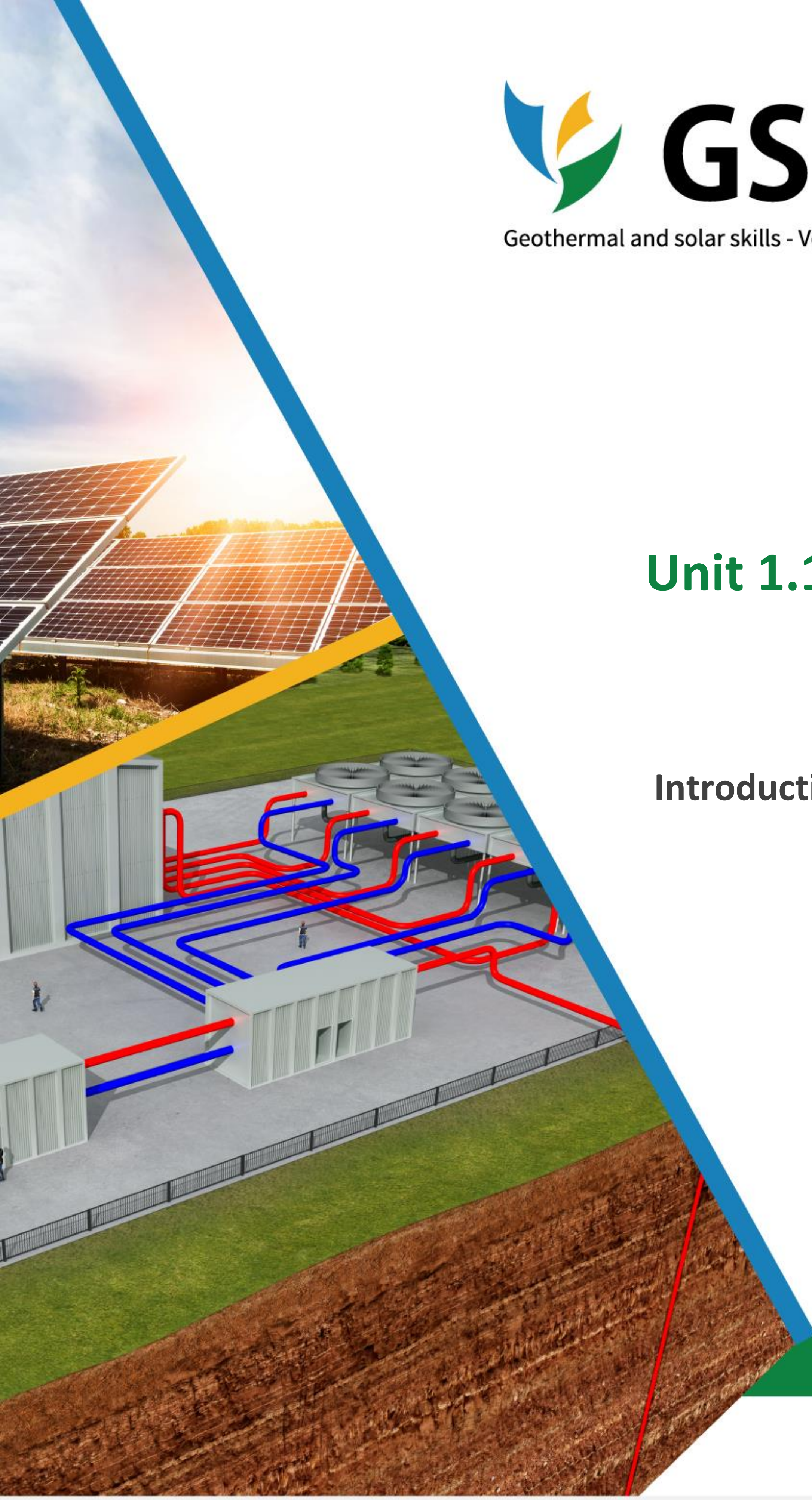

GSS-VET

Geothermal and solar skills - Vocational education and training

Unit 1.1. Solar Energy

Introduction to Solar Thermal Energy

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Introduction

Welcome.

This Unit is the first of the course of Solar Thermal Systems.

Modern solar thermal systems are advanced uses of the sun's energy, but their design and operation are based upon collecting the same solar resource as in earlier applications. In order to understand them well and build effective systems and full compliance with regulations and quality standards it is critical to understand basic solar principles and how they are applied.

This is the purpose of the Unit.

Objectives

By the end of this unit you should be able to:

1. **Define solar thermal technologies.**
2. **Explain basic solar thermal terms and principles, including:**
   - **Parameters of the solar irradiation on earth and surfaces.**
   - **Other determinants of solar thermal systems efficiency.**
3. **Explain how the solar basics are applied to have effective solar thermal systems, including:**
   - **Optimum tilt and orientation angles of solar collectors.**
   - **Other practical considerations for systems building.**

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1. Solar Thermal Technologies and Applications

Energy equates to life and solar energy, the energy coming from the sun, is always available. Understandably, along history people belonging to very different cultures have been interested in how to take the most benefit from the sun. Ancient cultures, for example, cumulated a profound knowledge of the natural solar cycles, key to survival; additionally, they invented some ways based on smart solar passive techniques to collect the sun energy to heat or cool their homes and buildings.

It's in the last century, when several well-established solar technologies have finally flourished in a wide variety of practical and affordable solutions for specific market segments, or applications, or solar energy systems. One is **Solar Thermal**, which are amongst the most diverse, effective and widespread renewable energy technologies.

This course is basically about a professional use of Solar Thermal Technologies.

Locate them in the Figure 1.

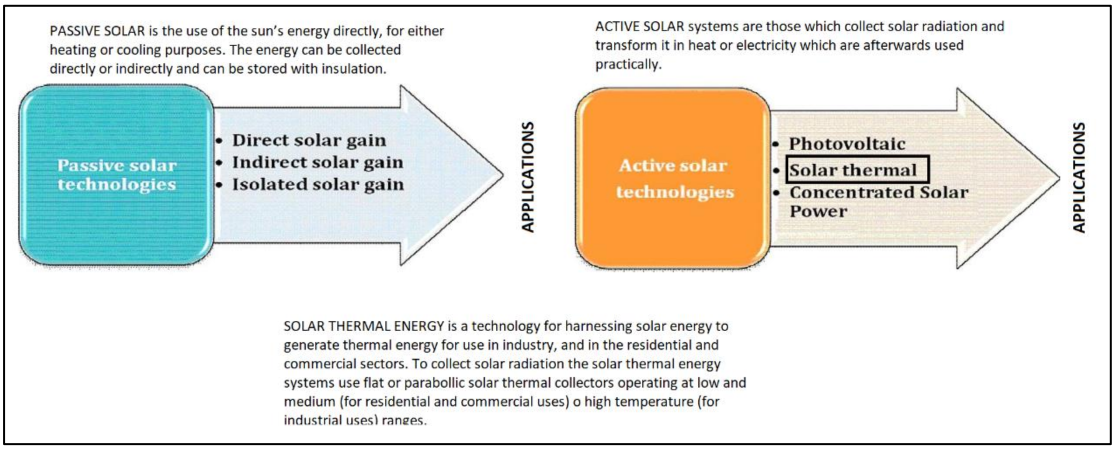

Figure 1. Solar Thermal Technologies located in the context of Solar Energy Technologies

Particularly, the use of Solar Thermal Systems is most predominant in the **residential and commercial** markets, but they find application in **industrial and agricultural** sectors, too. See Figure 2.

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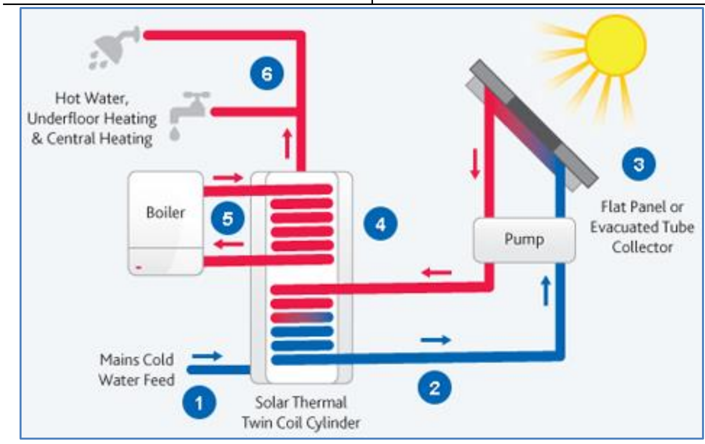
<table>
<tr>
<td>
</td>
<td>
</td>
<td>Residential Applications:

Domestic hot water.
Swimming pool and spa heating.
Space heating.
Water purification/ distillation.
Air conditioning.
Others.
</td>
</tr>
<tr>
<td colspan="2">
</td>
<td>Standard domestic hot water system. Forced circulation model. Diagram and operation:

Cold water feed to hot water storage tank.
Separated forced fluid circulation system with controls.
Solar collector absorbing solar radiation.
Hot water storage tank insulated and with heat exchanger.
Complementary water boiler (gas, oil, etc.).
Hot water uses. Consumption.
</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial Applications:

Hotels.
Schools.
Condominium complexes.
Recreation areas.
Hospitals/Nursing homes.
Restaurants.
Laundries.
Car washes.
Light commercial businesses.
Summer camps.
Others.
</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial Applications:

Beverage manufacturing
Cane sugar refining
Canning facilities
Food processing
Meat packing facilities
Poultry farms
Industrial process heat
Crop drying
Green houses
Dairy processing
Meat processing
Aqua-culture
Food processing
</td>
</tr>
</table>

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		• Others.

