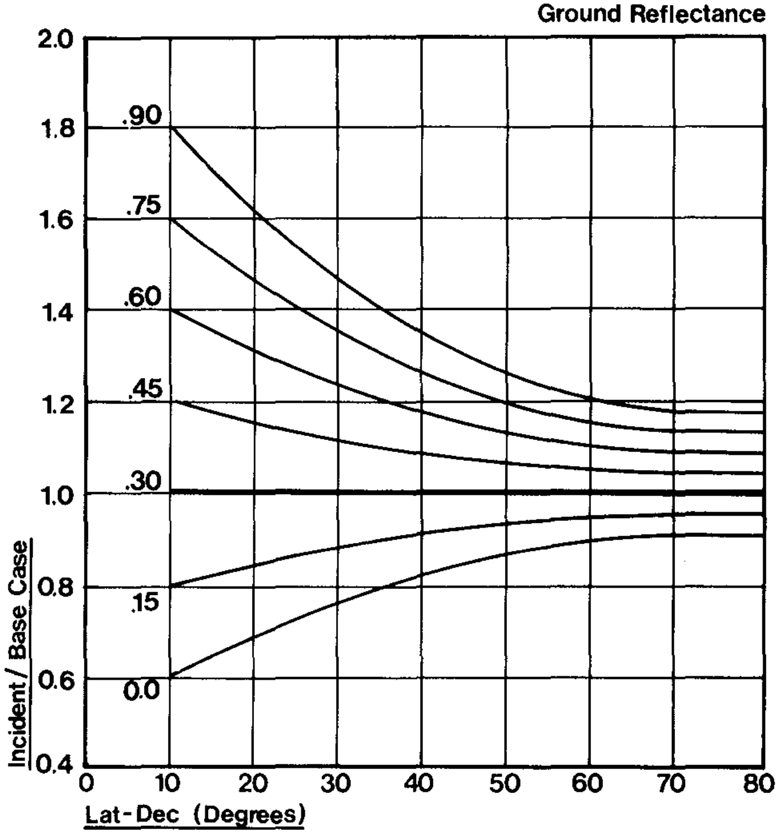


Figure E6. Effect of ground reflectance on incident radiation.

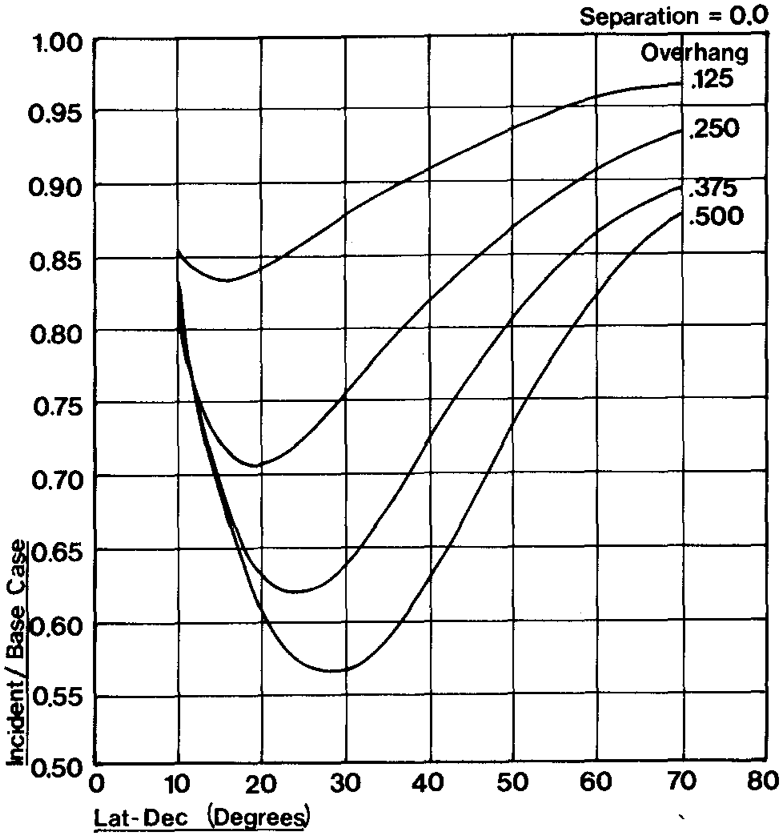


Figure E7. Effect of an overhang on incident radiation, separation = 0.0.

