Government of India
Ministry of New and Renewable Energies

कौशल बलम्

Solar Thermal and Photovoltaic Field Engineers Training course

Prepared by

The Energy and Resources Institute, New Delhi, India

In association with

Directorate General Of Employment And Training

Under the

Human Resources Development Programme of
Ministry of New and Renewable Energy, Government of India
(2010-2012)

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Section-A: Renewable Energy

Chapter 1: Introduction to Renewable Energy

1.1 What is Renewable Energy?

Renewable energy is a form of energy, which comes directly from natural resources such as sunlight, wind, rain, tides and geothermal heat. It does not have a limited supply and thus can be used again and again. Further, it will not get exhausted like non-renewable energy sources such as coal, oil and gas. Most of the renewable energy comes from the sun. Solar energy is produced from the constant heat and light given out by the sun. Remember sun drives the weather too. Renewable energy sources can be put down as:

Solar

Wind

Biomass

Small Hydro

Geothermal

Tidal

Wave

Coal, oil and gas too owe their birth to the mighty sun in one way or the other. Figure 1.1 gives a quick glimpse of both the renewable and non-renewable sources of energy for an easy understanding.

1.1.1 Underlying processes in brief

Each renewable energy source is created out of one natural process or the other. These are mentioned briefly as under. Figure 1.2 gives a symbolic representation of these sources together with the balance sheet of solar radiation availability from the sun on earth's surface etc.

Solar

The source of all energy given out by the sun lies in its core. In this hydrogen atoms are fused together to make helium. This results in release of a large amount of energy at the rate of 3.86x1026 Joules per second. Solar energy has been in use since long for heating and drying etc. Presently, it is being used for lighting homes and buildings, producing electricity and heating water etc. More the amount of solar energy received by us on earth, more useful it will be.

Wind

Earth absorbs the sun's heat at different rates. Thus one point gets more heated than the other. It moves the air giving rise to wind energy. This form of energy has been in use for thousands of years in one way or the other. In the olden times, people used the wind for sailing in the sea. Wind machines were earlier used to pump water. We now use energy in the wind to produce electricity.

Biomass

It is a natural matter that makes up plants and trees. Sunlight is absorbed during a process known as photosynthesis. Some of the sunlight remains inside the plants and trees. This form of energy is called as biomass. It can be used to produce heat, electricity and even fuel to run automobiles.

Small Hydro

It is a clean method of producing electricity from a trapped wall of water. Just like the wind, the earth naturally produces flowing waters. These can be in the form of rivers, streams and water falls etc. Water energy or hydro power was used in the past to run flour mills etc. As water flows, modern turbines change energy into electricity.

Geothermal

The geothermal energy is heat from deep within the earth. Some materials just decay in the earth's crust and give out energy. Such energy can be taken out and used to produce both heat and electricity.