Figure 2. Applications of Solar Thermal Technologies

Generally speaking, solar thermal applications can have a significant impact on local and national energy usage and conservation, which explains why they have been subject of regulations across the globe in the last decades, in the context of national energy politics deployment and, more recently, fight against climate change effects.

This course concentrates on **residential applications** and in domestic water heating systems, particularly.

2. Solar terms and basic principles

It is critical to understand **basic solar principles** and how they affect the performance of solar heating systems, which are primarily based on capturing effectively the energy coming from the sun. In this section we present and briefly discuss a selection of essential concepts and principles about solar radiation and other basic determinants of solar thermal systems efficiency. Later, we will want to apply these principles.

2.1 Solar Radiation

Sun is the basic source of energy for the Earth. It's in essence a large sphere of very hot gases, heat being generated continuously by the various fusion reactions in internal layers. The enormeous amount of energy thus released ($1{,}1 \times 10^{20}$ kW-h every second) is radiated into space in the form of electromagnetic radiation, uniformly projected in all directions and in the entire electromagnetic spectrum (see Figure 3). We call simply this (composed) type of energy radiated as the **solar radiation**. We are far away from the sun, so the direct radiation received on earth is almost parallel.

The sun is about 148 million km from the earth and only a tiny fraction of its radiation reaches the earth. The earth's outer atmosphere intercepts about two-billionth of the energy radiated or about 1.5×10^{18} kW-h per year. Due to phenomena such as scattering, absorption or reflection by gases and aerosols in the atmosphere only 47% of this energy, that is 7x1017 kW-h per year, reaches the surface of the earth. Despite all this, the sun offers to us in 4 hours more energy than we use in a whole year.

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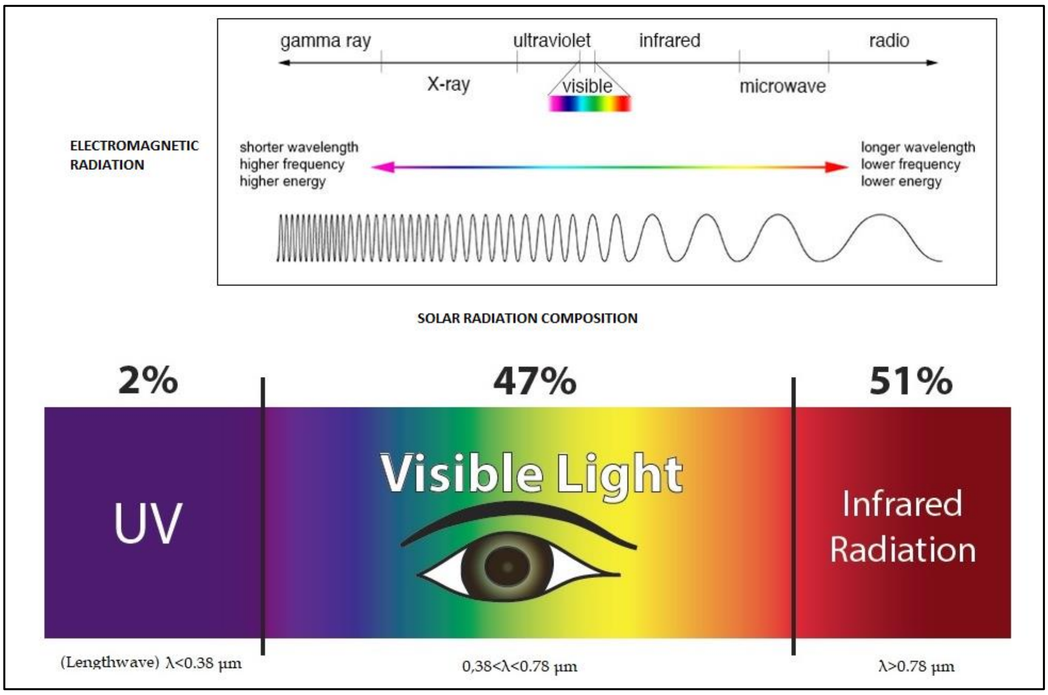

Figure 3. The solar spectrum

2.2 Insolation and irradiance

Irradiance (G) is a measure, usually expressed in Watts per square meter (W/m^2), of the sun's power at a given moment, whereas **Insolation** is the total amount of solar energy available over a period of time and is typically measured in kilowatt-hours per square meter per day (kWh/m2/day). Insolation is G x time. When talking about solar radiation we are referring to insolation (that is, totalized amounts or energy).

In another example, it happens that in the outer edge of the earth's atmosphere the irradiated power of the sun is virtually constant. This radiation intensity, or irradiance, falling perpendicularly on an imagined area of one square meter equals to 1.367 W/m^2, which is known as the *solar constant*. See Figure 4.

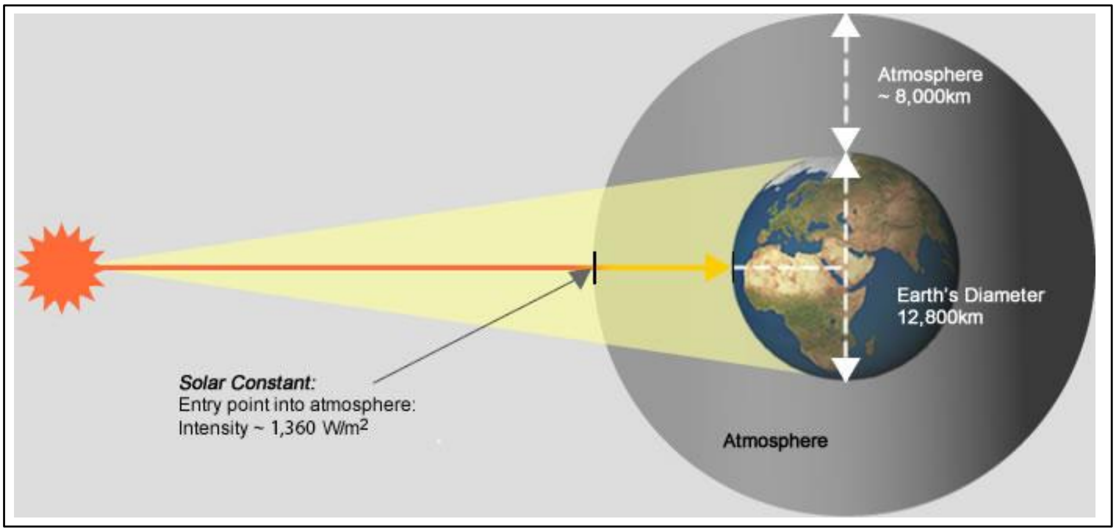

Figure 4. Representation of the solar constant

However, the irradiance (and insolation) available on given locations on the earth surface (or unit area and day round) are very variable since they depend on several operating factors such as: geographical latitude, the time of the day, season of the year, atmospheric conditions, shading or orientation. It's not difficult to imagine the irradiance on a hypothetical solar collector fluctuating from 700W/m^2 to 900W/m^2 from 9am to 3pm on a cloudy day placed on a roof in a certain city and country of the northern hemisphere. The insolation that this collector totalizes during this period will be 8,4–10,8kWh, if we assume that it has a total surface of 2 square meters.

The efficiency of such thermal system part depends on its ability to convert insolation (radiant energy) to usable energy (heat).

2.3 Sun path

On the surface of the earth, insolation varies over time and cyclically mainly because of the planet's daily rotation (from day to night), tilted earth's axis (seasons) and elliptical orbit around the sun (distance to sun). This last cause only accounts for 6% of total fluctuations, so it can be practically overlooked.

As it's known, the seasons are characterized by weather patterns and daylight hours. That is, the length of the day depends on seasonal change. In northern hemisphere they are more than 12 hours long in summer and less than 12 hours long in winter. Also, in summer the sun rises higher in the horizon and is warmer (more irradiance) whereas in winter the sun keeps lower and warm less. In spring and fall both day and

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night are of similar long, about 12 hours. The opposite applies to the southern hemisphere. These changes are progressive as earth revolves around the sun and seasons come and go.

Why? For basic clarification, refer to figure 5.