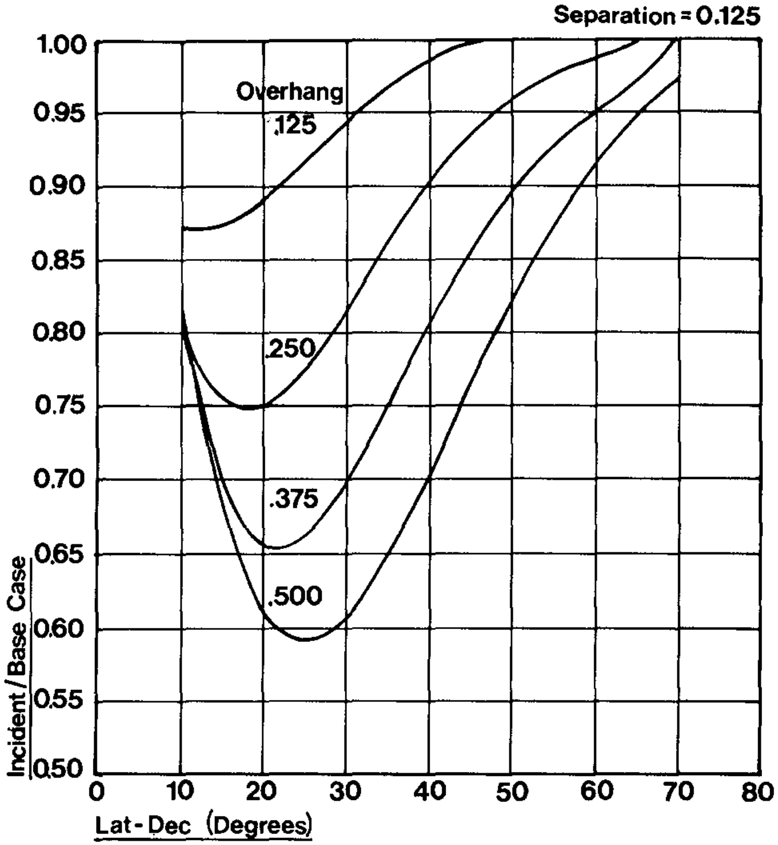


Figure E8. Effect of an overhang on incident radiation, separation = 0.125.

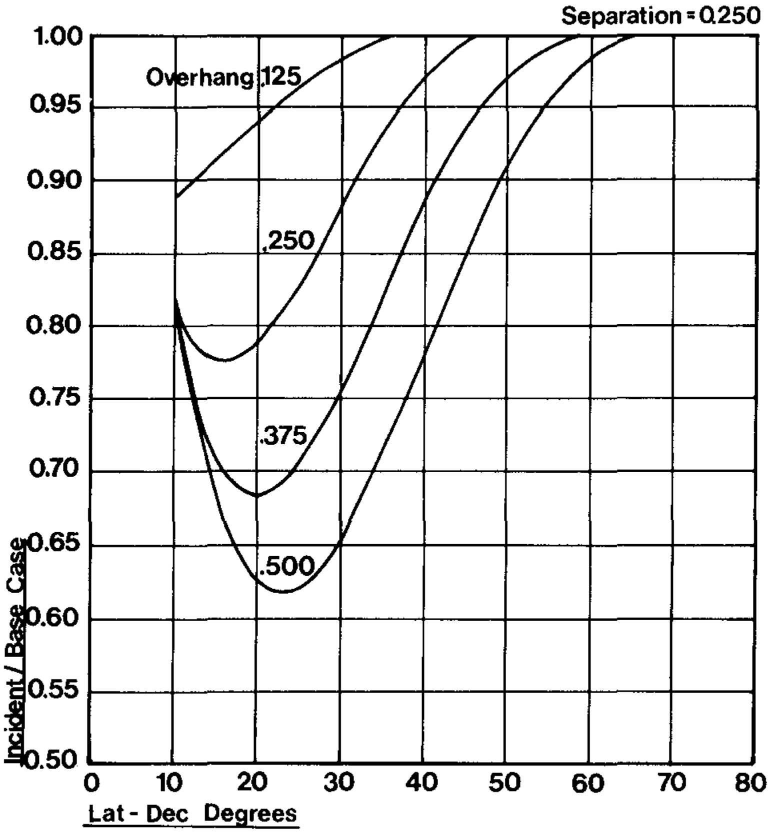


Figure E9. Effect of an overhang on incident radiation, separation = 0.250.

