DOCUMENT RESUME

ED 204 535 · CE 029 431

AUTHOR	Knapp, Henry H., III
TITLE	Solar Energy: Solar and the Weather.
INSTITUTION	Linn-Benton Community Coll., Albany, Oreg.
SPONS AGENCY	Oregon State Dept. of Education, Salem. Career and Vocational Education Section.
PUB DATE	Sep 78
NOTE	49p.: For related documents see CE 029 430-435.
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Behavioral Objectives: Energy: *Energy Conservation: Individualized Instruction: Learning Modules: Postsecondary Education: *Programed Instruction: *Solar Radiation: *Technical Education: Tests: Two Year Colleges: Vocational Education: *Weather
IDENTIFIERS	Oregon: *Solar Collectors

ABSTRACT

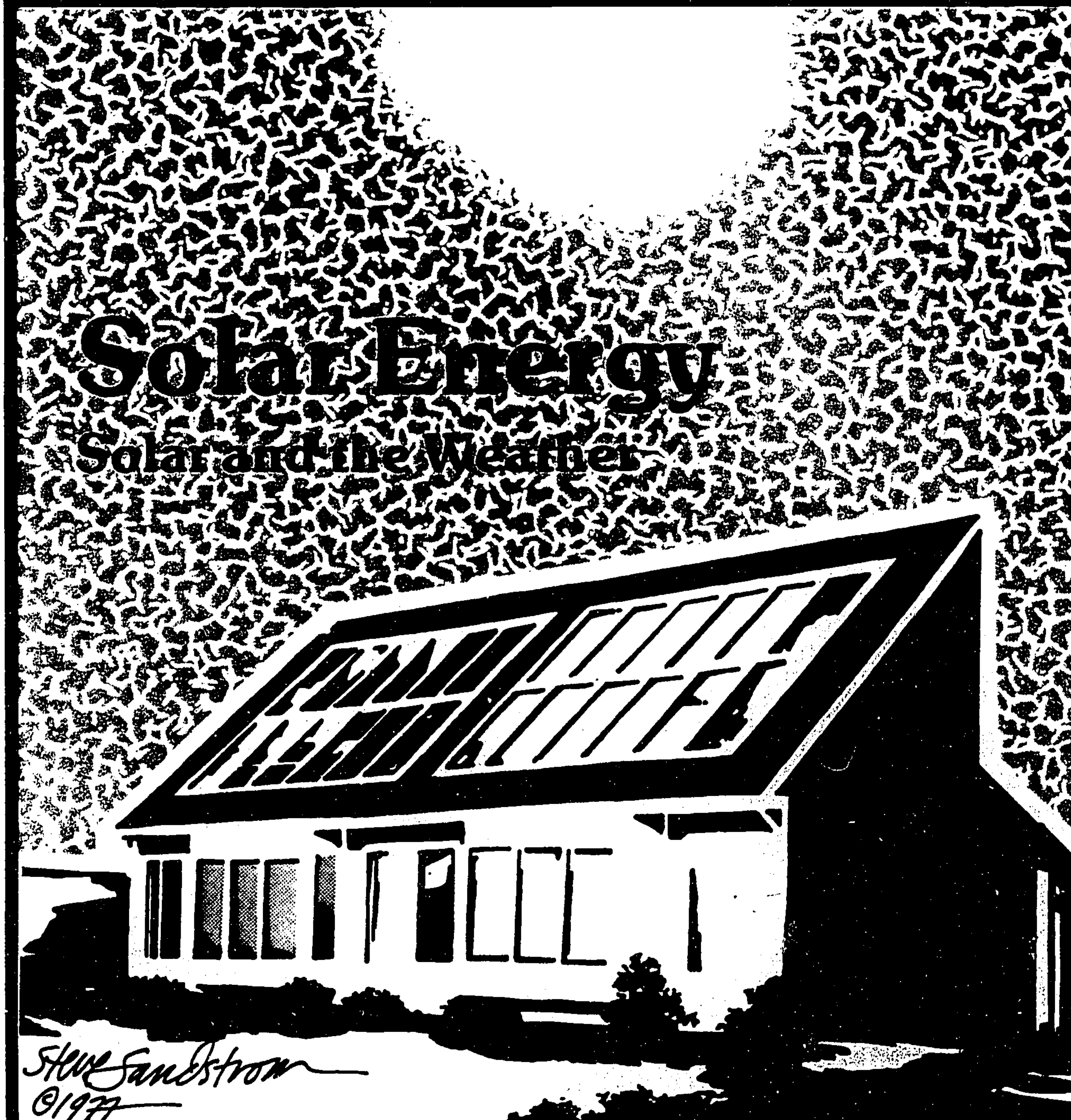
This module on solar and the weather is one of six in a series intended for use as supplements to currently available materials on solar energy and energy conservation. Together with the recommended texts and references (sources are identified), these modules provide an effective introduction to energy conservation and solar energy technologies. The module is divided into these sections: (1) set of objectives: (2) programed instructional materials, consisting of short readings describing ideas and techniques one step at a time, and a question or problem on each reading: (3) review questions and answers at intervals: and (4) posttest. Objectives for this module are for the student to be able to list and explain factors affecting the amount of solar radiation striking a solar collector, estimate solar intensities on solar collectors, and estimate the typical number of cloudy days per clear day. (YLB)

iLS

INDIVIDUALIZED LEARNING SYSTEMS

Solar Energy

Solar and the Weather



Introduction

These modules are intended to be used as supplements to currently available materials on solar energy and energy conservation. The two best available texts are

Leckie, Masters, Whitehouse and Young; Other Homes and Garbage, Sierra Club Books, 1975

and

Anderson, The Solar Home Book, Cheshire Books, 1975

There are several reference works that would also be very useful to have on hand. The three most useful ones are

ASHRAE Guide and Data Book, Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1977.

U.S. Department of Commerce, Climatic Atlas of the United States, Environmental Data Service, Reprinted by the National Oceanic and Atmospheric Administration, 1974.

U.S. Department of Commerce, Monthly Normal of Temperature, Precipitation and Heating and Cooling Degree-Days (1941-1970) National Oceanic and Atmospheric Administration, Climatography of the United States (by state).

The last two references can be obtained from the National Climatic Center, Environmental Data Service, Federal Building, Asheville, NC 28801. The most important data to have on hand are the percent possible sunshine and heating degree-day records for locations in Oregon. They're available in the last two references. Some data are also available in the two texts and the modules themselves.

The modules are designed to simplify and supplement the treatment of some of the subjects discussed in the texts and references. In combination, the modules, texts, and references provide an effective introduction to energy conservation and solar energy technologies.

The technique you'll use to learn the skills presented in this module is called programmed instruction. It's a technique which we think will enable you to learn these new skills quickly and easily.

The module is divided into several sections:

1. A set of objectives, which tells you what you should expect to learn from this module.
2. Programmed instructional material which we'll describe later on in this introduction.
3. A post-test, which will help you find out what you were able to learn by using the module.
4. A student evaluation form which you can use to tell us what you liked and disliked about the module, so we can make it better for students who use it later on.

The programmed part of the module consists of short readings which show you the ideas and techniques you need a step at a time. Most are followed by a question or problem which gives you a chance to review what you just read. Depending on your answer to the question or problem, you'll be guided to another short reading which will either help you review a little more, or introduce you to a new idea or technique. Each short reading is called a frame.

To get the most out of the programmed part, you need to follow the directions exactly. Resist any temptations to skip around, and respond in the best way you can to the question in each frame before moving on to the frame you're told to read next.

It'll help to have pencil, paper, and a pocket calculator handy for some of the computations you're asked to do.

Don't forget about your instructor. You don't have to do it all by yourself. Ask for help with any part of the module that you can't get through by yourself. Good luck!

OBJECTIVES

Overall Objective 1:

The student will be able to list and explain the factors affecting the amount of solar radiation striking a solar collector.

Sub Objectives:

The student will be able to explain how solar intensity is affected by:

A. time of year

B. collector tilt

C. local weather conditions

The student will be able to list the most common collector tilt angles used in Oregon, and give a likely use for a solar collector tilted at each angle.

Overall Objective 2:

The student will be able to estimate solar intensities on horizontal, vertical and tilted solar collectors using percent possible sunshine data for any location in Oregon.

Overall Objective 3:

The student will be able to estimate the typical number of cloudy days per clear day using either percent possible sunshine data or horizontal solar intensity data for any location in Oregon.