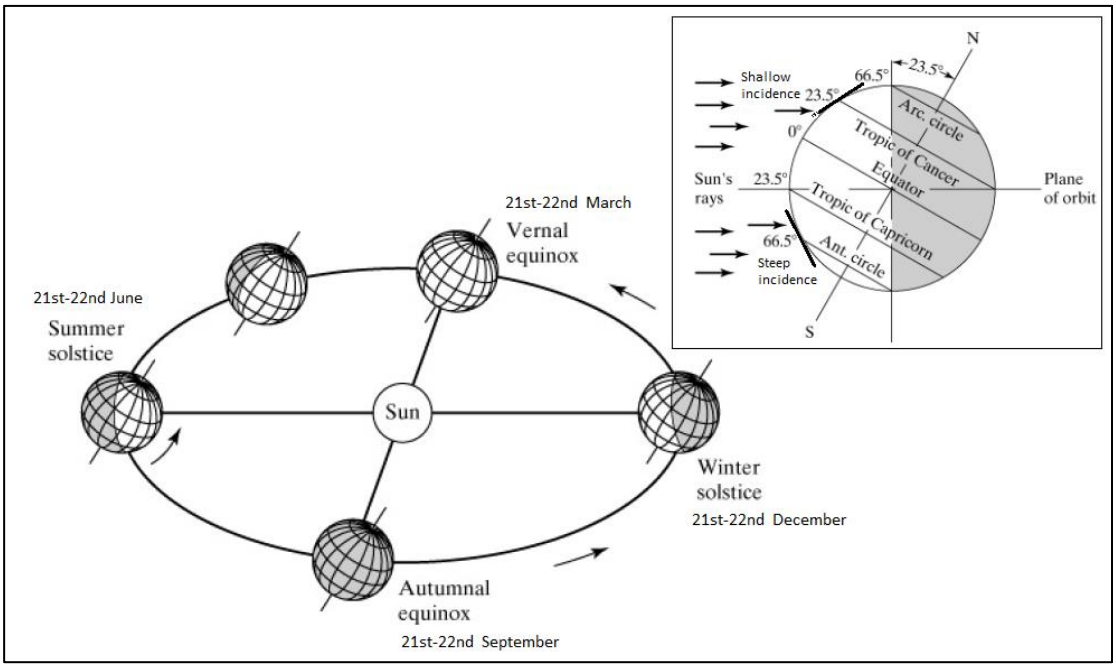

Figure 5. Earth axis's tilt, seasons and insolation variations

The earth's equator (or rotation axis) is tilted 23,5º to the plane of his orbit, and this it happens to be the only cause of seasons. Note how as earth travels around the sun the poles (or hemispheres) are going to be closer/farther to the sun and therefore the latitudes are going to be irradiated with more/less intensity.

The squared detail in Figure 5 shows the position of the earth relative to the sun's rays at the time of winter solstice. Note how the North Pole is inclined 23.5 degrees away from the sun. All points on the earth's surface north of 66.5 degrees north latitude are in total darkness (while all regions within 23.5 degrees of the South Pole receive continuous sunlight). The days are shorter than 12 hours. In winter solstice the northern hemisphere can get less of the sun's direct rays and cold is felt. At the time of the summer solstice, the situation is completely reversed. At the times of the two equinoxes, both poles are equidistant from the sun and all points on the earth's surface have 12 hours of daylight, 12 hours of darkness and the same irradiation.

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Now, we can imagine the sky as a dome with the horizon as its edge. From this perspective, the sun's path describes an arc across the sky from dawn until dusk. This perceived path and its variations over time can be plotted, as in Figure 6, which approximates the annual **sun path** (at a given latitude of 28º N).

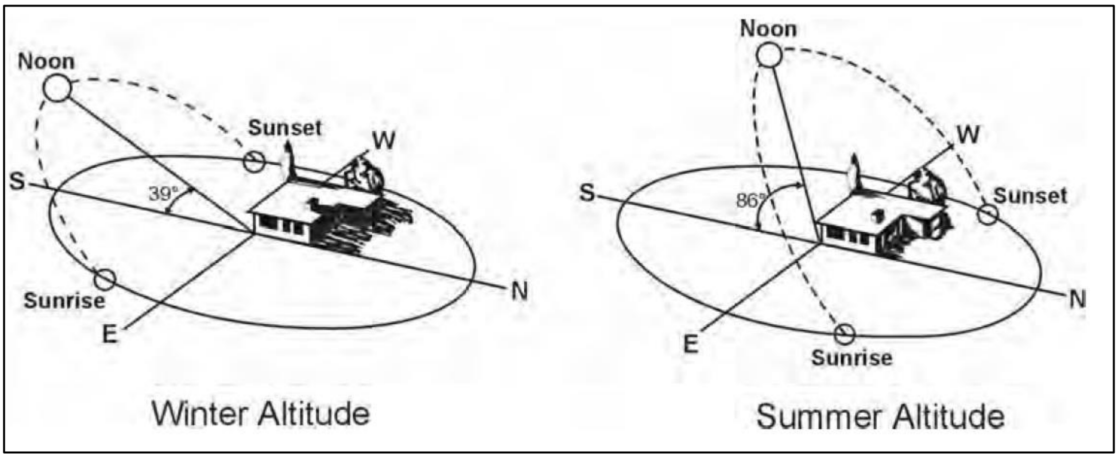

Figure 6. Different sun paths in winter and summer as they are experienced in a given latitude.

Note in Figure 6 how in winter the sun rises in the Southeast, sets in the Southwest, has a relatively short path and rises to a shallow 39º angle above the horizon at noon (the moment of maximum sun irradiance, also known as "true south"). In the summertime, the sun rises in the Northeast, sets in the Northwest, has a longer path and rises to a much higher angle above the horizon (86º).

The higher the sun rises, the more perpendicular the solar radiation strikes the earth, the less thickness of atmosphere (less interaction with radiation), the more irradiance and the more insolation collected over time.

2.4 Solar Angles

Solar angles can give to us the exact position of the sun in the sun path for a given location and observer. Figure 7 shows three solar angles commonly used in solar thermal technology.

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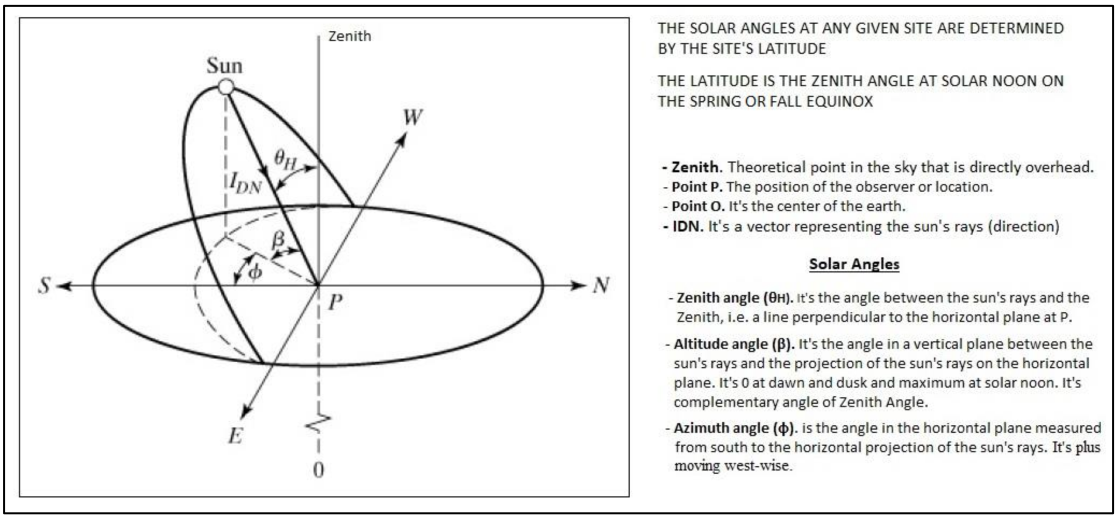

Figure 7. Sun's Zenith, Altitude and Azimuth angles

Altitude angles are particularly important in determining the collector tilt angle required to maximize the usable energy produced by a solar system as well as to determine whether nearby obstructions might shade the collector (or array of collectors). Figure 8 shows how maximum solar altitude angles vary between different latitudes and how solar path charts appear after plotted by every hour and year time for a given latitude. Charts like these are very useful for professionals.

Solar altitude angle at solar noon

Latitude	Winter Solstice	Spring/Fall Equinox	Summer Solstice
0 (the equator)	66.5°	90°	66.5°
10	56.5°	80°	76.5°
20	46.5°	70°	86.5°
23.5 (the Tropics)	43°	66.5°	90°
30	36.5°	60°	83.5°
40	26.5°	50°	73.5°
50	16.5°	40°	63.5°
60	6.5°	30°	53.5°
70		20°	43.5°
80		10°	33.5°
90 (the Poles)		0°	23.5°

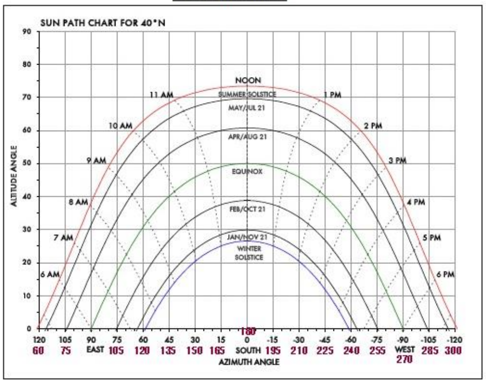

Figure 8. Maximum solar altitude angles and example of sun path chart.