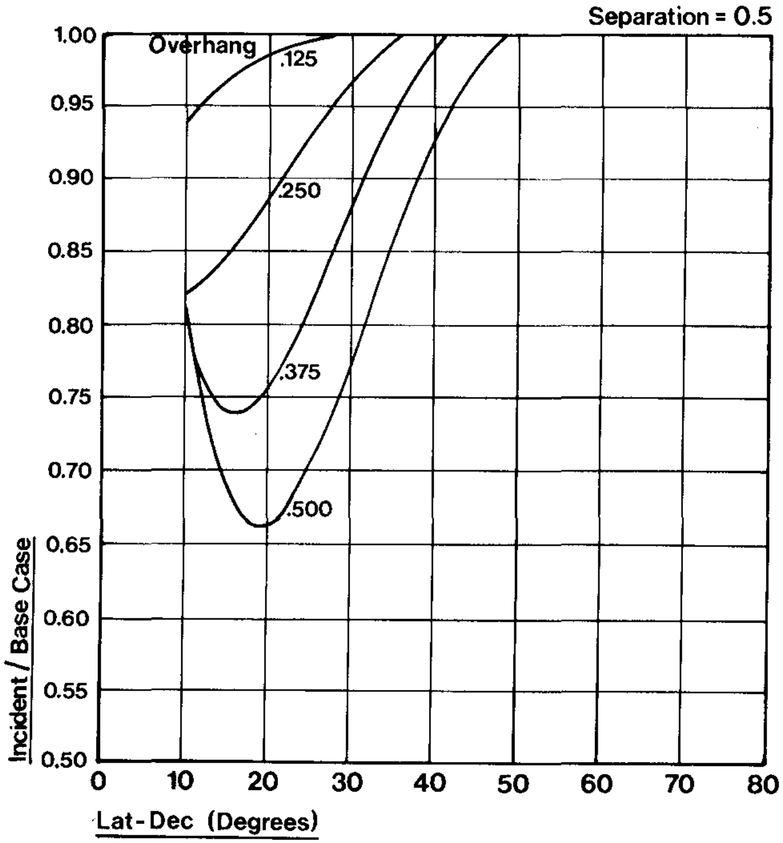
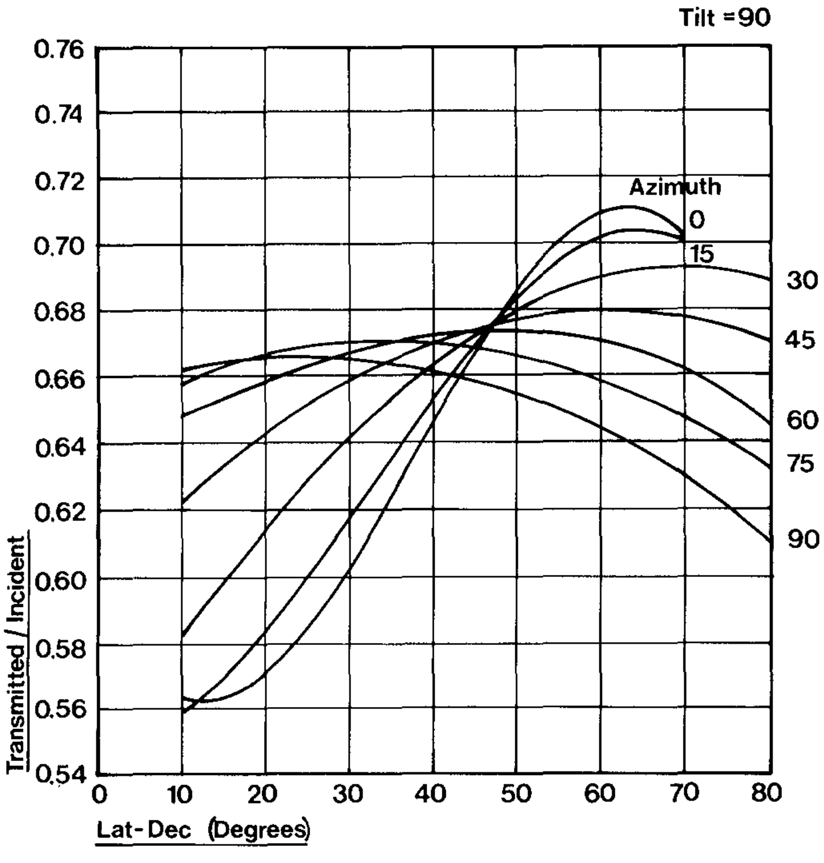


Figure E10. Effect of an overhang on incident radiation, separation = 0.5.



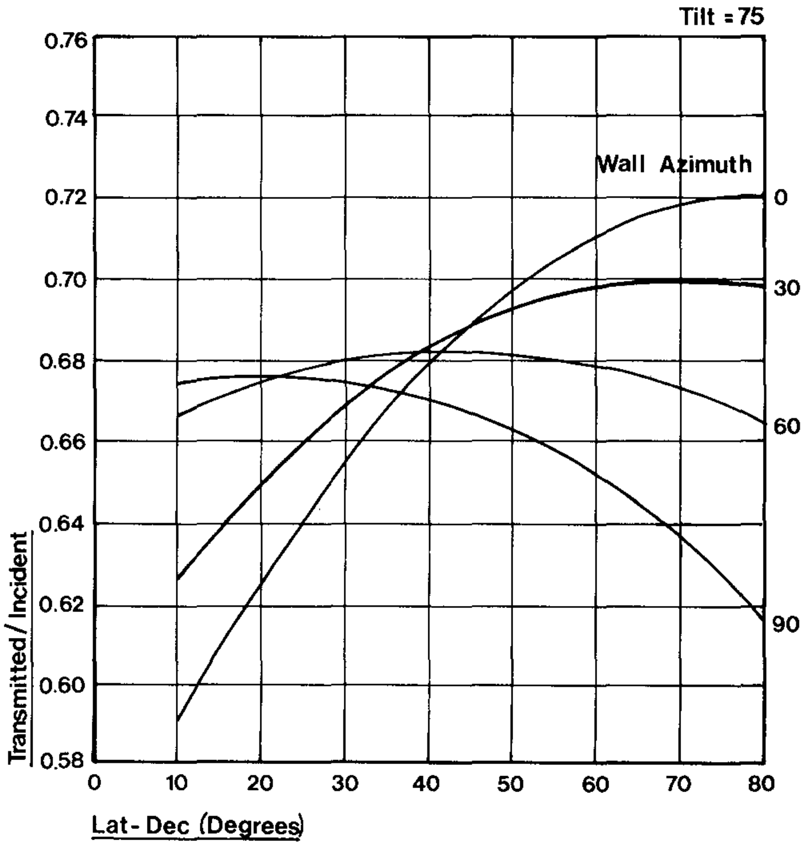


Figure E11. Transmitted versus incident radiation for a vertical double glazing, tilt = 90°.