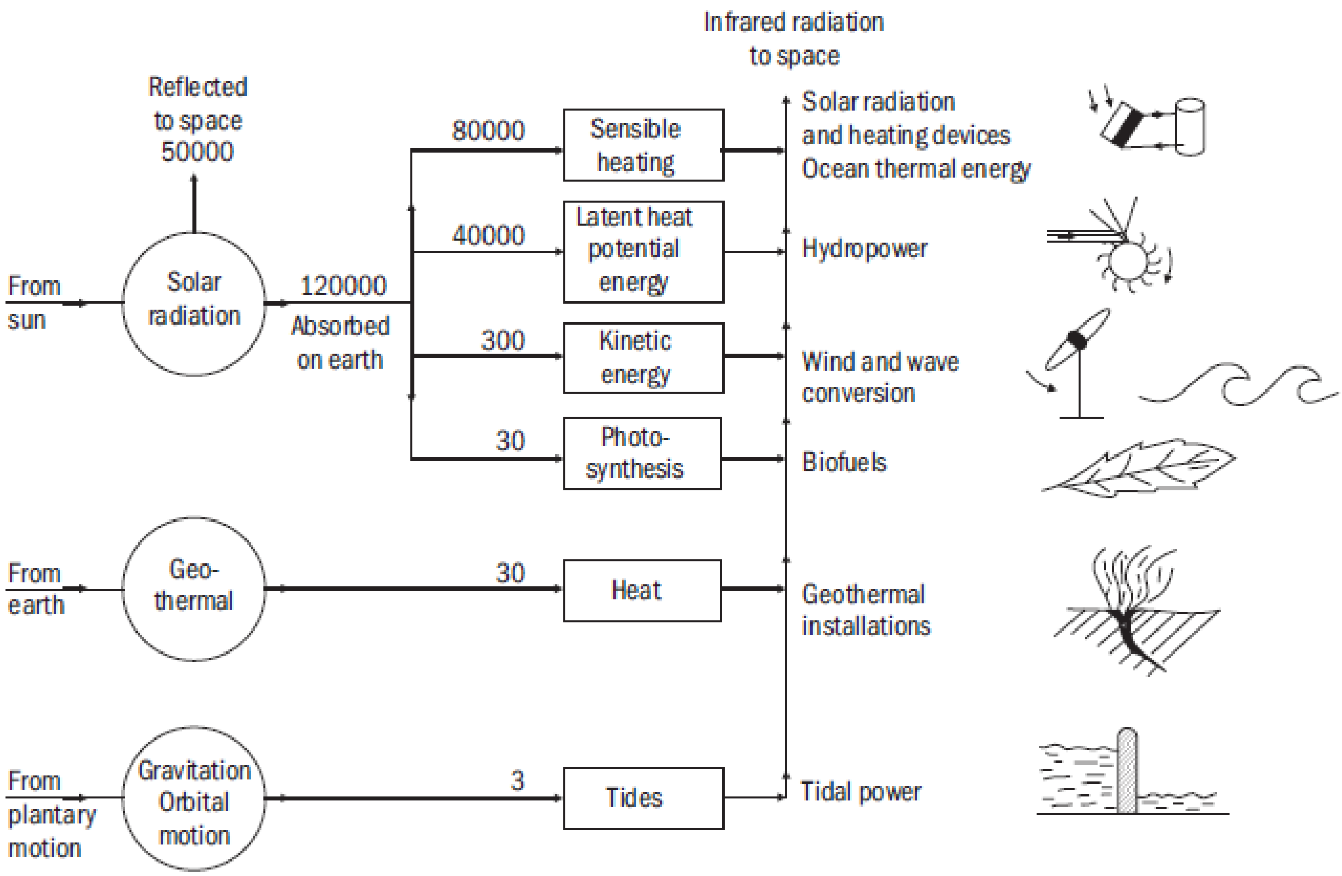


Figure 1.2: Renewable and Non-Renewable Energy Sources

Tidal

Tidal energy is created by the relative motion of earth, moon and sun. The gravitational contact is also present amongst them. Mostly, every coastal region has two high and two low tides in nearly 24-hour period. However, this type of energy use is still quite small worldwide.

Wave

Water covers around 70% of the earth's surface. The sea waves hold enough energy in them. This gives rise to wave energy which can be trapped. It can then be used for generating some useful power. However, this type of energy use is also still very low.

> Quite clearly, solar energy is at work here and there rather everywhere. We must try to use it for meeting some of our daily energy needs. If, not now, then when can we think about its use?

These new sources of energy need some technology support. Table 1.1 gives all possible technology choices etc.