2.5 Atmosphere, air mass and global irradiance on earth surface

The atmosphere absorbs certain wavelengths of light more than others. Air molecules (O_2, O_3, etc.) and humidity are responsible. The exact spectral distribution (energy) of light reaching the earth's surface depends on how much atmosphere the light passes through. In the morning and evening, the sun is low in the sky and light

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waves pass through more atmosphere than at noon. The winter sunlight also passes through more atmosphere versus summer.

A concept related to quantify the attenuation effect of atmosphere on solar radiation is the Air Mass (AM), which is 1 when the sun is in the Zenith (altitude = 90º) and the atmosphere thickness is the lower. For other altitudes of the sun the atmosphere is thicker and AM = 1/Cos(β), that is AM > 1. It must be known that some operating parameters of commercial solar collectors are given with reference to standardized values of AM.

Figure 9 illustrates the atmospheric effects on solar energy reaching the earth. Droplets in clouds, smoke and dust particles absorb and reflect some solar insolation back up into the atmosphere, allowing less solar energy to fall on a terrestrial object. These conditions also diffuse or scatter the amount of solar energy that does pass through.

Direct or beam radiation is solar radiation that does not get absorbed or scattered but reaches ground directly from the sun. It produces shadow when interrupted by an opaque object. Diffuse radiation is solar radiation received after its direction has been changed by reflection and scattering in the atmosphere. Diffuse radiation is what let us see in shadowed places. Global radiation is the sum of both, direct and diffuse radiation.

Solar collectors work mainly with **direct radiation.**

A practical simplification is to consider at sea level an average irradiance of 1000 W/m2 (73% of solar constant).

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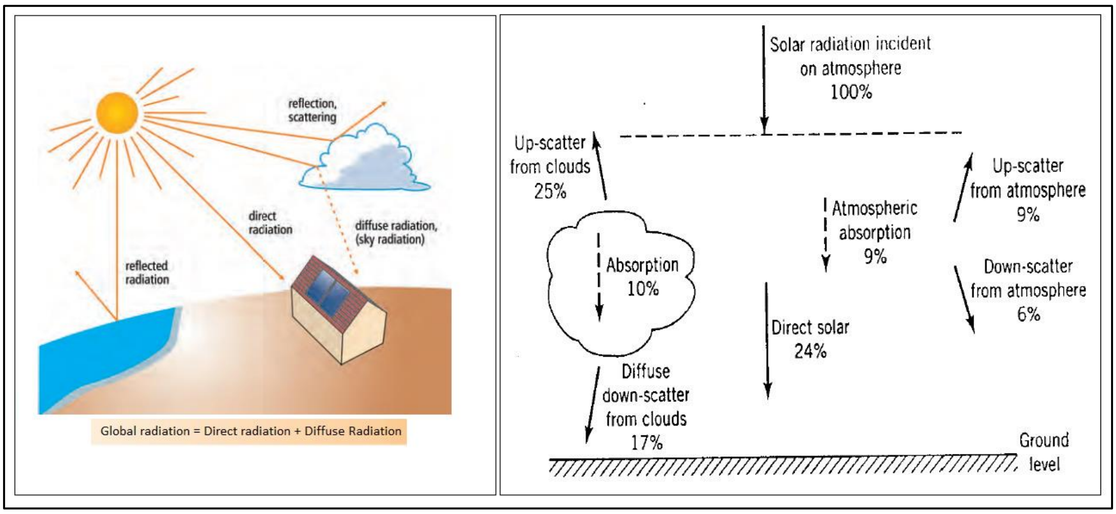

Figure 9. Basic components of solar radiation and effects on solar radiation of atmospheric phenomenon

2.6 Angle of incidence on surfaces

The sun's electromagnetic energy travels in a straight line. The angle at which these rays fall on an object is called the **angle of incidence** (See Figure 10).

A flat surface receives more solar energy when the angle of incidence is closer to zero (normal, perpendicular) and therefore receives significantly less in early morning and late evening.

Because the angle of incidence is so large in the morning and evening on earth, about six hours of "usable" solar energy is available daily. This is the so called "**solar window**".

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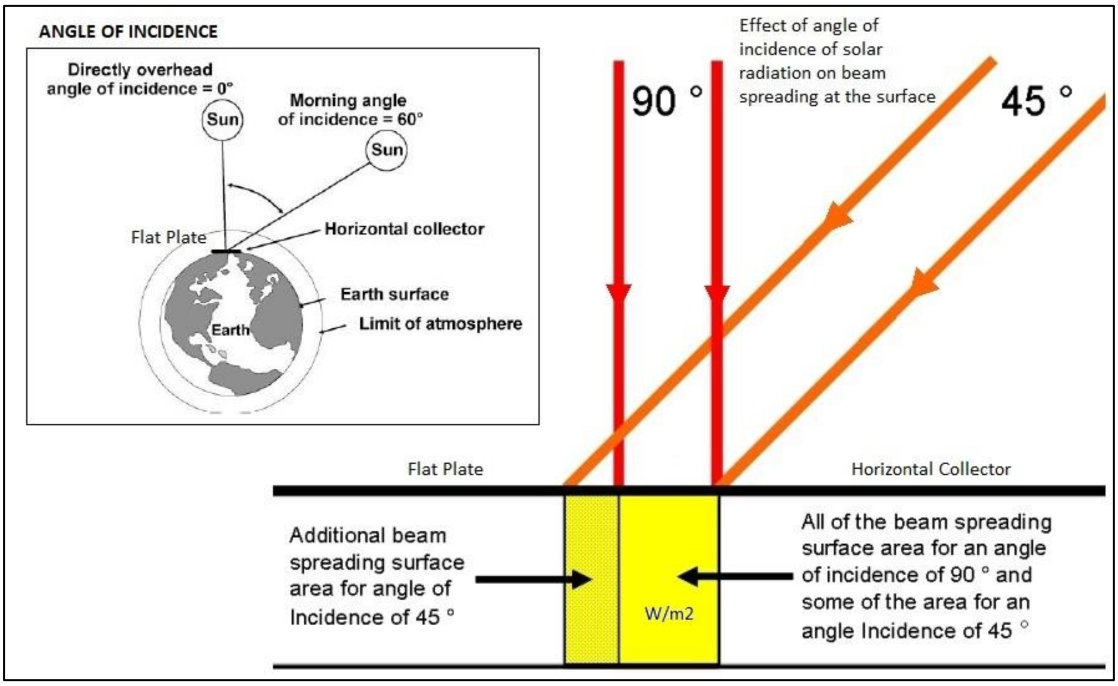

Figure 10. Angle of incidence and effects on solar irradiation of a flat surface.

Note in Figure 10 how a location with the sun directly overhead (i.e. an angle of incidence of 0°) receives 40% more solar radiation per square meter (irradiance, W/ m^2) than will a location with the sun at an altitude of 45°. The lower sun angle (45°) causes the solar radiation to be received over a much larger surface area, which decreases the irradiance.

Note that this effect is independent of atmospheric conditions (effect of air mass). That is, in practice low altitudes represent more atmosphere path to the sun's rays and added power attenuation.

To maximize irradiance in the case of Figure 10, tilting the surface up to the sun's rays strike on it perpendicularly is an obvious solution. **Tilting and orientating** solar collectors (which can be placed on the floor, walls or in inclined roofs, etc.) is a common practice.

So, in calculations involving other than horizontal surfaces, it is convenient to express the sun's position relative to the surface in terms of the incidence angle. To orientate, see in Figure 11 the so called basic **surface angles**.

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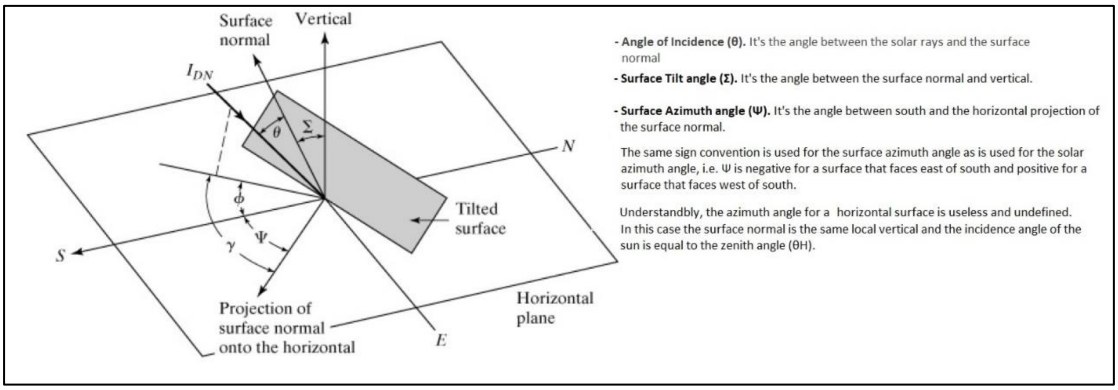

Figure 11. Surface Azimut and Tilt angles, and the relation of the sun's rays to a tilted surface

2.7 Absorptance of materials

The same irradiated objects on earth absorb and reflect radiation at the same time. As it's obvious, what is more important is that solar collectors absorb incident radiation as much as possible, reflecting a minimum. More absorptive materials are generally dark with a matte finish, while more-reflective materials are generally lighter colored with a smooth or shiny finish. The solar collector's absorber (Figure 12) and absorber coating efficiency are determined by the rate of **absorption** versus the rate of **reflectance**. High absorptivity and low reflectivity means efficiency.