Figure E12. Transmitted versus incident radiation, tilt = 75°.

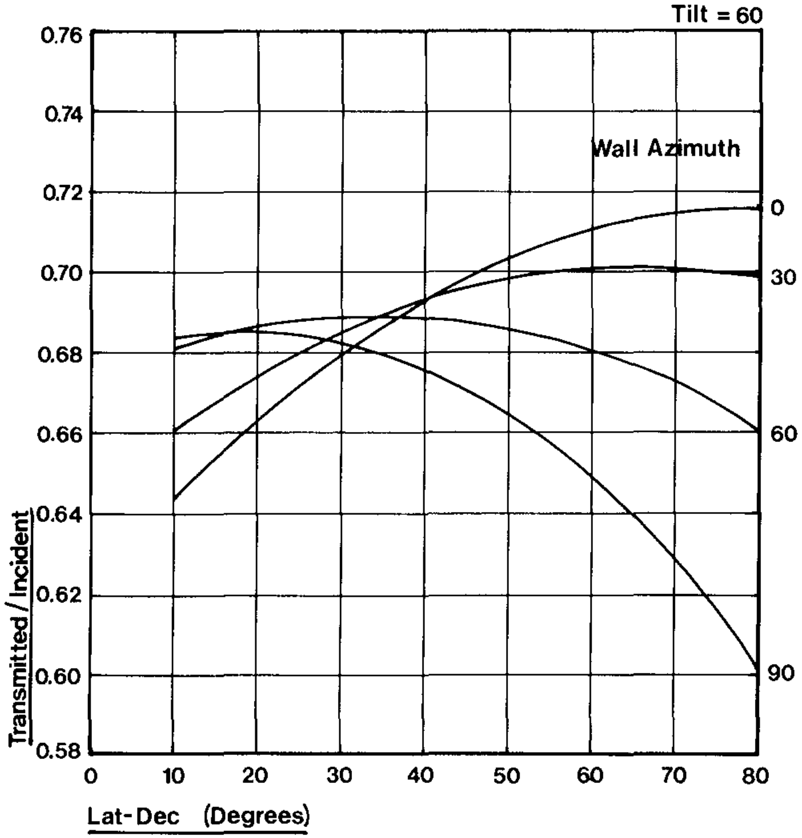


Figure E13. Transmitted versus incident radiation, tilt = 60°.

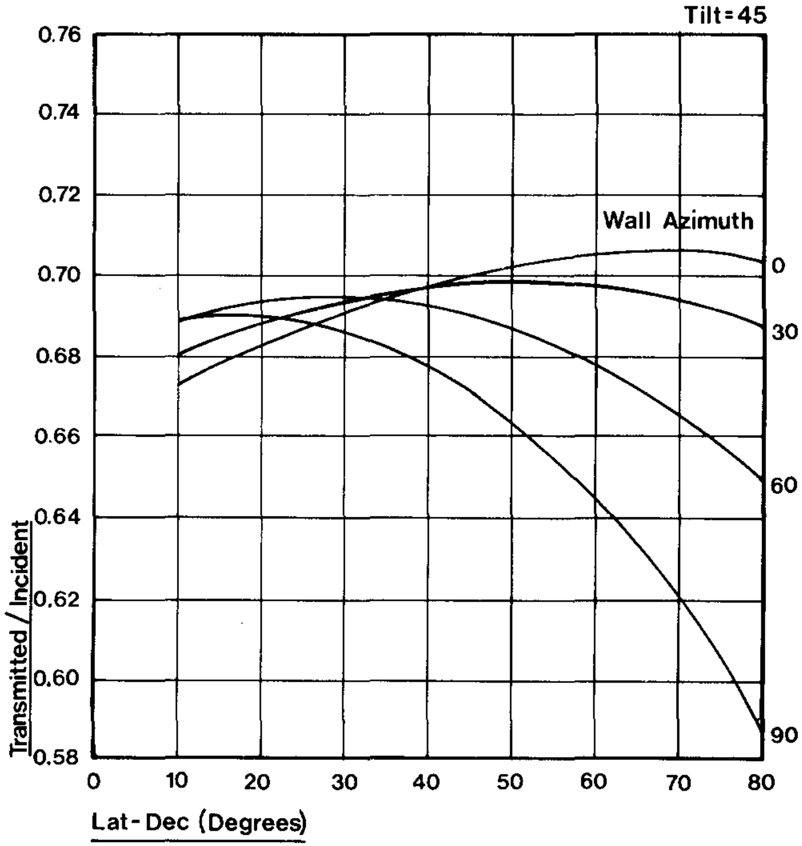


Figure E14. Transmitted versus incident radiation, tilt = 45°.