Table 1.1: Technology Choices

Primary Energy Source	Representation	Technology choices For conversion	Important End-use Energy
Sun	Solar radiation	Solar Photovoltaic (PV) Cell PV power plant Solar collector Solar thermal power plant	Electricity Heat, Electricity
	Wind power Atmospheric motion Wave motion Ocean currents	Wind Turbine(please align the wave power station to wave motion in 2nd column)Wave power station Ocean current power station	Electricity Electricity Electricity
	Biomass	Power generator, Cogeneration plant	Heat, electricity, fuel
	Hydropower	Hydropower plant	Electricity
Earth	Geothermal	Geothermal cogeneration plant	Heat, Electricity
Moon	Tides	Tidal power station	Electricity

1.2 Indian Renewable Energy Programme

India has enough sunshine, fast blowing wind in some areas, lot of water sources and plenty of biomass matter. The Ministry of New and Renewable Energy (MNRE) has been running a country wide programme since long. Under this programme, a large number of products and systems have been installed so far (Table 1.2 below). These have benefited the rural people the most. Several organizations have helped MNRE to achieve such a large scale gain. These mainly include the following:

State Nodal Agencies for renewable energy (there is one such agency in every state which implements the RE programme within that state)
Indian Renewable Energy Development Agency (IREDA)/Nationalised Banks etc. (provide soft loans etc. to different types of end-users etc.)
manufacturers of the renewable energy devices (those who produce the products and systems)

Non governmental Organisations/Voluntary agencies/Village Energy Committees (those which carry out rural surveys and maintain the systems in some cases as well)
Academic and Technical Institutes/Research Laboratories (those which help in developing technology etc.)

The Jawaharlal Nehru National Solar Mission (JNNSM) has just taken off. A total solar power capacity of 20,000 MW is expected to come up under this mission by 2022. One of the most important tasks is to prepare a large number of well trained Solar technicians. The Industrial Training Institutes (ITI's) numbering around 6000 can take part in this exercise. These technicians can then install, operate and maintain the solar energy systems in any part of our country.

Table 1.2: Indian Renewable Energy Programme Achievements at a glance (as on 31 March, 2011)

Renewable Energy Programme/ Systems	Target for 2010-11	Achievement duringMarch 2011	Total achievement during 2010-11	Cumulative achievement up to 31.03.2011
I. POWER FROM RENEWABLES:				
A. GRID-INTERACTIVE POWER (CAPACITIES IN MW)				
Wind Power	2000	872.68	2350.35	14157.10
Small Hydro Power	300	56.70	307.22	3042.63
Biomass Power	455	-	143.50	997.10
Bagasse Cogeneration		31.50	321.50	1667.53
Waste to Power - Urban	17	-	-	19.00
- Industrial		-	7.50	53.46
Solar Power (SPV)	200	5.29	26.59	37.66
Total	2972	966.17	3156.66	19974.48
B. OFF-GRID/ CAPTIVE POWER (CAPACITIES IN MWeq)				
Waste to Energy - Urban		-	-	3.50
- Industrial	13.00	0.83	23.70	66.92
Biomass(non-bagasse) Cogeneration	75.00	11.69	80.73	301.61
Biomass Gasifiers - Rural	4.00	0.40	1.37	14.47
- Industrial	15.00	3.25	9.00	117.34
Aero-Genrators/Hybrid systems	0.50	0.05	0.05	1.12
SPV Systems (>1kW)	32.00	1.25	2.60	5.80
Water mills/micro hydel	2.50	0.17(34nos)	2.2(444nos)	6.98(1397)
Total	**142.00**			

*** We had included some figures pertaining to off-grid solar products like SL, HLS, SLS and solar thermal collectors etc. in the earlier version. What about their inclusion here as the training programme/material deals with these products essentially?