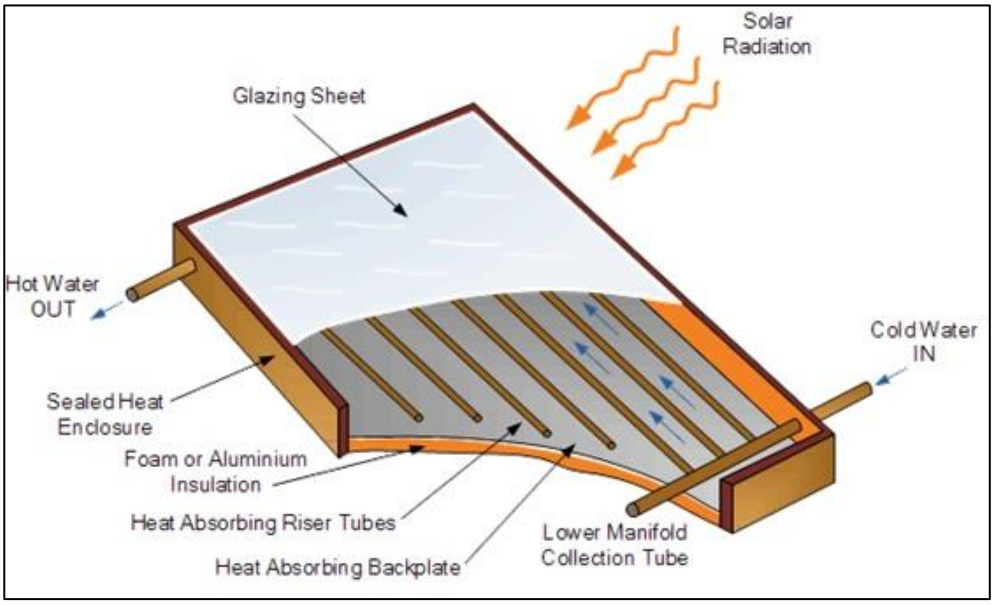

Figure 12. A solar collector is a system made for high absorption of radiated energy

2.8 Heat transfer

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Because all-natural systems seek a balance, heat always moves from warm (more energy) to cool (less energy). Heat moves by three methods: conduction, convection and radiation (Figure 13).

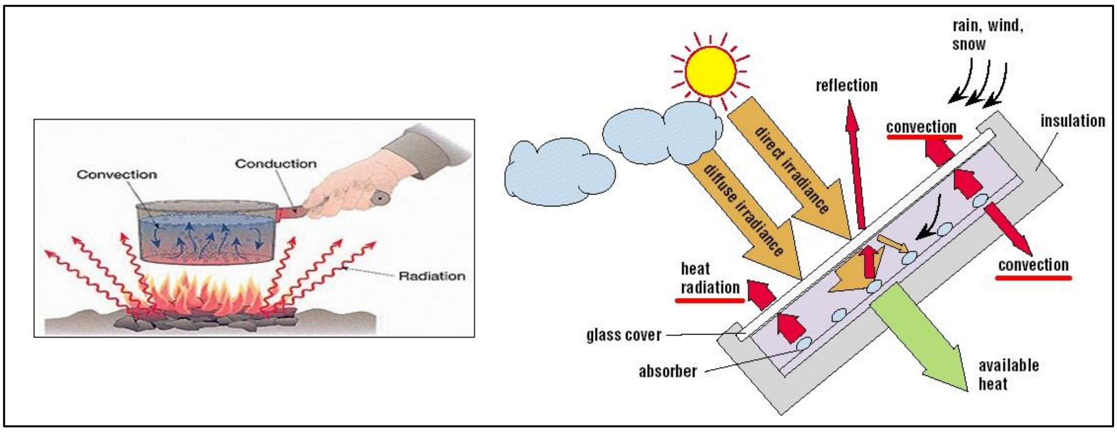

Figure 13. Heat transfer methods. Radiation and convection methods are relevant in transforming solar radiation to usable heat inside solar panels. Eventually as heat losses.

Conduction. It occurs when a solid material is heated. Molecules exposed to a heat source become energized. These energetic molecules collide with neighboring, less-energetic molecules, transferring their energy. The greater the energy transfer ability of the solid's molecules, the more energy they can transfer and the better the solid's conductivity. Copper has high conductivity while glass has low conductivity, for example.

Convection. Like conduction, convection occurs by molecular motion but in a fluid (such as a gas or liquid). When a gas or liquid is heated, the energized molecules begin to flow. On earth, where gravity is a factor, the heated, less-dense fluid flows upward as cooler, more compact fluid moves down. This process of displacement continues as long as the heat source remains.

Radiation. It occurs not by molecular action but rather by emission of electromagnetic waves, generally in the invisible, infrared spectrum (see Figure 3). Because radiation does not rely on the presence of matter (molecules) for transport, it can occur in a vacuum. Just as the sun radiates to the earth, a warm object on earth will radiate infrared waves at night to objects in deep space. All objects with heat radiate to objects with less heat that are in a direct path.

2.9 Temperature gradient or ΔT

The greater the difference in temperature between two points of an object or between two objects, the greater the **driving force** to move heat from the warmer to the cooler point. This applies whether the heat transfer method is conduction, convection or radiation. Consider the following examples:

- Conduction: Applying a 200ºC heat source to the bottom of a copper tube will make the top of the tube hotter and it will heat faster than if the heat source were at 50ºC.
- Convection: A hot air ballon will rise faster if its air is 80ºC rather than at 25ºC.
- Radiation: a camper sitting before a bonfire will feel much warmer than sometime after sitting by the fire's embers.

Solar collectors lose less energy and increase efficiency when the difference between their operating temperature and ambient temperature is reduced. This happens in summertime.

2.10 Thermal mass

Thermal mass is the measure of a material's molecules ability to hold thermal energy. The higher the thermal mass the more efficiently the material can store sensible heat. Rock and masonry are two such materials that have high thermal mass and are solids. Water is a fluid with good energy capacity, making it a good thermal mass medium for energy storage.

In solar collectors the energy of radiation captured is used to heat a conductive solution made of water with antifreeze properties which is enclosed in a primary hydraulic circuit.

3. Applying the basics

In essence, the purpose of a solar heating system is to collect solar energy, convert it to heat, store the heat, and provide the stored heat for an intended purpose. The efficacy and efficiency of the system depends on how well the solar basics, like the ideas and principles discussed so far, are applied. In this section, some orientation is given about how the basics are applied by professionals.

3.1 Measurement of solar radiation.

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Installers, designers or researchers in the field of solar thermal technologies find very useful to collect solar radiation data to know things as the following:

- Average daily, monthly or yearly solar insolation for a given location.
- Solar radiation values (at different times of the day).
- Typical mean year data for a particular location.
- Number of hours of sunshine (on a daily basis).
- Total number of sunny days in a year.
- Calculations of Solar Radiation and elaboration of radiation maps and databases.

These goals require dedicated measurement instruments. In addition, solar radiation is made of several components like direct and diffuse, which are measured with even more specific instruments. Following few choices of solar radiation measuring instruments are (See Figure 14):

- Pyranometer. For measurement of total and diffuse solar radiation.
- Pyrheliometer. For measurement of beam radiation.
- Sunshine recorder. For knowing the duration of sunshine.
- Portable Solar Radiation Meters. For measurement of total and diffuse solar irradiance and power from any other visible light.

Pyranometer with shaded ring

Pyrheliometer

	
Campbell-Stokes sunshine recorder	Hand-held solar power irradiance meter

Figure 14. Solar radiation measurement instruments

Pyranometer. A Pyranometer is an instrument which measures either global or diffuse radiation over a hemispherical field of view. The radiation receiver is seated beneath a spherical glass cover and consists of a star-shaped arrangement of black and white thermo-elements (thermopile). These elements generate thermo-electromotive forces, depending on their temperature, which can be measured and totalized. To measure just the diffuse radiation, the pyranometer is mounted at the center of a semicircular shading ring, which properly adjusted shades the direct sunshine across the (known) sun path in a particular day or season time. Pyranometers are precise, expensive and relative measuring instruments, that is, they need to be calibrated.

Pyreheliometer. It measures the intensity of direct solar radiation. This instrument is more in use when planning the installation of concentrated solar power systems. Hot junction of a thermopile is attached to a black absorber plate which in turn is placed at the base of a tube. The tube is put in the path of the sun rays by a two-axis tracking mechanism/alignment indicator. In this way, black plate receives just the beam radiation along with a very small amount of diffuse radiation.