1. Part of the process of designing any system is attempting to predict what the system will do after it's been built. You had a glimpse of the prediction process when you learned how to predict the rate of heat loss from a building in module 3.

To predict the heat loss of the building, you had to make a good guess at what the temperature outside the building was going to be. You had to estimate how cold it would be on very cold days, and what the average outside temperature would be over long periods of time.

To predict the performance of a solar heating system, you need to have a good idea of how much heat energy will be available from the sun. You have to estimate how much will be available on sunny days, cloudy days, and on the average over long periods of time.

Unfortunately, records of arriving solar energy haven't been kept as well as records of outside temperature. Arriving solar radiation has only been measured in a few locations around the country, and often those measurements haven't been very accurate. Go to frame 2.

---

2. The intensity of solar radiation arriving on a flat surface is usually described in units of BTU/Ft.^{2}-Hr. or BTU/Ft.^{2}-Day. Those units are the most convenient ones to use when you're comparing the rate of solar heat arriving to the rate of heat loss from a building. Both involve BTU and hours or days, so they can be compared fairly easily.

You'll occasionally see a map or a record of solar radiation which gives the intensity of the arriving solar energy in units called langleys per day. A langley is a metric unit which is equal to 3.69 BTU/Ft.^{2}. 1 langley/Day = 3.69 BTU/Ft.^{2}-Day. It's almost always easiest to change a solar radiation measurement given in langleys to one in BTU/Ft.^{2} before trying to use it to predict the performance of a solar system. Write down the conversion factor between langleys and BTU/Ft.^{2}. Check your answer in frame 3.

---

3. The conversion factor is 3.69 $BTU/Ft.^2$-langley. As an example:

$$100 \text{ langley/Day} = (3.69 \text{ BTU/Ft.}^2\text{-langley}) (100 \text{ langley/Day})$$
$$= 369 \text{ BTU/Ft.}^2\text{-Day}$$

The intensity of solar radiation arriving in a given location is almost always measured with a detector that sits on a flat surface parallel to the ground. The amount of radiation that's measured in that way is called the horizontal insolation, and is usually represented by the symbol H. The word ins*o*lation sounds and looks a lot like the word ins*u*lation. It's not. It means the amount of solar energy arriving. Go to frame 4.

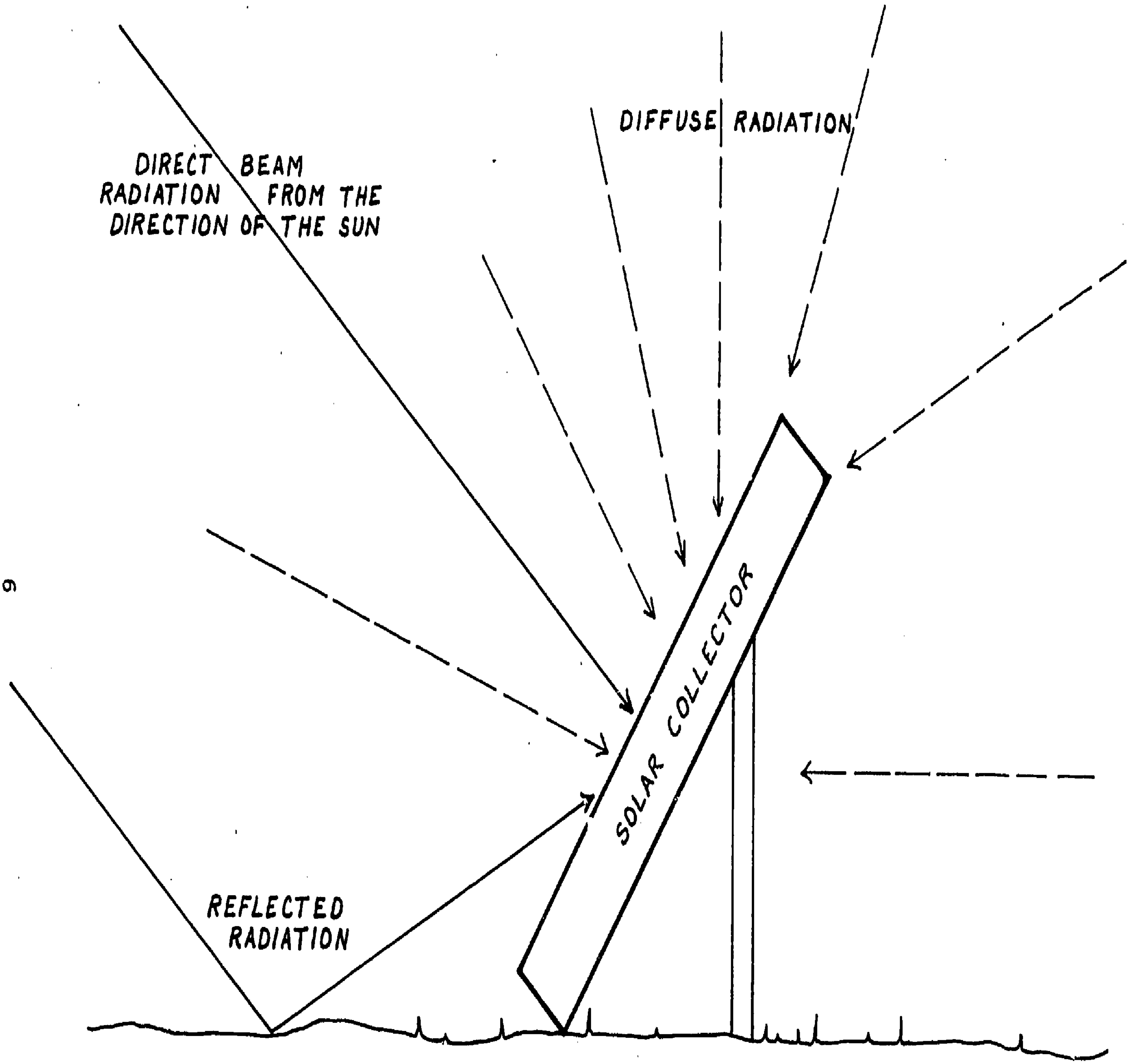
---

4. Radiation coming straight from the direction of the sun is called direct beam radiation. Tilting a solar collector to point directly at the sun increases the intensity of the direct beam radiation landing on it. Direct beam radiation is by far the most intense form of solar radiation on clear days.

There are two other kinds of solar radiation. One is called diffuse radiation. It's the sunlight scattered by clouds and dust in the sky. It arrives from all directions. A horizontal solar collector (lying flat parallel to the ground) collects the maximum possible amount of that type of radiation. A tilted collector misses the diffuse radiation coming from behind it.

The third kind of solar radiation is called reflected radiation. It's the radiation that gets reflected off the ground and onto a tilted solar collector or south facing building wall. Horizontal solar collectors don't receive any of that type of radiation.

Name the three kinds of solar radiation, and describe the differences between them. Check your answers in frame 5.



THE THREE TYPES OF SOLAR RADIATION

5. Direct beam radiation comes from the direction of the sun. It's by far the most intense form of solar radiation on clear days. Diffuse radiation is sunlight scattered by clouds and dust in the atmosphere. Reflected radiation is sunlight reflected off the ground.

Tilting a solar collector to face the sun more directly increases the intensity of the direct beam radiation and reflected radiation landing on it, but reduces the intensity of diffuse radiation it receives. On clear days, direct beam and reflected radiation are much stronger than diffuse radiation, so a collector aimed directly at the sun receives much more solar radiation than one lying flat on the ground. On cloudy days, diffuse radiation can be as intense as direct beam and reflected radiation, so a horizontal collector could receive about as much solar energy as a tilted one.