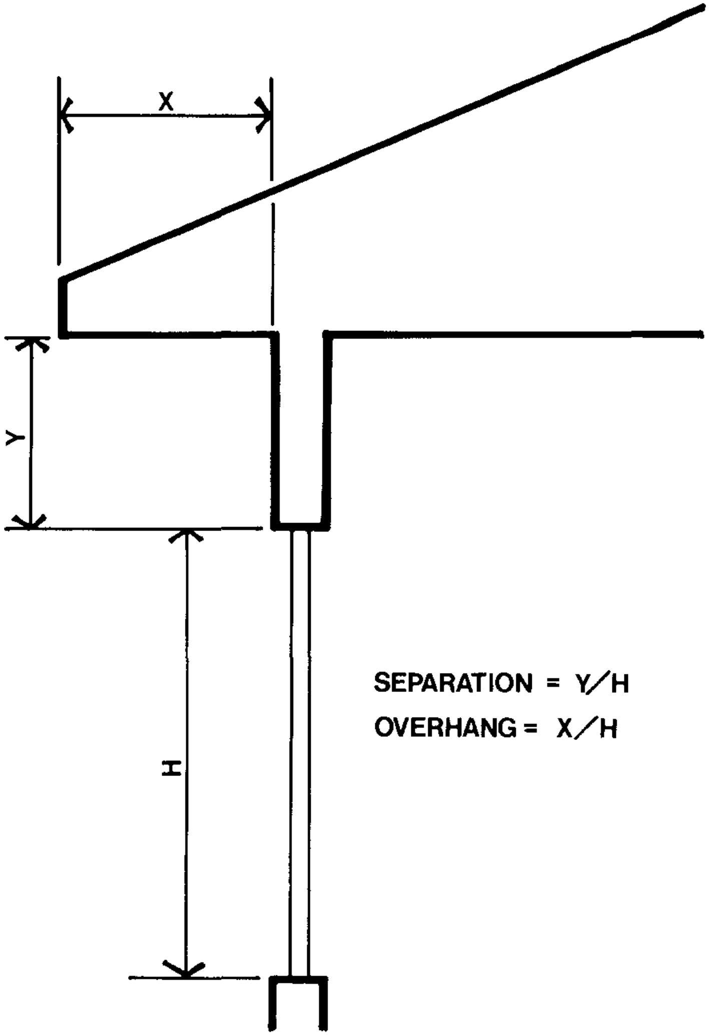


Figure E15. Overhang geometry.

APPENDIX F : POSSIBLE SOLAR RADIATION AT VARIOUS LOCATIONS AND LATITUDES

These charts contain data needed for the sizing calculations used for active solar energy systems.

TABLE F1: MEAN PERCENTAGE OF POSSIBLE SUNSHINE.

Month Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anchorage	39	46	56	58	50	51	45	39	35	32	33	29
Fairbanks	34	50	61	58	55	53	45	35	31	28	38	29
Juneau	30	32	39	37	34	35	28	30	25	18	21	18
Nome	44	46	48	53	51	48	32	26	34	35	36	30

TABLE F2: MEAN NUMBER OF HOURS OF SUNSHINE.

Month Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anchorage	78	114	210	254	268	288	255	184	128	96	68	49
Fairbanks	54	120	224	302	319	334	274	164	122	85	71	36
Juneau	71	102	171	200	230	251	193	161	123	67	60	51
Nome	72	109	193	226	285	291	204	146	142	101	67	42

TABLE F3: SOLAR POSITION AND INSOLATION VALUES FOR 56° NORTH LATITUDE.[1]