Sunshine recorder. It is a simple device to record hours of sunlight in a day. It is generally made of a glass sphere that focuses the sun rays on a graduated paper strip. The sun rays are focused to a point on the card strip, which is held in a groove in a spherical bowl mounted concentrically with the sphere. During the bright sunshine, a powerful image is formed since it is enough to burn a spot on the card strip. This image moves along the strip as the sun moves throughout the day across

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the sky. Traces of burning form in this way. The length of these traces is proportional to the time period of the sunshine.

Solar radiation meter. It is a simple hand-held device to measure the solar radiation. It uses a silicon solar cell to sense the incoming radiation. This cell simply acts as a photo or light sensor. They are relatively inexpensive and are preferred by installers.

3.2 Collecting and converting solar energy. Solar Collectors.

Solar collectors are used to capture the sun's electromagnetic energy and convert it to heat energy (see Figure 15). How they are designed and what materials they are made of make a substantial difference in efficiency.

Figure 15. Solar collector types

However, the efficiency of a solar collector depends not only on its materials and design but also on its size, tilt and orientation. In addition, size, tilt and orientation aren't completely independent of the type of collectors.

3.3 Daily variations. The solar window.

As we already know, available solar energy is at its maximum at noon. The sun's daily motion across the sky has an impact on any solar collector's performance (and efficiency) in the following ways:

- Since the angle of incidence of the solar energy changes throughout the day, solar power is lower at dawn and dusk. In reality, there are only about **6 hours of maximum energy available daily**. This is the solar window, which is a practical installation criterion for professionals. See Figure 16.
- The total energy received by a fixed surface during a given period depends on its orientation and tilt and varies with weather conditions and time of day and season.

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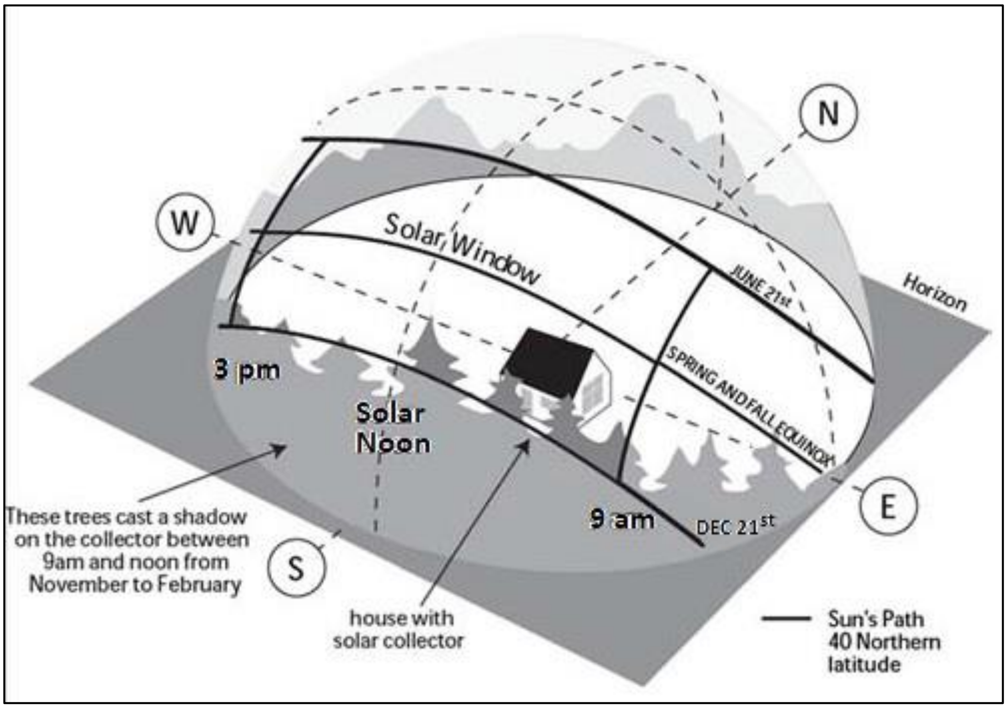

Figure 16. Solar window marked on the year sun paths mapped for a given latitude. It accounts for 90% of daily insolation. Sun paths and solar window allow to analyze eventual shading due to obstacles in the surroundings (trees, other buildings, mountains, etc.).

Aiming the solar device to track the sun's rays to strike it at right angles all day seems logical, but solar collectors are large and heavy and must be strong to withstand weather conditions. Tracking the sun requires considerably more hardware than does fixed mounting. Most practical designs accept the loss of energy suffered through fixed mounting and use an orientation close to that which collects the most solar energy possible.

Consequently, **fixed solar collectors are best positioned to face true south in the northern hemisphere and true north in the southern hemisphere**.

If the collector will be unavoidable shaded in the morning when installed at its best solar location it can be re-oriented slightly west in the northern hemisphere and slightly east in the southern hemisphere.

3.4 Seasonal variations. Collector tilt.

The dome of the sky and the sun’s path at various times of the year are shown in Figure 17 projected on a flat surface (note that is an example referred to a latitude of 32° North).

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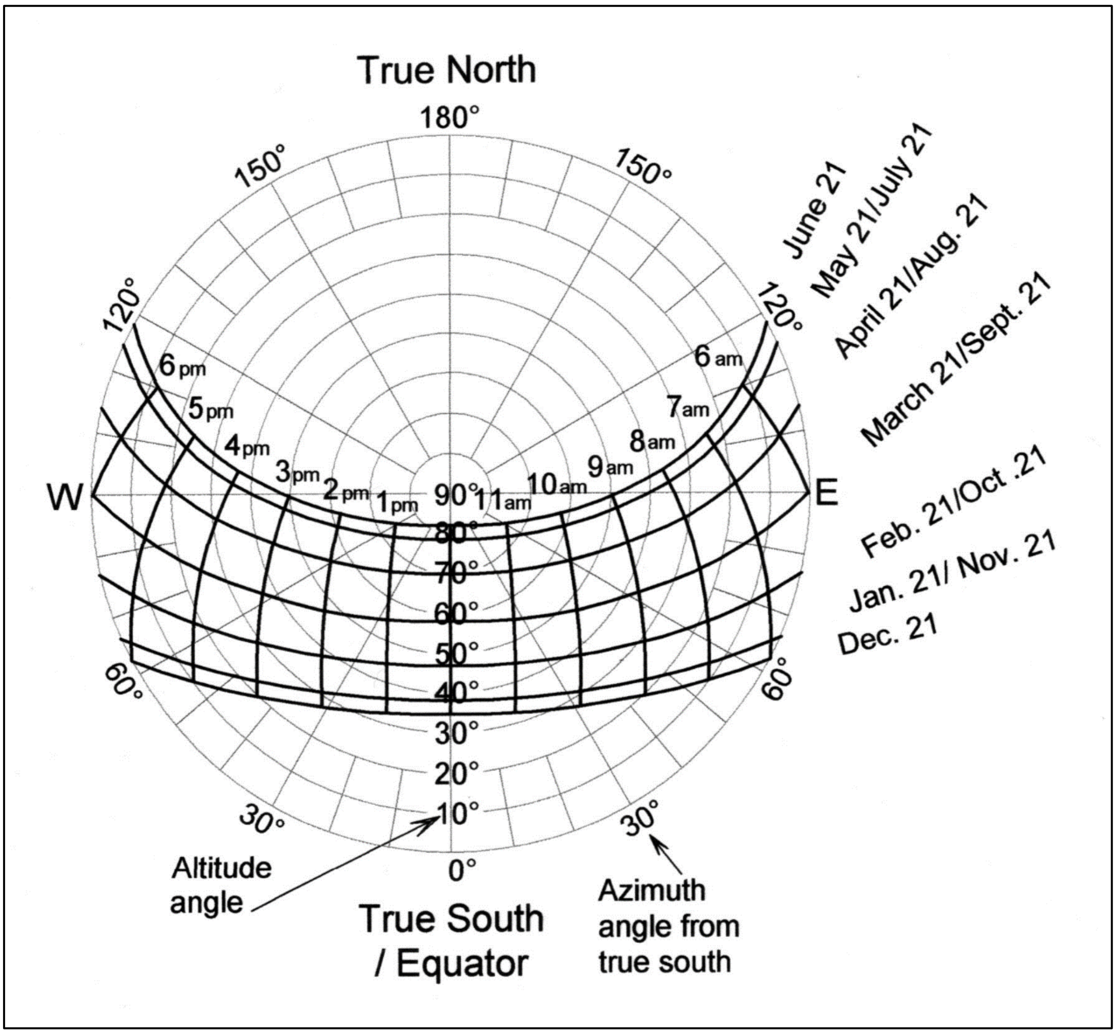

Figure 17. Sun path diagram, 32º N Latitude

Reading the map, note how in mid-June the days are long; the sun rises well north of due east and sets well north of due west. It also passes almost directly overhead (82°) so that at solar noon on June 21 a horizontal plate will almost collect a maximum amount of solar energy (see Figure 18a). But in December, the sun rises later – south of due east – to a noon elevation of less than 40°. It sets early on the west-southwest horizon. So, to get about the most solar power at noon in December, a fixed collector should face south and be tilted up at an angle of about 55° to the horizontal, as shown in Figure 18b.