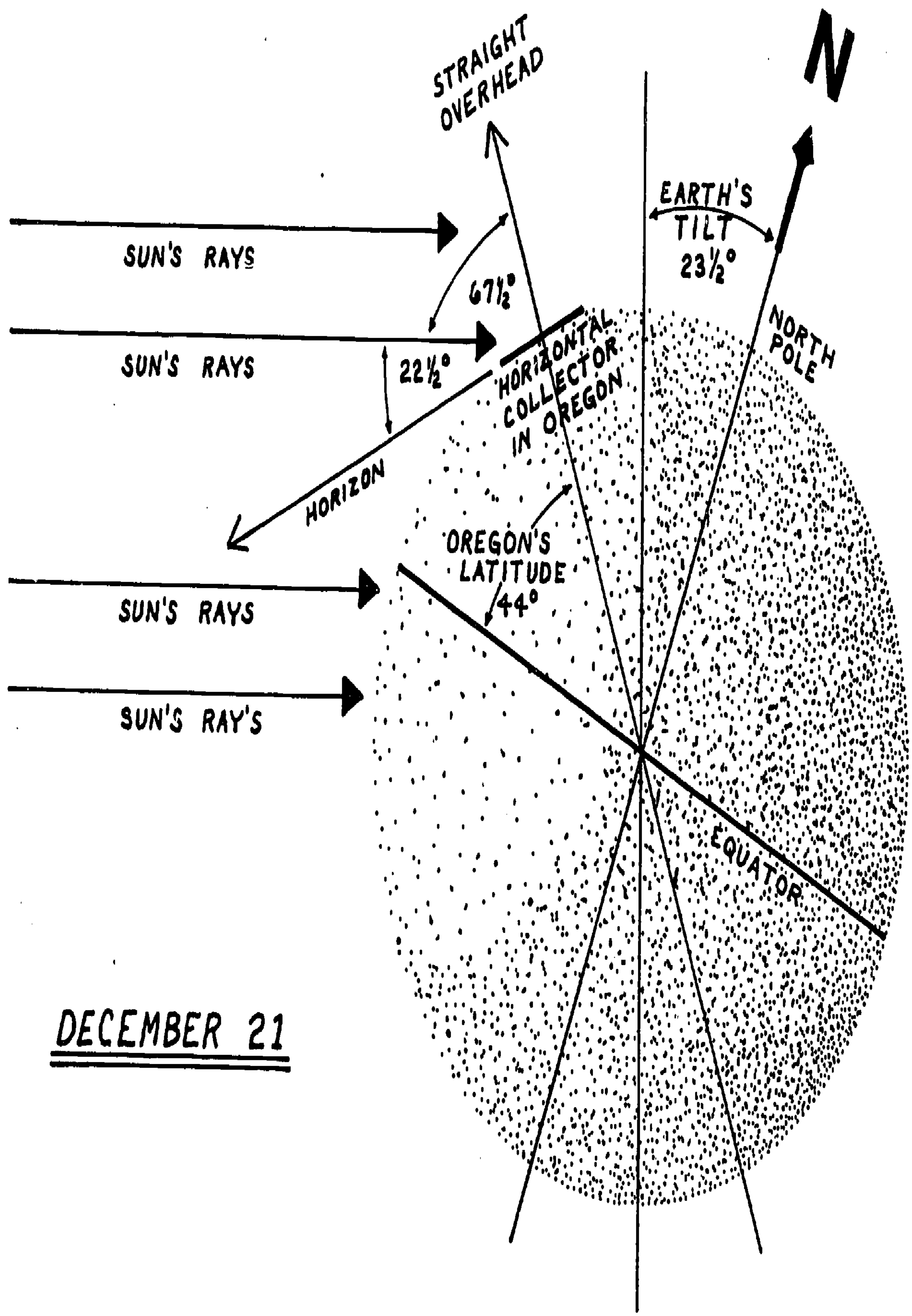
You can see that measuring the amount of horizontal insolation--the intensity of solar radiation arriving on a flat surface parallel to the ground--won't tell you directly how much radiation will fall on a collector surface tilted toward the sun. On clear days a tilted surface will receive much more solar radiation than a horizontal surface, and on cloudy days it might not receive as much. Go to frame 6.

---

6. The best angle of tilt for a solar collector depends on the angle between the ground and a straight line aimed toward the sun. When the sun is directly overhead, a collector lying flat on the ground is aimed straight up at it. When the sun is low, near the horizon, a collector has to be standing almost straight up to be aimed in its direction.

Because the earth's surface is curved and Oregon is at about 44° N. latitude, the ground in Oregon is tilted about 44° away from the direction of the sun in spring and fall. At noon the direction to the sun is 44° away from straight overhead or 46° above the southern horizon. A solar collector should be tilted up toward the south at about a 44° angle to be aimed directly at the sun at noon in spring or fall.

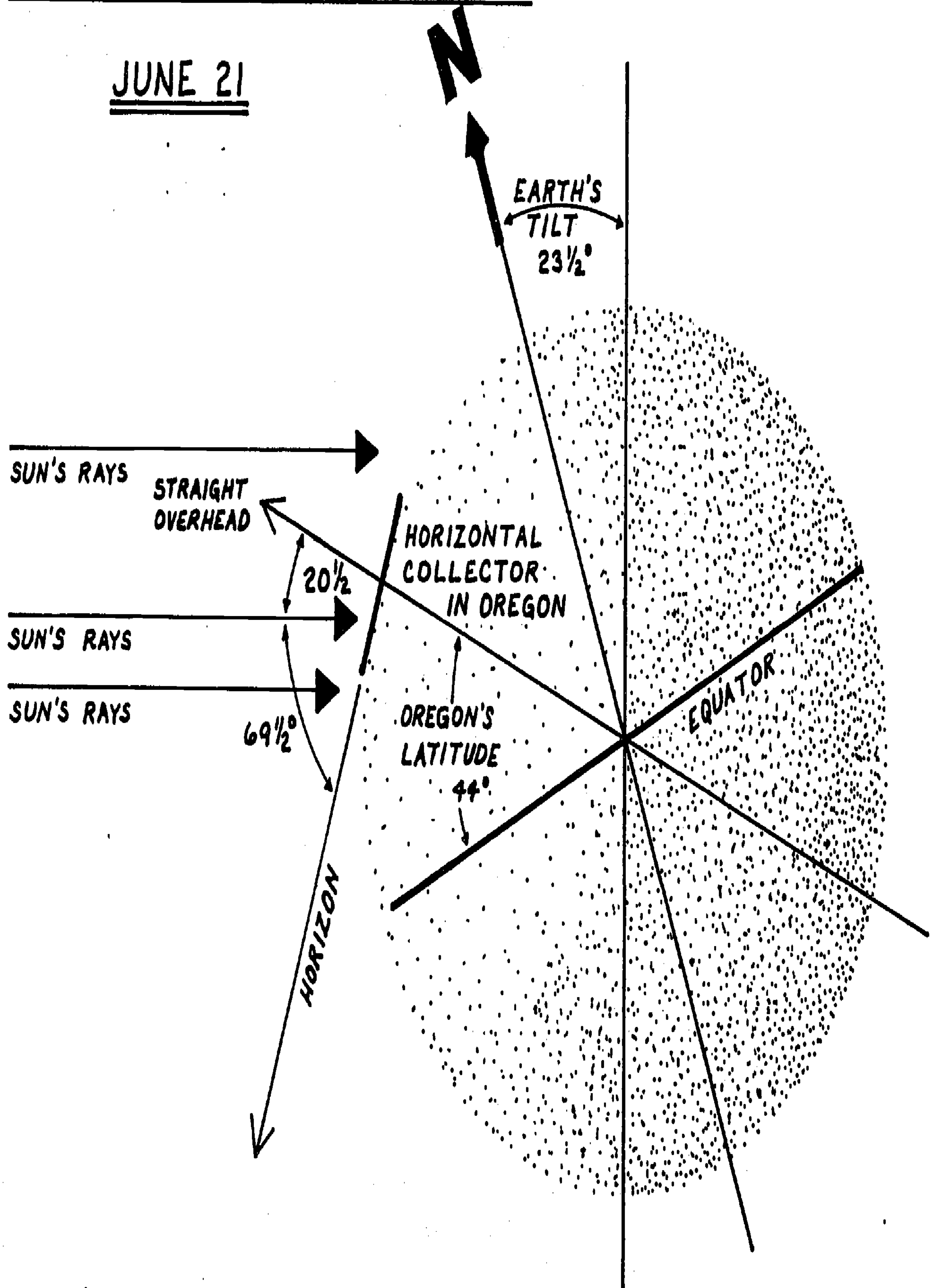
The earth's axis of rotation is tilted by about 23.5°. In summer, the northern hemisphere (including Oregon) is tilted toward the sun. In winter, it's tilted away. The tilt of the earth's axis increases the angle



EFFECT ON THE EARTH'S TILT and THE LATITUDE ON HORIZONTAL SOLAR INTENSITY.