	Solar Time		Solar Position		Total Insolation on Surfaces, BTU/sq ft/hr						
					Normal to Solar Radiation		South-facing Surface Angle with Horizon				
Date	AM	PM	Alt.	Azm.		Horiz.	46	56	66	76	90
Jan 21	9	3	5.0	41.8	78	11	50	55	59	60	60
	10	2	9.9	28.5	170	39	135	146	154	156	153
	11	1	12.9	14.5	207	58	183	197	206	208	201
	12		14.0	0.0	217	65	198	214	222	225	217
		Surface Daily Totals			1126	282	934	1010	1058	1074	1044
Feb 21	8	4	7.6	59.4	129	25	65	69	72	72	69
	9	3	14.2	45.9	214	65	151	159	162	161	151
	10	2	19.4	31.5	250	98	215	225	228	224	208
	11	1	22.8	16.1	266	119	254	265	268	263	243
	12		24.0	0.0	270	126	268	279	282	276	255
		Surface Daily Totals			1986	740	1640	1716	1742	1716	1598
Mar 21	7	5	8.3	77.5	128	28	40	40	39	37	32
	8	4	16.2	64.4	215	75	119	120	117	111	97
	9	3	23.3	50.3	253	118	192	193	189	180	154
	10	2	29.0	34.9	272	151	249	251	246	234	205
	11	1	32.7	17.9	282	172	285	288	282	268	236
	12		34.0	0.0	284	179	297	300	294	280	246
		Surface Daily Totals			2586	1268	2066	2084	2040	1938	1700
Apr 21	5	7	1.4	108.8	0	0	0	0	0	0	0
	6	6	9.6	96.5	122	32	14	9	8	7	6
	7	5	18.0	84.1	201	81	74	66	57	46	29
	8	4	26.1	70.9	239	129	143	135	123	108	82
	9	3	33.6	56.3	260	169	208	200	186	167	133
	10	2	39.9	39.7	272	201	259	251	236	214	174
	11	1	44.1	20.7	278	220	292	284	268	245	200
	12		45.6	0.0	280	227	303	295	279	255	209
		Surface Daily Totals			3024	1892	2282	2186	2038	1830	1458
May 21	4	8	1.2	125.5	0	0	0	0	0	0	0
	5	7	8.5	113.4	93	25	10	9	8	7	6
	6	6	16.5	101.5	175	71	28	17	15	13	11
	7	5	24.8	89.3	219	119	88	74	58	41	16
	8	4	33.1	76.3	244	163	153	138	119	98	63
	9	3	40.9	61.6	259	201	212	197	176	151	109
	10	2	47.6	44.2	268	231	259	244	222	194	146
	11	1	52.3	23.4	273	249	288	274	251	222	170
	12		54.0	0.0	275	255	299	284	261	231	178
		Surface Daily Totals			3340	2374	2374	2188	1962	1682	1218
Jun 21	4	8	4.2	127.2	21	4	2	2	2	2	1
	5	7	11.4	115.3	122	40	14	13	11	10	8
	6	6	19.3	103.6	185	86	34	19	17	15	12
	7	5	27.6	91.7	222	132	92	76	57	38	15
	8	4	35.9	78.8	243	175	154	137	116	92	55
	9	3	43.8	64.1	257	212	211	193	170	143	98
	10	2	50.7	46.4	265	240	255	238	214	184	133
	11	1	55.6	24.9	269	258	284	267	242	210	156
	12		57.5	0.0	271	264	294	276	251	219	164
		Surface Daily Totals			3438	2562	2388	2166	1910	1606	1120
Jul 21	4	8	1.7	125.8	0	0	0	0	0	0	0
	5	7	9.0	113.7	91	27	11	10	9	8	6
	6	6	17.0	101.9	169	72	30	18	16	14	12
	7	5	25.3	89.7	212	119	88	74	58	41	15
	8	4	33.6	76.7	237	163	151	136	117	96	61
	9	3	41.4	62.0	252	201	208	193	173	147	106
	10	2	48.2	44.6	261	230	254	239	217	189	142
	11	1	52.9	23.7	265	248	283	268	245	216	165
	12		54.6	0.0	267	254	293	278	255	225	173
		Surface Daily Totals			3240	2372	2342	2152	1926	1646	1186
Aug 21	5	7	2.0	109.2	1	0	0	0	0	0	0
	6	6	10.2	97.0	112	34	16	11	10	9	7
	7	5	18.5	84.5	187	82	73	65	56	45	28
	8	4	26.7	71.3	225	128	140	131	119	104	78
	9	3	34.3	56.7	246	168	202	193	179	160	126
	10	2	40.5	40.0	258	199	251	242	227	206	166
	11	1	44.8	20.9	264	218	282	274	258	235	191
	12		46.3	0.0	266	225	293	285	269	245	200
		Surface Daily Totals			2850	1884	2218	2118	1966	1760	1392
Sep 21	7	5	8.3	77.5	107	25	36	36	34	32	28
	8	4	16.2	64.4	194	72	111	111	108	102	89
	9	3	23.3	50.3	233	114	181	182	178	168	147
	10	2	29.0	34.9	253	146	236	237	232	221	193
	11	1	32.7	17.9	263	166	271	273	267	254	223
	12		34.0	0.0	266	173	283	285	279	265	233
		Surface Daily Totals			2368	1220	1950	1962	1918	1820	1594
Oct 21	8	4	7.1	59.1	104	20	53	57	59	59	57
	9	3	13.8	45.7	193	60	138	145	148	147	138
	10	2	19.0	31.3	231	92	201	210	213	210	195
	11	1	22.3	16.0	248	112	240	250	253	248	230
	12		23.5	0.0	253	119	253	263	266	261	241
		Surface Daily Totals			1804	688	1516	1586	1612	1588	1480
Nov 21	9	3	5.2	41.9	76	12	49	54	57	59	58
	10	2	10.0	28.5	165	39	132	143	149	152	148
	11	1	13.1	14.5	201	58	179	193	201	203	196
	12		14.2	0.0	211	65	194	209	217	219	211
		Surface Daily Totals			1094	284	914	986	1032	1046	1016
Dec 21	9	3	1.9	40.5	5	0	3	4	4	4	4
	10	2	6.6	27.5	113	19	86	95	101	104	103
	11	1	9.5	13.9	166	37	141	154	163	167	164
	12		10.6	0.0	180	43	159	173	182	186	182
		Surface Daily Totals			748	156	620	678	716	734	722

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[1] Assumes 0% ground reflectance and a 1.0 clearness factor; see Figure 4 in the *1972 ASHRAE Handbook of Fundamentals* for typical regional clearness factors.

[2] Normal to solar radiation means that the collector is moved continuously to remain perpendicular to incoming solar radiation.