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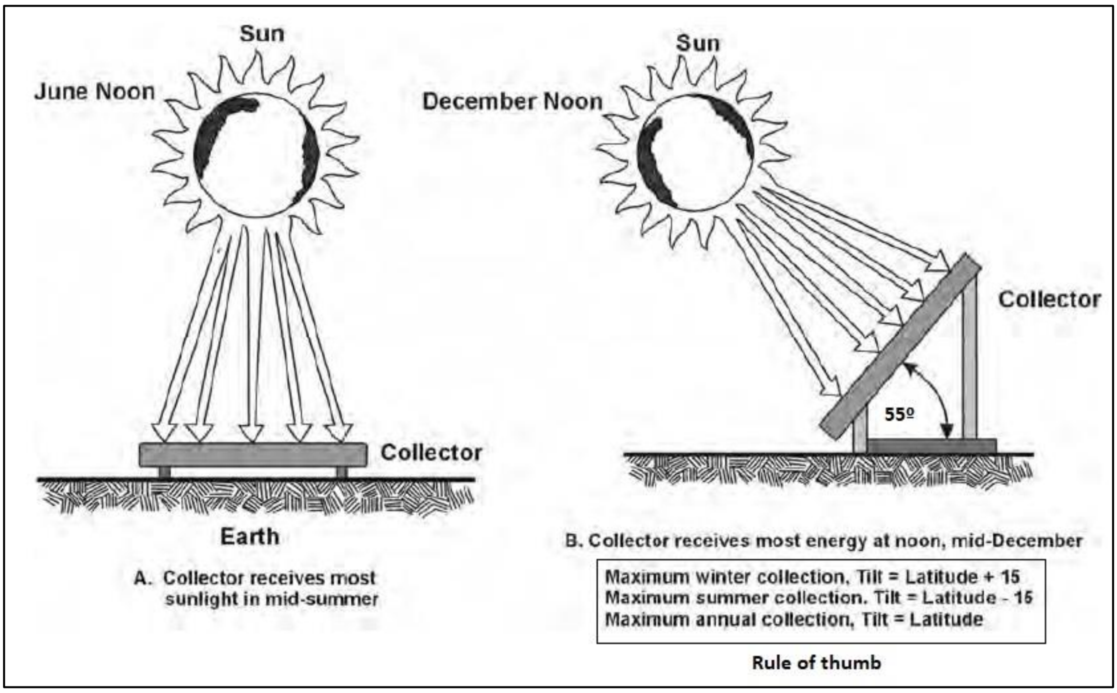

Figure 18. Collected energy varies with time of the year and tilt (illustration for 32º N Latitude).

For many solar applications, we will want maximum annual energy harvest. For others, maximum winter energy (or summer energy) collection will be our goal. What will the optimal collector tilt?

Well, different angles will be "best" for each different aim. In conclusion, **to orient the flat-plate collector properly we must consider our specific application.**

3.5 Collector orientation.

The basic and practical rule is that collectors work best when facing due south. If roof lines or other factors dictate different **orientations**, a small penalty will be paid, as shown in Figure 19.

As an example: for an orientation 20° east or west of due south, we must increase the collector area to 1.06 times the size needed with due south orientation (dashed line on Figure 14) to achieve same energy output. The orientation angle away from due south is the surface azimuth.

Correction factors like those in Figure 19 are provided by manufacturers and may be used to proper and easily size solar collectors which cannot fulfill the rule of due south orientation.

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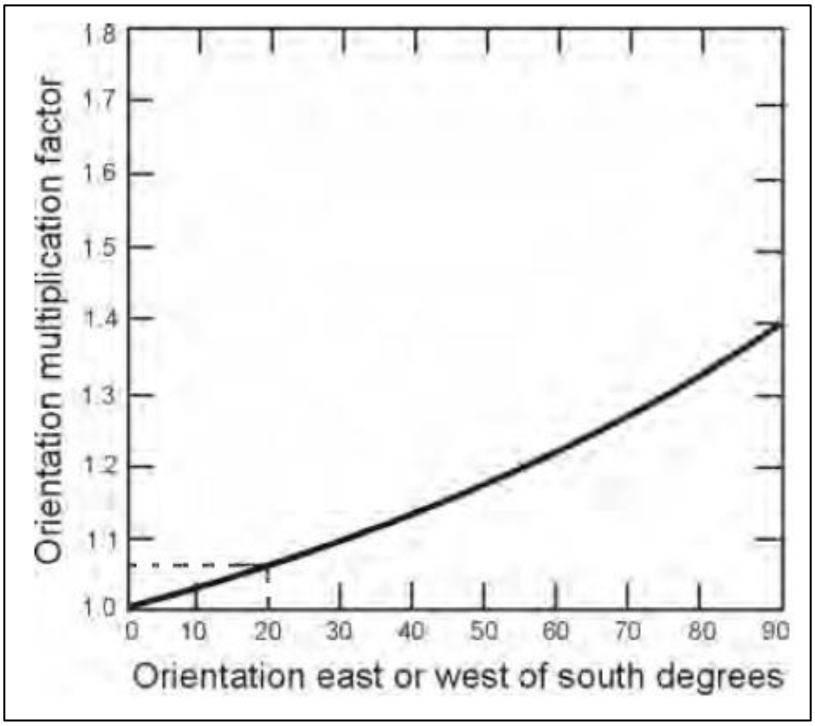

Figure 19. Size correcting factors of glazed flat plate solar collectors due to orientation

However, closer to the equator this is almost useless. The lower the tilt of the collector (accordingly to the high elevation of the sun in the sky), the less the orientation affects it. A collector at 5-10° tilt is almost flat to the sun. That is, the collector could be practically in any direction.

We have assumed that nothing shades the collector during any part of the day. **Shading** is precisely one reason for changing orientation. If tall trees, for example, shade a collector until 10 a.m., an orientation west of south (so that the afternoon sun will provide the bulk of the energy collected each day) would enable maximum solar energy collection. Moving the collector (and increasing its size accordingly) will correct disruptions to solar insolation.

To help the installer determine shading problems, **solar pathfinders** are available from several manufacturers. See in Figure 20 this additional instrumentation.

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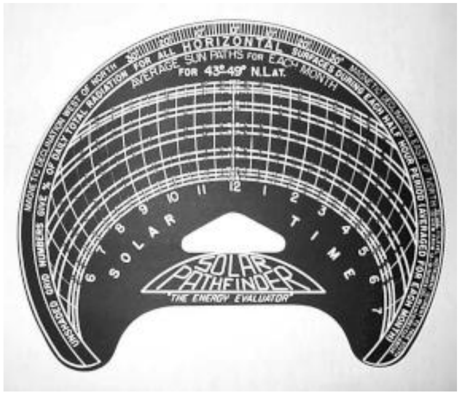

Solar pathfinder. Instrument.	Solar pathfinder. Sunpath diagram

DESCRIPTION

- A solar pathfinder allows accurately assess shading patterns, which is particularly recommendable at buildings, country houses and other solar projects representing major investments. In this way, it is possible to reduce gross errors in structure orientation, solar system sizing, collector placement and component specification.
- It uses a highly polished, transparent, convex plastic dome to give a panoramic view of the entire site. All the trees, buildings or other obstacles to the sun are plainly visible as reflections on the surface of the dome. The sun path diagram can be seen through the transparent dome at the same time.
- The solar pathfinder use diagrams or cards that are latitude and application specific: "South-facing" (for Northern hemisphere) or "Vertical" is for applications of 20-90 degrees tilt; "Horizontal" is for applications of 0-20 degrees tilt. The rays depict solar time. The arcs depict average sun path for given month. The small numbers given in half-hour increments give percentage of radiation for that half-hour.
- The solar pathfinder is not electronic but can be supplemented with software applications to increase power of calculations: radiation at any azimuth and tilt angle, integration of data with weather data and more.

Figure 20. Solar pathfinder

3.6 Optimum tilt angle

The best tilt angle will vary not only with the collector's geographical location but also with **seasonal function or with application**. For example:

- Domestic water heating systems are designed to provide heat year-round.
- Solar pool heating requires collecting sun energy mainly in summertime.
- Winter space heating requires collecting sun energy mainly in winter.

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From research, standard recommendations for collector tilt have been derived. According to them:

a) Mounting at an angle equal to the latitude works best for year-round energy use.