EFFECT ON THE EARTH'S TILT and THE LATITUDE ON HORIZONTAL SOLAR INTENSITY.

JUNE 21



9

of the ground's tilt away from the sun in winter, and decreases it in summer.

At noon on December 22, the winter solstice, the ground in Oregon is tilted about $44^{o} + 23.5^{o} = 67.5^{o}$ away from the direction of the sun. The direction to the sun is 67.5^{o} to the south of straight overhead, so the sun is only 22.5^{o} above the southern horizon. A solar collector should be tilted up toward the south at about a 67^{o} angle to be aimed directly at the sun at noon on December 22.

At noon on June 22, the summer solstice, the ground in Oregon is tilted about $44^{o} - 23.5^{o} = 20.5^{o}$ away from the sun. The direction to the sun is 20.5^{o} to the south of straight over head, so the sun is 69.5^{o} above the southern horizon. A solar collector should be tilted up toward the south at about a 20^{o} angle to be aimed directly at the sun at noon on June 22.

On a typical summer or winter day, the earth's tilt changes the angle between the ground and a surface aimed directly at the sun by 10^{o} to 15^{o}. The rest of the angle is due to the curvature of the earth and is equal to the latitude of the location. So in Oregon the average angle between the ground and a surface aimed directly at the sun varies from about 60^{o} in winter to about 30^{o} in summer. The year-round average angle between the ground and a surface aimed directly at the sun is the latitude--about 44^{o}.

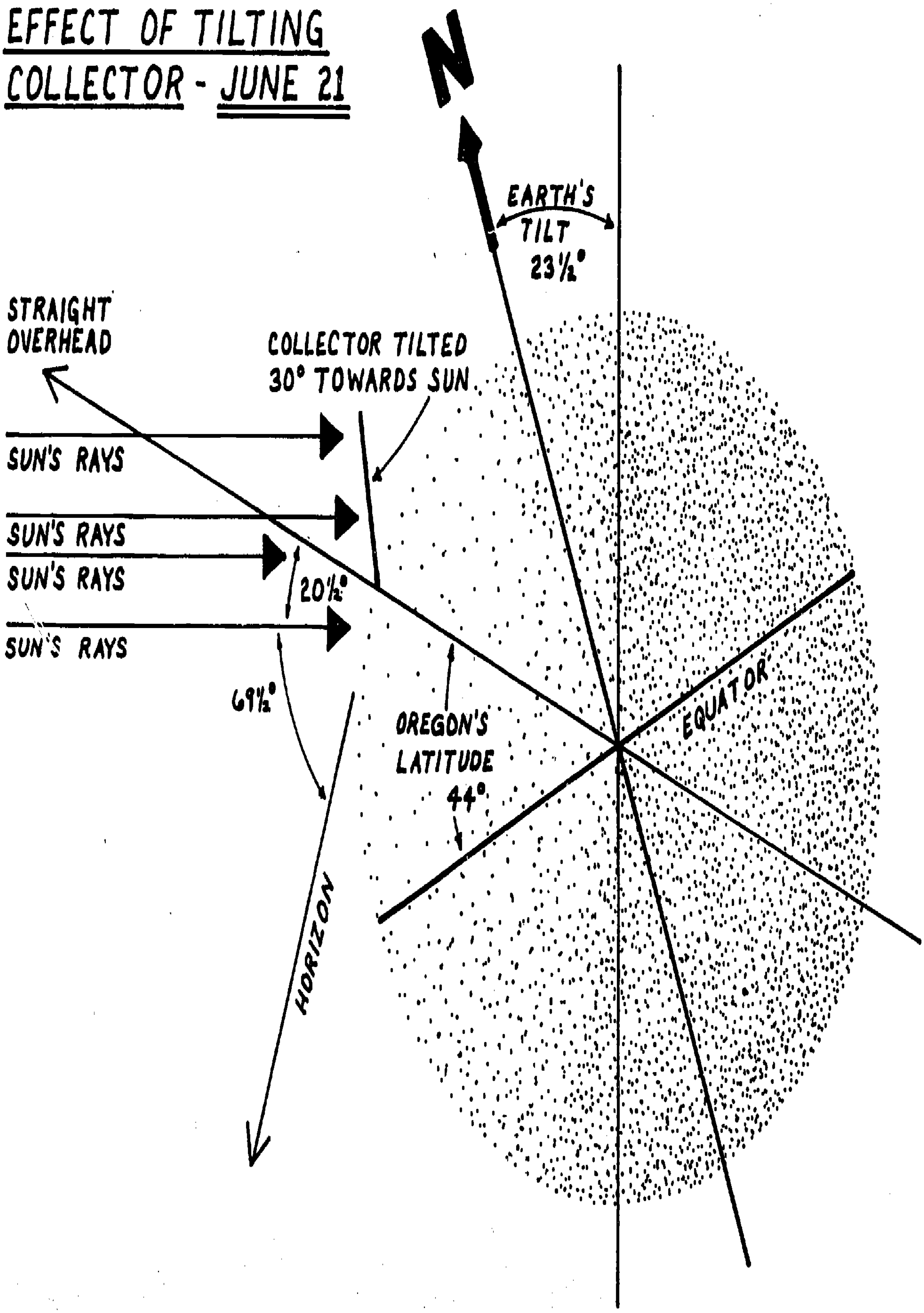
What's the best tilt angle for a solar collector that will be used to heat a home in winter in Oregon?

What's the best tilt angle for a solar collector that will be used to heat domestic hot water in Oregon?

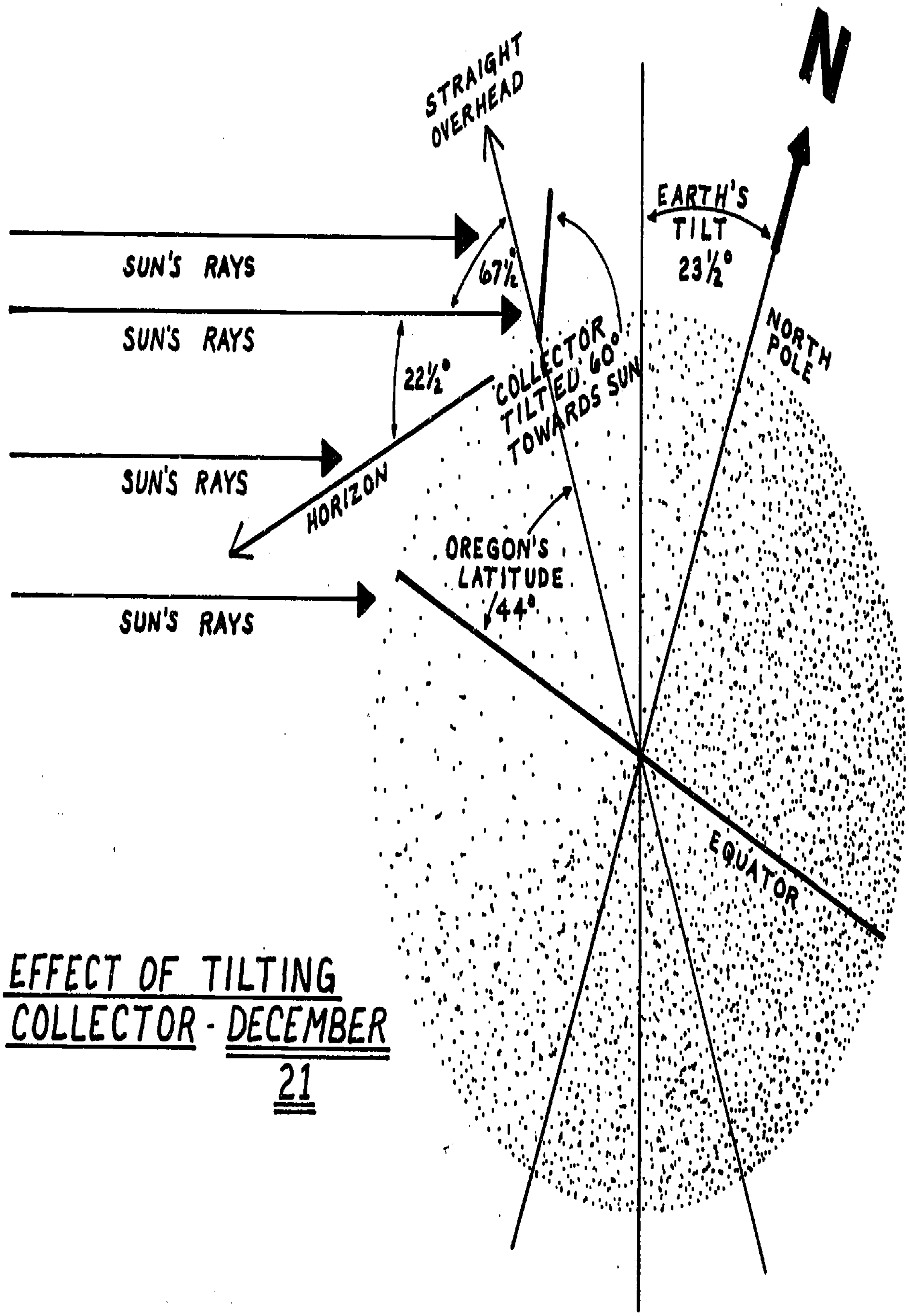
What's the best tilt angle for a solar collector that will be used to heat an outdoor swimming pool in Oregon?