TABLE F4: SOLAR POSITION AND INSOLATION VALUES FOR 64° NORTH LATITUDE.[1]

	Solar Time		Solar Position		Total Insolation on Surfaces, BTU/sq ft/hr						
					Normal to Solar Radiation		South-facing Surface Angle with Horizon				
Date	AM	PM	Alt.	Azm.		Horiz.	54	64	74	84	90
Jan 21	10	2	2.8	28.1	22	2	17	19	20	20	20
	11	1	5.2	14.1	81	12	72	77	80	81	81
	12		6.0	0.0	100	16	91	98	102	103	103
		Surface Daily Totals			306	45	268	290	302	306	304
Feb 21	8	4	3.4	58.7	35	4	17	19	19	19	19
	9	3	8.6	44.8	147	31	103	108	111	110	107
	10	2	12.6	30.3	199	55	170	178	181	178	173
	11	1	15.1	15.3	222	71	212	220	223	219	213
	12		16.0	0.0	228	77	225	235	237	232	226
		Surface Daily Totals			1432	400	1230	1286	1302	1282	1252
Mar 21	7	5	6.5	76.5	95	18	30	29	29	27	25
	8	4	20.7	62.6	185	54	101	102	99	94	89
	9	3	18.1	48.1	227	87	171	172	169	160	153
	10	2	22.3	32.7	249	112	227	229	224	213	203
	11	1	25.1	16.6	260	129	262	265	259	246	235
	12		26.0	0.0	263	134	274	277	271	258	246
		Surface Daily Totals			2296	932	1856	1870	1830	1736	1656
Apr 21	5	7	4.0	108.5	27	5	2	2	2	1	1
	6	6	10.4	95.1	133	37	15	9	8	7	6
	7	5	17.0	81.6	194	76	70	63	54	43	37
	8	4	23.3	67.5	228	112	136	128	116	102	91
	9	3	29.0	52.3	248	144	197	189	176	158	145
	10	2	33.5	36.0	260	169	246	239	224	203	188
	11	1	36.5	18.4	266	184	278	270	255	233	216
	12		37.6	0.0	268	190	289	281	266	243	225
		Surface Daily Totals			2982	1644	2176	2082	1936	1736	1594
May 21	4	8	5.8	125.1	51	11	5	4	4	3	3
	5	7	11.6	112.1	132	42	13	11	10	9	8
	6	6	17.9	99.1	185	79	29	16	14	12	11
	7	5	24.5	85.7	218	117	86	72	56	39	28
	8	4	30.9	71.5	239	152	148	133	115	94	80
	9	3	36.8	56.1	252	182	204	190	170	145	128
	10	2	41.6	38.9	261	205	249	235	213	186	167
	11	1	44.9	20.1	265	219	278	264	242	213	193
	12		46.0	0.0	267	224	288	274	251	222	201
		Surface Daily Totals			3470	2236	2312	2124	1898	1624	1436
Jun 21	3	9	4.2	139.4	21	4	2	2	2	2	1
	4	8	9.0	126.4	93	27	10	9	8	7	6
	5	7	14.7	113.6	154	60	16	15	13	11	10
	6	6	21.0	100.8	194	96	34	19	17	14	13
	7	5	27.5	87.5	221	132	91	74	55	36	23
	8	4	34.0	73.3	239	166	150	133	112	88	73
	9	3	39.9	57.8	251	195	204	187	164	137	119
	10	2	44.9	40.4	258	217	247	230	206	177	157
	11	1	48.3	20.9	262	231	275	258	233	202	181
	12		49.5	0.0	263	235	284	267	242	211	189
		Surface Daily Totals			3650	2488	2342	2118	1862	1558	1356
Jul 21	4	8	6.4	125.3	53	13	6	5	5	4	4
	5	7	12.1	112.4	128	44	14	13	11	10	9
	6	6	18.4	99.4	179	81	30	17	16	13	12
	7	5	25.0	86.0	211	118	86	72	56	38	28
	8	4	31.4	71.8	231	152	146	131	113	91	77
	9	3	37.3	56.3	245	182	201	186	166	141	124
	10	2	42.2	39.2	253	204	245	230	208	181	162
	11	1	45.4	20.2	257	218	273	258	236	207	187
	12		46.6	0.0	259	223	282	267	245	216	195
		Surface Daily Totals			3372	2248	2280	2090	1864	1588	1400
Aug 21	5	7	4.6	108.8	29	6	3	3	2	2	2
	6	6	11.0	95.5	123	39	16	11	10	8	7
	7	5	17.6	81.9	181	77	69	61	52	42	35
	8	4	23.9	67.8	214	113	132	123	112	97	87
	9	3	29.6	52.6	234	144	190	182	169	150	138
	10	2	34.2	36.2	246	168	237	229	215	194	179
	11	1	37.2	18.5	252	183	268	260	244	222	205
	12		38.3	0.0	254	188	278	270	255	232	215
		Surface Daily Totals			2808	1646	2108	2008	1860	1662	1622
Sep 21	7	5	6.5	76.5	77	16	26	25	24	23	21
	8	4	12.7	72.6	163	51	92	92	90	86	81
	9	3	18.1	48.1	206	83	159	159	156	147	141
	10	2	22.3	32.7	229	108	212	213	209	198	189
	11	1	25.1	16.6	240	124	246	248	243	230	220
	12		26.0	0.0	244	129	258	260	254	241	230
		Surface Daily Totals			2074	892	1726	1736	1696	1608	1532
Oct 21	8	4	3.0	58.5	17	2	9	9	10	10	10
	9	3	8.1	44.6	122	26	86	91	93	92	90
	10	2	12.1	30.2	176	50	152	159	161	159	155
	11	1	14.6	15.2	201	65	193	201	203	200	295
	12		15.5	0.0	208	71	207	215	217	213	208
		Surface Daily Totals			1238	358	1088	1136	1152	1134	1106
Nov 21	10	2	3.0	28.1	23	3	18	20	21	21	21
	11	1	5.4	14.2	79	12	70	76	79	80	79
	12		6.2	0.0	97	17	89	96	100	101	100
		Surface Daily Totals			302	46	266	286	298	302	300
Dec 21	11	1	1.8	13.7	4	0	3	4	4	4	4
	12		2.6	0.0	16	2	14	15	16	17	17
		Surface Daily Totals			24	2	20	22	24	24	24