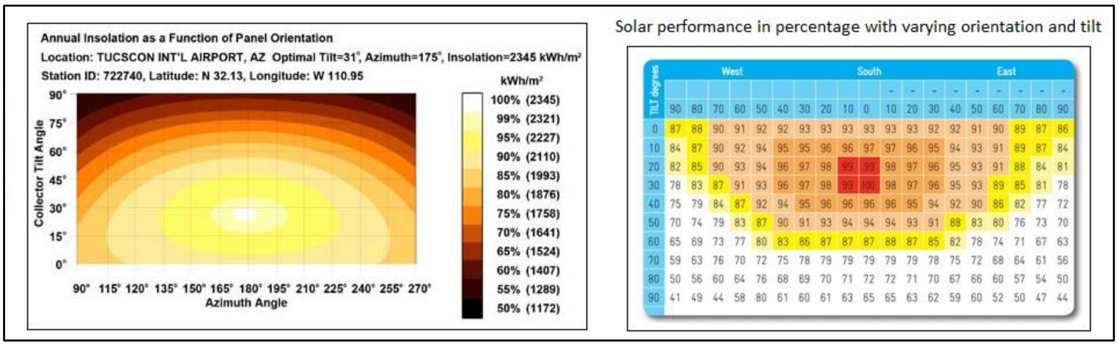
b) Latitude minus 15° mounting is best for summer energy collection.

c) Latitude plus 15° mounting is best for winter energy collection.

As it's been noted earlier, methods exist to move a collector so that the sun's rays strike it at a right angle all day and in all seasons. Use of such sun-tracking mechanisms increase the amount of energy a collector receives, but it also increases the system's cost, complexity and future maintenance requirements.

Concluding, most practical designs accept the loss of energy suffered through fixed mounting and use of general guidelines like those given above (i.e, an orientation and tilt to collect the most usable solar energy possible).

Other similar optimal installation criteria are available. See for example Figure 21 where a Surface Orientation Factor chart (SOF) is shown.



TILT degrees	West									South									East
	90	80	70	60	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60	-70	-80	-90
0	87	88	90	91	92	92	93	93	93	93	93	93	92	92	91	90	89	87	86
10	84	87	90	92	94	95	95	96	96	97	97	96	95	94	93	91	89	87	84
20	82	85	90	93	94	96	97	98	99	99	98	97	96	95	93	91	88	84	81
30	78	83	87	91	93	96	97	98	99	100	98	97	96	95	93	89	85	81	78
40	75	79	84	87	92	94	95	96	96	96	96	95	94	92	90	86	82	77	72
50	70	74	79	83	87	90	91	93	94	94	94	93	91	88	83	80	76	73	70
60	65	69	73	77	80	83	86	87	87	87	88	87	85	82	78	74	71	67	63
70	59	63	76	70	72	75	78	79	79	79	79	79	78	75	72	68	64	61	56
80	50	56	60	64	76	68	69	70	71	72	72	71	70	67	66	60	57	54	50
90	41	49	44	58	80	61	60	61	63	65	65	63	62	59	60	52	50	47	44

Figure 21. Examples of Surface Orientation Factor charts for optimal tilt and orientation angles of solar collectors.

SOF charts illustrate the combined effects of collector tilt and azimuth on the amount of annual solar insolation available at a given site. These charts illustrate either the percentage of the maximum solar insolation that is available for a given orientation or quantify the average total energy that falls on the collector annually when mounted at a specified tilt and azimuth. Again, SOF charts illustrate that **perfecting the tilt and azimuth of the collector array is not strictly necessary**. For many sites, orienting the collectors to the southwest or the southeast will have

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minimal impact on system production. Also, a less-than-optimal collector tilt will not reduce the annual system output significantly either. Private and public services provide consolidated SOF charts for various locations.

Now, it must be known that exceptions to the collector tilt guidelines given above are common with installers in particular regions and project scenarios. For example:

- Extremely northern regions where the winter solar resource is very diminished is recommendable mounting collectors at a tilt angle that is 15 degrees less than the latitude.
- When collectors are mounted at lower tilt angles, care must be taken to alleviate the potential for overheating under summer insolation levels. In desert areas with an intense solar resource, many installers will mount collectors at a tilt angle that is 15 degrees more than latitude to mitigate overheating in the summer.
- Collectors may also be mounted at low tilt angles if they are flush-mounted on an existing roof to provide for a more aesthetically pleasing appearance. In addition, this may contribute to overheating and will make it more difficult for the collector array to shed snow in colder climates.

3.7 Heat Storage considerations

Most solar thermal systems employ a material with high energy capacity to store sensible heat until it is needed for a specific purpose. When the purpose of the solar thermal system is to provide heated water, the water itself is the thermal mass that stores the heat generated by the solar collector. For these solar water heating systems, the water itself may be the fluid heated in the collector and then delivered directly to the tank.

In areas where freezing temperatures are common during winter, the heat collecting fluid may be glycol or another heat transfer fluid with high energy capacity that can withstand freezing temperatures. Such systems employ heat exchangers at the storage tank to transfer the heat from the collector fluid to the potable water.

In solar water heating systems, the storage is sized with generous proportions to hold as much heated water as may be needed for a given purpose during times of low solar insolation. The tanks are also highly insulated to reduce heat losses.

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Further from the equator, inlet water temperatures are colder, while in many cases, the insolation may be close to the same during some periods of the year. On a given day, if the amount of insolation is about the same, one might think solar systems in Stockholm or Athens, for example, would perform about the same. It happens that the total heat energy collected and stored in the tank may be about the same, but the end-of-the-day tank temperatures will be different.

Why? The Stockholm storage tank will be colder than the Athens storage tank due to the difference in cold water supply temperatures. So, more total solar energy is required to increase the Stockholm system to the same end-of-the-day tank temperature. If this is our objective, we must increase the size of collector area to increase the energy gain of the system.

Simply put, more collector is required in order to increase the total degrees of the water being heated.

Figure 22. Solar water heater on the roof with heat storage tank

3.8 Additional System Considerations

To meet its intended purpose, a solar thermal system must meet criteria beyond simply collecting and storing solar energy.

Safety. A solar thermal system must not contaminate the medium used to store or provide the system's energy output. For example, solar water heating systems must not contaminate water that may be used in food preparation or in human contact activities. For this reason, solar water heaters with heat exchangers frequently employ two walls to isolate the potentially dangerous heat collecting fluid from the water to be heated.

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Mechanical safety must also be assured in designing and installing solar collectors. A big solar collector can act like an airplane wing in strong winds, so it must be structurally well connected and securely attached to its mounting surface.

Figure 23. Installing solar thermal collector

Affordability. Affordability can be defined as performance balanced by price. A solar thermal system with collectors that track the sun's path will perform better than one with fixed collectors. However, the tracking mechanisms can double the cost of the system. To be affordable, a solar thermal system must balance performance and cost. Because solar thermal systems produce kWh. kWh per money (kWh/€) is a good measure of affordability.

Materials Used. Materials for solar energy systems must be chosen carefully. The most important factors are safety, performance, durability and cost.

Materials must retain their shape and strength during repeated thermal expansion and contraction–all the while being exposed to the weather. Collector materials lead hard lives. The collector is exposed to wind, rain, hail, temperature extremes and ultraviolet radiation. Untreated plastics, woods and synthetic boards deteriorate rapidly under such conditions. Even steel must be protected by plating, galvanizing or painting. The collectors must be able to tolerate stagnation temperatures. This can be as high as 200°C for some solar collectors. Durability is important in all materials used in a solar system because the cost effectiveness varies directly with their life expectancy.

4. Summary

These are important ideas addressed in the Unit:

- Solar thermal technologies find application in almost every sector and especially in residential and commercial sectors for water and space heating.
- Solar thermal systems are based on collecting the radiation of the sun that reaches the ground, especially the direct beam radiation.
- Solar radiation varies widely depending on the sun's position, which in turn depends on the time of the day and year. The resulting effect is a varying angle of incidence of the sun's rays and varying air mass, which together determine intensity of power on irradiated surfaces, such as solar collectors. The sun's position is determined by two solar angles: altitude and azimuth. The air mass is related to thickness and attenuating effects of atmosphere.
- Other determinants of the efficiency of the solar collectors are absorptance (better if: high) and reflectivity (low) of materials, heat transfer (high), temperature gradient (low) and thermal mass (high).
- The solar basics are to be applied for the sake of effectiveness and efficiency of solar thermal systems.
- Basically, for a given latitude, solar collectors are installed:
    - Inside the "solar window", when we know that irradiance and insolation are greatest.
    - Fixed on the floor, inclined or flat roofs or walls.
    - Perpendicularly to sun's rays seeking to collect the more solar power available and heat. That is, basically facing true south.
    - Adjusting collector tilt and orientation, to such aim. Frequently, tilt equals location latitude.
    - Applying correction factors to tilt and orientation angles, as needed. For example, to overcome shading problems or compensate roof slope.

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- However, there a number of valid reasons for not to follow strictly these guidelines and to adjust differently tilt and orientation angles:
  - The application or system function. Maybe year-round energy use is not the objective.
  - Latitude. We will want to adapt our installation to too much or too little irradiation.
  - Aesthetics, safety, shading and others. We could sacrifice some of efficiency.
  - Special applications where accuracy is a must (research, for example).
- Measuring solar radiation is basic for every professional involved. We can measure solar radiation with pyranometers, pyreheliometers, sunshine recorders or light meters. Solar pathfinder is other useful instrument for assessing and overcoming the undesirable effects of shading.
- Additional solar thermal system considerations are: components such as collector types and heat storage, materials, safety and affordability.

To conclude, this unit has provided an appropriate basis to learn the specificities of solar thermal systems calculation and installation.

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  - Solar Radiation Monitoring Laboratory.

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