Check your answers in frame 7.

EFFECT OF TILTING COLLECTOR - JUNE 21



11



EFFECT OF TILTING COLLECTOR - DECEMBER 21

7. The sun is at about a 60^{o} angle south of straight overhead at noon in the winter in Oregon, so a solar collector used for winter heat should be tilted up off the ground at about a 60^{o} angle toward the south.

On average, year-round, the sun in Oregon is at about a 44^{o} angle south of straight overhead at noon. A solar collector used to heat hot water year-round in Oregon should be tilted up toward the south at about a 44^{o} angle.

At noon in the summer in Oregon, the sun is at about a 30^{o} angle south of straight overhead. A solar collector used to heat an outdoor pool in Oregon should be tilted up toward the south at about a 30^{o} angle.

The surface of a solar collector can be tilted 5^{o} or 10^{o} away from the exact direction of the sun without greatly reducing the intensity of the solar radiation hitting the collector. You can vary the position of a collector slightly without losing much of the solar energy which might hit it.

Go on to frame 8.

---

8. It should be obvious by now that in Oregon a solar collector tilted up toward the south will collect more solar energy than a collector lying parallel to the ground. How much more depends on how directly the collector is aimed at the sun and how the amount of direct beam solar radiation compares with the amount of diffuse solar radiation.

Whether the collector is aimed directly at the sun depends on the collector tilt and the time of year. How much direct beam and diffuse radiation there is depends on the weather.

Of course, in winter both a tilted collector and a horizontal one receive less radiation than in summer, spring, or fall. The sun doesn't shine as many hours, and the weather is much cloudier.

We've said (in frame 5) that measurements of solar radiation are almost always made for horizontal collectors. We've also said (in frame 1) that records of such measurements haven't been kept for many locations in the United States. That means that you'll find virtually no information about solar radiation on tilted collector surfaces, and very little about solar radiation on horizontal surfaces.

Go to frame 9.

9. There's a way to convert estimates of the solar energy arriving on horizontal collectors into estimates of solar energy arriving on tilted collectors.

If you have good information about how much solar radiation you can expect on a horizontal collector in your area, you can make an estimate of how much more energy you can get by tilting the collector.

There's also a pretty good way to estimate how much solar energy will fall on a horizontal collector in an average month. It's based on knowing how much will arrive at the collector on a clear day in that month and knowing the percentage of the time the sky is clear during that month. The two numbers you use are called the clear day horizontal insolation and the percent possible sunshine.

The clear day horizontal insolation varies only with the latitude of the location and the time of year. Locations at the same latitude get the same amount of solar radiation at the same time of year on clear days.

The numbers in the first column of the table in this frame give the average clear day horizontal insolation for each month at 44° N. latitude, which corresponds to central Oregon. The second column contains information about solar radiation outside the earth's atmosphere. You'll learn how to use it later on.

The main references for these modules contain tables for other latitudes which also include clear day solar radiation on tilted surfaces. Those tables are for specific days of the year.

Solar Radiation on a Flat Surface
Parallel to the Earth's Surface at 44° N. Latitude
(Horizontal Insolation)

Month	H_0' - Monthly Average Clear Day at Earth's Surface (BTU/Ft.^{2}-Day)	H_0 - Monthly Average Extraterrestial (BTU/Ft.^{2}-Day)
Jan.	710	1100
Feb.	1120	1590
Mar.	1570	2220
Apr.	2060	2920
May	2420	3420
Jun.	2590	3640

Jul.	2500	3530
Aug.	2200	3110
Sep.	1730	2460
Oct.	1240	1770
Nov.	790	1230
Dec.	620	975

The percent possible sunshine varies with the weather. Different locations at the same latitude will have different proportions of clear and cloudy days. In any month the difference in horizontal insolation between two locations at the same latitude is entirely due to the difference in percent possible sunshine. Tables of percent possible sunshine for various area around Oregon are available from the National Oceanic and Atmospheric Administration. The introduction has information on how to obtain them.

List and explain the two numbers you can use to estimate the average amount of horizontal insolation for a particular location and time of year. Check your answers in frame 10.

---

10. The clear day horizontal insolation tells you how much solar radiation hits a horizontal surface at the time of year and latitude you're interested in. The percent possible sunshine tells you how much of the

time it's clear during the month at the exact location you're interested in.

Once you know the clear day horizontal insolation and the percent possible sunshine for the month and location, you can use a simple formula to estimate the average daily horizontal insolation. The formula is

$$H_{AV} = H_o' \left[.30 + .65 \left(\frac{\%\ \text{sunshine}}{100}\right)\right]$$

H_{AV} stands for the average daily horizontal insolation in BTU/Ft.^{2}-Day.

H_o' stands for the clear day horizontal insolation for the latitude and month.

The symbol ' is pronounced "prime." $[.30 + .65 (\frac{\%\ \text{sunshine}}{100})]$ is a correction factor which allows for the effects of clouds. It translates to "divide the percent possible sunshine by 100, multiply by .65 and add .30." The .30 is an estimate of the fraction of clear day radiation that would get through on a completely cloudy day. The .65 is an estimate of the additional direct beam radiation that would arrive on a 100% clear day. The % sunshine/100 is the portion of an "average day" of that month when the sky is clear in a particular location.

The correction factor is a statistical estimate which actually varies depending on the climate in the location. We've picked a kind of "average" correction factor which should work pretty well for Oregon.

Write down the formula for Oregon's average daily horizontal insolation and explain its symbols. Check your answer in frame 11.

11. The formula is

$$H_{AV} = H_o' \; [.30 + .65 \; (\frac{\% \text{ sunshine}}{100})]$$

H_{AV} stands for average daily horizontal insolation in BTU/Ft.^{2}-Day.

H_o' stands for clear day horizontal insolation for the month and latitude of interest in BTU/Ft.^{2}-Day.

$[.30 + .65 \; (\frac{\% \text{ sunshine}}{100})]$ stands for "divide the percent possible sunshine by 100, multiply by .65 and add.30." It's a correction factor for the effects of cloudiness.

You use the table of monthly average clear day horizontal insolation for 44^o N. latitude in frame 9 to find H_o'. You use the Climatic Atlas of the United States local weather data to find percent possible sunshine.

Here's an example:

In December in the Willamette Valley, the percent possible sunshine is about 15%. From the table of clear day horizontal insolation at 44^o N. latitude, we find that the average horizontal insolation on a clear day in December is 620 BTU/Ft.^{2}-Day. Using the formula for H_{AV}, we get

$$H_{AV} = 620 \text{ BTU/Ft.}^2\text{-Day } [(.30 + .65 \; (\frac{15}{100})]$$

$$H_{AV} = 620 \text{ BTU/Ft.}^2\text{-Day } [.30 + .65 \; (.15)]$$

$$H_{AV} = 620 \text{ BTU/Ft.}^2\text{-Day } [.30 + .0975]$$

$$H_{AV} = 620 \text{ BTU/Ft.}^2\text{-Day } [.398]$$

$$H_{AV} = 247 \text{ BTU/Ft.}^2\text{-Day}$$

So, the average horizontal insolation in December in the Willamette Valley is about 247 BTU/Ft.^{2}-Day. That number includes the effects of the latitude, seasonal changes of the earth's position in relation to the sun, and the weather in the Willamette Valley.