[1] Assumes 0% ground reflectance and a 1.0 clearness factor; see Figure 4 in the *1972 ASHRAE Handbook of Fundamentals* for typical regional clearness factors.

[2] Normal to solar radiation means that the collector is moved continuously to remain perpendicular to incoming solar radiation.

TABLE F5: MEAN POSSIBLE SUNSHINE AT MIDMONTH FOR VARIOUS LATITUDES, EXPRESSED IN HOURS AND MINUTES (h-m).

Month Latitude, °N	Jan h-m	Feb h-m	Mar h-m	Apr h-m	May h-m	Jun h-m	Jul h-m	Aug h-m	Sep h-m	Oct h-m	Nov h-m	Dec h-m
85°	0	0	9-50	24-00	24-00	24-00	24-00	24-00	18-15	0	0	0
80°	0	0	10-50	24-00	24-00	24-00	24-00	24-00	15-10	5-00	0	0
75°	0	5-10	11-23	17-56	24-00	24-00	24-00	23-19	13-57	7-58	0	0
70°	0	7-20	11-33	16-09	22-41	24-00	24-00	18-15	13-26	9-06	3-52	0
65°	5-02	8-28	11-40	15-11	18-43	21-53	20-15	16-39	13-07	9-46	6-16	3-42
50°	6-43	9-12	11-44	14-34	17-08	18-49	18-05	15-41	12-55	10-13	7-34	5-56
55°	7-47	9-43	11-47	14-06	16-08	17-21	16-49	15-00	12-46	10-33	8-25	7-13
50°	8-33	10-07	11-51	13-45	15-24	16-21	15-57	14-30	12-39	10-49	9-04	8-06
45°	9-09	10-27	11-53	13-29	14-51	15-35	15-17	14-06	12-34	11-01	9-35	8-48
40°	9-39	10-43	11-55	13-15	14-23	15-00	14-45	13-46	12-28	11-11	9-59	9-21
35°	10-04	10-57	11-56	13-04	13-59	14-30	14-17	13-29	12-24	11-20	10-21	9-50
30°	10-25	11-09	11-58	12-53	13-39	14-04	13-54	13-14	12-22	11-28	10-39	15-14
25°	10-45	11-19	11-59	12-44	13-21	13-41	13-33	13-01	12-18	11-35	10-56	10-36

APPENDIX G : WORKSHEETS FOR PASSIVE SOLAR DESIGN PROBLEMS

TABLE G1: SOLAR RADIATION ABSORBED PER SQUARE FOOT.

Location ________ Latitude ________

Aperture Type ______ Collection Area (Ac) ________ ft^2

Column		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mon	L-D (From) Table 22)	VS x Days/Mon (VS Taken from Appendix B) $\frac{\text{BTU}}{\text{mon} \cdot \text{ft}^2}$	← Factors →						Product of All Factors	S=(1)x(8) $\frac{\text{BTU}}{\text{mon} \cdot \text{ft}^2}$
Sep										
Oct										
Nov										
Dec										
Jan										
Feb										
Mar										
Apr										
May										
Jun										

TABLE G2: SOLAR SAVINGS FRACTION AND AUXILIARY ENERGY.

Column	(1) S	(2) DD	(3) S/DD	(4) Monthly SSF	(5) Q_{aux}
Source and Units / Month	From Column 9 of Table G1 $\frac{BTU}{mon \cdot ft^2}$	From Appendix B $\frac{DD}{mon}$	(1) ÷ (2) $\frac{BTU}{mon \cdot ft^2 \cdot DD}$	From Figures 88 and 89 in Appendix E	[1-(4)] x (2) x BLC 10^6 BTU/mon
Sep					
Oct					
Nov					
Dec					
Jan					
Feb					
Mar					
Apr					
May					
Jun					
				Total	

Location ________

System ________

BLC ________ BTU/DD

DD ________ °F·day

LCR ________ BTU/DD·ft^2

$$\text{Yearly SSF} = 1 - \frac{\Sigma(5)}{\text{BLC x DD}}$$

Yearly SSF = ________

Annual Auxiliary Heat

índex