Here's one for you. The percent possible sunshine for November in the Willamette Valley is about 30%. What's the average daily horizontal insolation for November? Be sure to use the correct column of the table. The left hand column is clear day horizontal insolation at the earth's surface, which is what you want. The right hand column is horizontal insolation at 44^o N. latitude in outer space. You'll use that later. Check your answer in frame 12.

12. You should have

$$H_{AV} = 391 \text{ BTU/Ft.}^2\text{-Day}$$

Check your work carefully if you didn't get that answer. If you still can't get it, look at the solution in frame 13. When you get it, go to frame 14.

---

13. Here's the solution:

$$H_{AV} = H_o' \; [.30 + .65 \; (\frac{\%\ \text{sunshine}}{100})]$$

From the table, H_o' = 790 BTU/Ft.^{2}-Day for November.

$$H_{AV} = 790 \text{ BTU/Ft.}^2\text{-Day } [.30 + .65 \; (\frac{30}{100})]$$

$$H_{AV} = 790 \text{ BTU/Ft.}^2\text{-Day } [.30 + .65 \; (.30)]$$

$$H_{AV} = 790 \text{ BTU/Ft.}^2\text{-Day } [.30 + .195]$$

$$H_{AV} = 790 \text{ BTU/Ft.}^2\text{-Day } [.495]$$

$$H_{AV} = 391 \text{ BTU/Ft.}^2\text{-Day}$$

Look at it carefully. Make sure you can use the table. Look at how the brackets were handled.

---

14. The formula is easy to use after a little practice.

Here's another one:

The percent possible sunshine in January in the Willamette Valley is about 20%. Find H_{AV}. Check your answer in Frame 15.

15. You should have H_{AV} = 305 BTU/Ft.^{2}-Day. If you don't, check to see whether you followed the procedure outlined in frames 11 and 13. Check all your computations. When you've got it, go on to frame 16.

16. O.K. You can find H_{AV} using the clear day horizontal insolation data in one table and information about percent possible sunshine. For some locations H_{AV} is reported directly. For all locations where either percent possible sunshine or horizontal insolation are reported, you can get H_{AV}.

H_{AV} is the average daily insolation on a horizontal surface. It's an estimate of the intensity of solar radiation that will hit the ground on an average day in a particular month. The effects of clouds and the tilt and curvature of the earth are all included in the estimate of H_{AV}.

Of course what you'd like to know is the intensity of solar radiation striking the surface tilted toward the south. You expect it to be greater than the intensity of radiation striking the ground, because a tilted collector is aimed more directly at the sun.

Tilting the collector to the south will increase the intensity of the direct beam radiation falling on it and reduce the intensity of diffuse radiation falling on it. It may also add some reflected radiation bounced off the ground. Exactly what happens depends on how cloudy the weather is and how far the earth's surface is tilted away from the direction of the sun. Go on to frame 17.

---

17. If the earth had no atmosphere there would be no clouds or dust to scatter, or diffuse, the sun's rays. H_{AV} would be made up entirely of direct beam radiation. Monthly variations in H_{AV} would be due only to the changes in angle between the earth's surface and the direction to the sun. H_{AV} would be larger than the values we actually measure, because none of the radiation aimed at the ground would be deflected by clouds or dust in the atmosphere.

The value H_{AV} would have if the earth had no atmosphere is called H_o. It's also called the extraterrestrial horizontal insolation. H_o has been computed for all latitudes and months by using satellite measurements of solar radiation. The satellite measurements have been corrected to take the curvature and tilt of the earth into account. The value of H_o for each month in Oregon is listed in the second column of the table in frame 9 -- the small table that contains the monthly values of H_o' -- the average clear day horizontal insolation.

Go on to frame 18.

---

18. A glance at the table will show you that in every month H_o is greater than H_o' . That's because even on clear days quite a lot of solar radiation is scattered by dust and water vapor in the atmosphere.

The ratio of H_{AV} to H_o, written H_{AV}/H_o, is called K_T. It's always less than 1. Compute K_T for an average clear day in Oregon in December.

Check your answer in frame 19.

The scattered light is just diffuse solar radiation. The value of K_T can also give you a rough estimate of how much direct beam radiation is getting through the atmosphere. The higher the value of K_T, the more direct beam radiation is reaching the ground.

As we said before, tilting a solar collector toward the south will increase the intensity of the direct beam radiation hitting it, but decrease the intensity of the diffuse radiation. The increase in radiation intensity on the collector when you tilt it thus depends on the relative amounts of diffuse and direct beam radiation reaching the ground. The value of K_T can give you some indication of those relative amounts.

Suppose the percent possible sunshine in Portland in April is 40%. Find H_{AV} and K_T for the average April day in Portland. Check your answer in frame 22.

92

19. $K_T = .636$

You use the December value of H_o' for H_{AV} and then use $K_T = H_{AV}/H_o$

$K_T = \frac{620 \text{ BTU/Ft.}^2\text{-Day}}{975 \text{ BTU/Ft.}^2\text{-Day}} = .636$ The units cancel out.

What's K_T for an average clear day in January in Oregon?

Check your answer in frame 20.

---

20. $K_T = .645$

If you didn't get it, check back into the procedure shown in frames 18 and 19. Make sure you used the right numbers from the table. When you've got it, go on to frame 21.

---

21. Notice that an average clear day in January has a higher value of K_T than an average clear day in December — .645 instead of .636. In June in Oregon, K_T for an average clear day is .712. That's because when the sun is higher in the sky its light passes through a smaller thickness of the earth's atmosphere and less of it is scattered. The sun is lowest in the sky in December, somewhat higher in January, and highest in June. The value of K_T gives you a rough idea of how much sunlight is being scattered from clouds and dust. The lower its value, the more light is being scattered.

22. You should have written

$$H_{AV} = H_o' \; [.30 + .65 \; (\frac{\%\ sunshine}{100})]$$

$$H_{AV} = 2060 \text{ BTU/Ft.}^2\text{-Day} \; [.30 + .65 \; (\frac{40}{100})]$$

$$H_{AV} = 2060 \text{ BTU/Ft.}^2\text{-Day} \; [.30 + .65 \; (.40)]$$

$$H_{AV} = 2060 \text{ BTU/Ft.}^2\text{-Day} \; [.30 + .26]$$

$$H_{AV} = 2060 \text{ BTU/Ft}^2\text{-Day} \; (.56)$$

$$H_{AV} = 1153.6 \text{ BTU/Ft.}^2\text{-Day}$$

$$K_T = H_{AV}/H_o$$

$$K_T = \frac{1153.6 \text{ BTU/Ft.}^2\text{-Day}}{2920 \text{ BTU/Ft.}^2\text{-Day}}$$

$$K_T = .395$$

Try this one. The percent possible sunshine for July in Eugene is about 60%. What are H_{AV} and K_T for an average July day in Eugene? Check your answer in frame 23.

94

30

23. H_{AV} = 1725 BTU/Ft.^{2}-Day

K_T = .489

Make sure you used the right values of H_o' and H_o and computed H_{AV} using H_o' and the correct formula. When you get our answers, go on to frame 24.

---

24. Good. Now you can estimate H_{AV} <u>and</u> K_T for an average day of any month in any location in Oregon, if you know the percent possible sunshine for that month and location. It's only one step from estimating H_{AV} and K_T to estimating how much solar radiation will fall on a tilted collector in an average day in that month and location.

We already said that the value of K_T gives you some indication of how much direct beam radiation is reaching the earth from the sun. The direct beam radiation is the part of the radiation which increases in intensity when a solar collector is tilted toward the sun. The value of K_T must be associated in some way with the increase in the intensity of solar radiation which can be obtained by tilting a solar collector toward the south.

Computer studies have been made that related K_T to the portion of H_{AV} which is composed of direct beam radiation. Those studies have then been used to estimate the gain in intensity that would occur if a collector were tilted up toward the south. The results of the studies are tables of a number called R.

R is the ratio of the intensity of solar radiation on a south-facing tilted solar collector to the intensity of solar radiation on a horizontal collector. R varies depending on the time of year, the latitude of the location, the angle of the collector tilt, and K_T.

This frame contains tables of R for various values of K_T, all the months of the year, and various collector angles. The tables are for 44^o N. latitude, which corresponds to central Oregon. We chose collector angles and months suitable for solar space, hot water, and swimming pool water heating.

More complete tables for other latitudes are available in the appendices of the U.S. Department of Housing and Urban Development's

"Intermediate Minimum Property Supplement, Solar and Domestic Hot Water Systems" (Document 4930.2).

Using the tables is easy. First you find or compute H_{AV} for the month and location. Then you compute K_T using the table of values of H_o. You then look in the table of R for the collector angle you've chosen. Find the value of R that corresponds to the month and the nearest value of K_T.

For example, you found that K_T for July in Portland is about .489. If you look in the tables of R for K_T = .5 (the closest value to .489) you'll find that R for a 30° tilted collector in July is .96. For a 45° tilted collector in July, R is .87.

Tables of R at 44° N. Latitude for Various Values of K_T

Vertical Collector

K_T	.3	.4	.5	.6	.7
Oct.	1.04	1.18	1.29	1.36	1.45
Nov.	1.21	1.68	1.86	2.02	2.17
Dec.	1.66	2.01	2.26	2.46	2.06
Jan.	1.52	1.82	2.06	2.22	2.39
Feb.	1.15	1.32	1.46	1.56	1.67
Mar.	.82	.92	.98	1.02	1.07
Apr.	.63	.64	.65	.65	.65

60° Collector Tilt

K_T	.3	.4	.5	.6	.7
Oct.	1.25	1.40	1.50	1.59	1.68
Nov.	1.59	1.82	2.01	2.16	2.30
Dec.	1.79	2.11	2.35	2.53	2.73
Jan.	1.67	1.95	2.16	2.32	2.49
Feb.	1.35	1.53	1.66	1.76	1.87
Mar.	1.09	1.18	1.25	1.30	1.36
Apr.	.90	.93	.96	.97	.98

45° Collector Tilt

K_T	.3	.4	.5	.6	.7
Jan.	1.61	1.85	2.02	2.17	2.30
Feb.	1.26	1.50	1.63	1.70	1.80
Mar.	1.14	1.22	1.28	1.33	1.38
Apr.	.99	1.02	1.04	1.05	1.07
May	.90	.90	.90	.91	.91
Jun.	.86	.86	.85	.85	.84
Jul.	.88	.88	.87	.87	.87
Aug.	.94	.96	.98	.99	1.00
Sep.	1.07	1.13	1.17	1.21	1.25
Oct.	1.27	1.40	1.49	1.56	1.64
Nov.	1.54	1.75	1.90	2.02	2.15
Dec.	1.72	1.98	2.17	2.33	2.49

30° Collector Tilt

K_T	.3	.4	.5	.6	.7
Apr.	1.02	1.06	1.07	1.09	1.10
May	.97	.97	.98	.98	.99
Jun.	.94	.94	.94	.94	.94
Jul.	.95	.95	.96	.96	.96
Aug.	1.00	1.02	1.03	1.04	1.05
Sep.	1.10	1.14	1.17	1.20	1.23

96

You found that K_T in Portland in April is .395.
What are the values of R for
A 60^o tilted collector?
A 45^o tilted collector?
A 30^o tilted collector?
A vertical surface?
Check your answers in frame 25.

---

25. You should have the following values of R:

60^o tilt: R = .93
45^o tilt: R = 1.02
30^o tilt: R = 1.06
Vertical: R = .64
The closest K_T value was .4.

Having found R, it's easy to compute the average solar radiation intensity on a tilted collector in the month of interest. You just use the formula

$$I = RH_{AV}$$

I stands for intensity on a tilted surface. The formula uses the definition of R as the ratio of the intensity of solar radiation on a tilted south-facing solar collector (I) to the intensity of solar radiation on a horizontal collector (H_{AV}).

$$R = I/H_{AV}$$

Reversing the formula you get

$$I = RH_{AV}$$

so you can work from H_{AV} and R to get I.

You probably noticed that several of the values of R that we looked up in the tables were less than 1. That means that in those months and for those collector tilts, I is less than H_{AV}.

Low values of R occur in some months for any collector tilt because the direction of the sun is continually changing with the seasons. Collector tilts are chosen to give high <u>average</u> values of R over longer periods than one month.

Go on to frame 26.

---

26. You're now prepared to estimate the average intensity of solar radiation on a tilted collector for any month and all useful collector tilt angles. The procedure is as follows:

1. Find the average horizontal intensity (H_{AV}) for the month. You can use records of direct measurements, or records of percent possible sunshine, the table of clear day horizontal intensities (H_o') and the formula you learned.
2. Find K_T for the H_{AV} you just found by dividing H_{AV} by the average extraterrestrial horizontal intensity for the month (H_o).
3. Find the R in the tables which corresponds to the month, collector angle, and the value of K_T closest to the one you computed.
4. Multiply H_{AV} by R to find I, the average intensity on a tilted collector.
5. Relax, you're done — at least for that month.

Here's an example:

Suppose the percent possible sunshine in October in Portland is 40%. Find H_{AV}, K_T, R, and I, for a collector tilted at a 60^o angle toward the south.

1. We use

$$H_{AV} = H_o' [.30 + .65 (\frac{\% \text{ sunshine}}{100})]$$

H_o' is 1240 BTU/Ft.^{2}-Day in October, according to the table.

$$H_{AV} = 1240 \text{ BTU/Ft.}^2\text{-Day } [.30 + .65 (\frac{40}{100})]$$

$$H_{AV} = 1240 \text{ BTU/Ft.}^2\text{-Day } [.30 + .65 (.4)]$$

$$H_{AV} = 1240 \text{ BTU/Ft.}^2\text{-Day } [.30 + .26]$$

$$H_{AV} = 1240 \text{ BTU/Ft.}^2\text{-Day } [.56]$$

$$H_{AV} = 694.4 \text{ BTU/Ft.}^2\text{-Day}$$

2. H_o for October is 1770 BTU/Ft.^{2}-Day.

$$K_T = \frac{H_{AV}}{H_o}$$

$$K_T = \frac{694.4 \text{ BTU/Ft.}^2\text{-Day}}{1770 \text{ BTU/Ft.}^2\text{-Day}}$$

$$K_T = .392$$

3. From the tables of R for October, a 60^o collector tilt angle, and $K_T = .4$, we get R = 1.40.

4. $I = RH_{AV}$

$I = (1.40)$ (694.4 BTU/Ft^2-Day)

$I =$ 972.2 BTU/Ft.^{2}-Day)

Go on to frame 27.

---

27. Now you try one. Suppose the percent possible sunshine in Bend in December is 40%. What are H_{AV}, K_T, R and I for a collector tilted at a 60^o angle? Check your answers in frame 28.

---

28. H_{AV} = 347.2 BTU/Ft.^{2}-Day

K_T = .36

R = 2.11

I = 732.6 BTU/Ft.^{2}-Day

You notice we used the value of R for K_T = .4. It's a little high, because K_T is actually .36, but the error is small compared to the probable error in H_{AV} and K_T.

If you had trouble getting our answers, go over the example in frame 26 and try again. The most likely place for a mistake is in using the formula for H_{AV}. Check carefully also to see that you looked things up properly in the tables. Go on to frame 29.

---

29. Here's another problem. Suppose the percent possible sunshine in Prineville in January is 50%. What are H_{AV} and K_T? What are R and I for a collector tilted at a 60^0 angle? Check your answers in frame 30.

---

30. H_{AV} = 443.75 BTU/Ft.^{2}-Day

K_T = .40

R - 1.95

I = 865.3

Go over this problem and the example in frame 26 until you get our answers. Get help from your instructor if you need it. When you've got it, go on to frame 31.

---

31. Congratulations. You should now be able to compute average solar radiation intensities for tilted collectors in any Oregon location for which either average horizontal insolation or percent possible sunshine records are available. Go on to the review questions and check your understanding.

Review Questions

1. Name the three kinds of solar radiation which contribute to the radiation intensity on a tilted solar collector.

2. List the three collector tilt angles most likely to be used in Oregon, and the likely use for a collector tilted at each angle.

3. Below are some percent possible sunshine figures for an imaginary location in Oregon. Compute the average horizontal insolation H_{AV} for each of the months given.

   Oct. 60%

   Dec. 20%

   Jan. 25%

   Feb. 30%

4. Below are some values of H_{AV} for an imaginary location in Oregon. Find K_T and the solar intensity on a collector tilted at a 60^o angle for each of the given months.

Oct.	708 BTU/Ft.^{2}-Day
Nov.	443 BTU/Ft.^{2}-Day
Dec.	298 BTU/Ft.^{2}-Day
Jan.	363 BTU/Ft.^{2}-Day

5. List the factors which affect the amount of solar radiation falling on a solar collector.

Answers to Review Questions

1. Direct beam radiation, diffuse radiation, reflected radiation.

2. 60^o; space heating
   45^o; hot water heating
   30^o; swimming pool heating

3. Oct. 855.6 BTU/Ft.^{2}-Day
   Dec. 266.6 BTU/Ft.^{2}-Day
   Jan. 518 BTU/Ft.^{2}-Day
   Feb. 777.15 BTU/Ft.^{2}-Day

4.

Month	K_T	I (60^o)
Oct.	.4	991.2 BTU/Ft.^{2}-Day
Nov.	.36	806.3 BTU/Ft.^{2}-Day
Dec.	.3	524.5 BTU/Ft.^{2}-Day
Jan.	.33	606.2 BTU/Ft.^{2}-Day

5. The latitude of the location
   The time of year
   The local weather conditions
   The tilt angle of the collector

If you had difficulty with any of the review questions, review frames 1 through 31 until you can answer them all. Then go on to frame 32.

32. Estimates of the amount of solar radiation available in an area help you decide how big a solar collector you'll need. So do heat loss estimates for the building to be heated.

To estimate the amount of solar heat that you may want to store for cloudy days, you'll need an estimate of the typical number of consecutive cloudy days that occur at the building location in various months. Either percent possible sunshine records or horizontal insolation records can be used to make the estimate.

Go to frame 33.

---

33. Percent possible sunshine numbers can be used to estimate the number of cloudy days for each clear day in the following way:

A rough formula for percent possible sunshine is

$$PPS = 100 \frac{N_C}{N_T}$$

PPS is the symbol for the percent possible sunshine for the month.

N_C is the symbol for the number of clear daylight hours in the month.

N_T is the symbol for the total number of daylight hours — hours the sun is above the horizon in the month.

The number of cloudy days in the month per clear day is roughly $\frac{N_T-N_C}{N_C}$

N_T-N_C is the number of cloudy hours in the month. N_C is the number of clear hours.

You can reverse the formula for percent possible sunshine to find $\frac{N_T-N_C}{N_C}$. We did it for you and found $\frac{N_T-N_C}{N_C} = \frac{100-PPS}{PPS}$

or "the number of cloudy days per clear day is 100 minus the percent possible sunshine then divided by the percent possible sunshine." Go on to frame 34

---

34. Write the formula for the number of cloudy days per clear day using percent possible sunshine and explain the symbols in it. Check your answers in frame 35.

35. $\frac{N_T-N_C}{N_C} = \underline{100\text{-}PPS}$

N_T is the total number of daylight hours — hours the sun is above the horizon in the month.

N_C is the total number of clear daylight hours in the month.

PPS is the percent possible sunshine.

$\frac{N_T-N_C}{N_C}$ is the average number of cloudy days per clear day in the month.

$\frac{N_T-N_C}{N_C}$ is what you want — the number of cloudy days per clear day.

Go over frames 33, 34, and 35 until you have the formula and symbols firmly in mind. Then go on to frame 36.

---

36. Suppose the percent possible sunshine in Eugene in December is 16.7%. How many cloudy days are there on the average for each clear day in December in Eugene? Check your answer in frame 37.

---

37. You use

$$\frac{N_T-N_C}{N_C} = \frac{100-PPS}{PPS} = \frac{100 - 16.7}{16.7} = \frac{83.3}{16.7} = \text{About } 5.$$

$$\frac{N_T-N_C}{N_C} = 5$$

There are about 5 cloudy days for each clear day in December in Eugene. Go on to frame 38.

---

38. Try this one: The percent possible sunshine in Corvallis in January is about 20%. About how many cloudy days are there per clear day in Corvallis in January? Check your answer in frame 39.

---

39. There are about 4 cloudy days per clear day in January in Corvallis. Check the example in frame 37 if you had trouble with this one. When you can get it, go on to frame 40

---

40. One more for practice. The percent possible sunshine in December is 40%. About how many cloudy days are there per clear day in Bend in December? Check your answer in frame 41.

---

41. There are about 1.5 cloudy days per clear day in Bend in December. That's the last practice you'll get in using the formula before the review questions. Make sure you can do it before going on. Then go on to frame 42.

---

42. Good. Now you can estimate necessary days of heat storage using percent possible sunshine records. Suppose you have horizontal insolation records, but no percent possible sunshine records. You can use the formula relating percent possible sunshine to average and clear day horizontal insolation to get an estimate of percent possible sunshine.

We'll repeat that formula and then show you how it can be reversed to estimate percent possible sunshine.

$$H_{AV} = H_o' \left[.30 + .65 \left(\frac{\%\ sunshine}{100}\right)\right]$$

Reversing it, we get

$$\text{PPS (or \% sunshine)} = 153.8 \left(\frac{H_{AV}}{H_o'}\right) - 46.2$$

Let's take some of the H_{AV} figures we got before and work backward to find percent possible sunshine. We should get the same numbers we started with to get H_{AV}.

Try finding PPS using the H_{AV} values we got earlier in this module:

Dec.	Corvallis	248 BTU/Ft.^{2}-Day
Nov.	Eugene	391.05 BTU/Ft.^{2}-Day
Apr.	Portland	1153.6 BTU/Ft.^{2}-Day

See if you can get the values of PPS we started with. Be careful looking up H_o' in the table Check your answers in frame 43.

---

43. You should have (about)

Month		H_{AV}	PPS
Dec.	Corvallis	248 BTU/Ft.^{2}-Day	PPS = 15%
Nov.	Eugene	391.05 BTU/Ft.^{2}-Day	PPS = 30%
Apr.	Portland	1153.6 BTU/Ft.^{2}-Day	PPS = 40%

If you missed any of these, recheck your use of the formula and the table of H_o' until you get it right. When you have them all, go on to frame 44.

---

44. Use the answers in frame 43 to estimate the average number of cloudy days per clear day in the 3 situations. Check your answers in frame 45.

1~~3

45. You should have

Dec.	Corvallis	5.67 cloudy days
Nov.	Eugene	2.33 cloudy days
Apr.	Portland	1.5 cloudy days

If you missed any of them, be sure you used the correct formula:

$$\frac{N_T - N_C}{N_C} = \frac{100 - PPS}{PPS}$$

Go on to frame 46 when you have them all.

46. At least approximate knowledge of the monthly average intensity of solar radiation in south-facing tilted surfaces is essential to a designer of a solar heating system. It's also essential that a designer know the typical number of cloudy days for which a solar system must store heat. Knowledge of those two features of the weather of a building site enables the designer to make most of the important design decisions about a solar heating system without having to guess or go by rules of thumb.

You should now be able to use standard weather data to estimate both solar radiation intensity and typical numbers of consecutive cloudy days. Later modules will show you how that information can be used in combination with climate and heat loss information to make decisions about how to build solar systems.

Go on to the review questions and post-test.

Review Questions

1. Find the number of cloudy days per clear day for each of the percent possible sunshine figures given below:

   15%

   20%

   25%

   30%

2. Find the percent possible sunshine for each of the months and horizontal solar radiation intensities given below.

   Oct. 708 $BTU/Ft.^2$-Day

   Nov. 443 $BTU/Ft.^2$-Day

   Dec. 293 $BTU/Ft.^2$-Day

   Jan. 363 $BTU/Ft.^2$-Day

Answers to Review Questions

1. 5.67; 4; 3; 2.33.
2. 41.6%; 40%; 26.5%; 32.4%.

   If you missed any of these, review frames 32 through 46 until you can get the ones you missed. Then go on to the post-test.

Post-Test

1. Explain the meanings of the symbols H_o', H_o, and H_{AV}.

2. Explain the meanings of the symbols K_T and R.

3. Write the formula for H_{AV} in terms of percent possible sunshine.

4. Write the formula for the typical number of cloudy days per clear day in terms of percent possible sunshine.

5. Fill in the table below:

Month	Percent Possible Sunshine	H_{AV}	K_T	R	$I(60^{\circ}$ Tilt Angle)
Jan.	22				
Feb.	28				
Mar.	34				
Apr.	40				

6. Fill in the table below:

Month	Percent Possible Sunshine	Typical Number of Cloudy Days per Clear Day
Apr.	40	
May	50	
Jun.	45	