Source: www.mnre.gov.in

Following few things are quite clear from this Table:

- the size of Indian RE programme is very large
- the programme offers large scope for trained manpower at various levels (ITI trained solar technicians included)

1.3 Jawaharlal Nehru National Solar Mission

India wants to reap the benefits of sun than never before. The mobile telephony revolution in the country is there for all of us to cheer about. Solar energy can work wonders in this area too by connecting people far and wide. It is just one of the many applications conceived under a large canvass of a recently launched solar mission. This solar mission is better known as the Jawaharlal Nehru National Solar Mission (JNNSM). It has set up several short term and long term targets for solar power development in the country. The aim is to achieve the following by the end of 13th Five-Year-Plan i.e. by the year 2022:

- 20,000 MW of grid connected installed solar capacity made of large Photovoltaic (PV), Solar thermal power plants and small PV systems
- 2000 MW of off-grid distributed power plants
- 20 million square meters of solar collectors for low-temperature applications
- 20 million solar lighting systems for rural areas

Additional goals

- promote research and development, mass awareness generation and develop trained and well skilled human resource to meet the upcoming needs of solar industry as a whole
- expand the scope and coverage of earlier incentives for industries to set up PV production facilities in India
-

Table 1.3 shows the phase-wise total and annual targets set by the JNNSM

S. No	Activity	Achievements in 2009 (under MNRE programme)	Phase-I 2010-13	Phase-II 2013-17	Phase-III 2017-2022	Total
1	Grid connected Solar (MW)	6	1000	3000	16000	20000
2	Off-grid Solar (MW)	2.4	200	800	1000	2000
3	Solar Thermal Collector million m2	3.3	7	8	5	20
4	Solar Lighting Systems (million)	1.3				20

1.3.1 Manpower Development under JNNSM

India launched the JawaharLal Nehru National Solar Mission (JNNSM) in 2010, with the twin objective of contributing to the country's long-term energy security and its ecologically sustainable growth towards building a 'Solar India'. The mission focuses on creating an enabling environment for the penetration of solar technology in the country, both at the centralized and decentralized (off-grid) levels. The rapid and large-scale diffusion of solar energy will require an increase in technically qualified human resources in the sector, simultaneously.

The mission, thus, places strong emphasis on human resource development, with plans for countrywide training programmes and specialized courses for technicians, to meet the requirements of skilled manpower for field installations and after-sales service networks. The JNNSM envisages that:

"…at the end of Mission period in 2022,the solar industry will employ at least 100,000 trained and specialized personnel across the skill spectrum."

The success of the JNNSM will require involvement by a large number of Project Implementing Agencies (PIAs), including strengthening of the solar product manufacturing base, as well as a well-developed and established network of 'solar technicians cum entrepreneurs' in rural areas. Solar technicians can provide services to PIAs and manufacturers to establish the projects and also ensure project sustainability through effective after-sales repair and maintenance services.

Apart from providing technical support both during and after installations, solar technicians can also act as rural level solar integrators to disseminate various solar applications in rural areas not only for their livelihood, but also to contribute towards the overall goal of the mission. Their added role will greatly assist in creating 'the paradigm shift needed for commoditization of off-grid decentralized solar applications', as envisaged under the off-grid and decentralized applications scheme of the JNNSM.

The Ministry of New and Renewable Energy (MNRE) has already undertaken a few major initiatives in this direction. Like for example, the ministry has provided for a nation wide training programme initiative at the Energy and Resources Institute (TERI). Key objective of this programme is to run multi-level training programmes in active coordination with the Directorate General of Employment and Training (DGET). DGET is managing the affairs of around 6000 ITI's at present and these ITI's are going to be the centres of such activities soon. Solar technicians once trained are expected to take care of the field installations and after-sales servicing too. JNNSM has set a quite ambitious target to employ at least 100000 of trained and specialized personnel across the skill spectrum by 2022. This large scale programme is expected to have the following type of channel partners for a smooth nation wide implementation. Programme financing is going to be a mix of subsidy and soft loan facility:

Channel Partners

Renewable Energy Service Providing Companies
Financial Institutions as Aggregators
Financial Integrators
System Integrators
Programme Administrators

Financing

MNRE subsidy
Soft re-finance facility to Banks through IREDA

Ministry has also supported the establishment of a national centre for PV research and education (NCPRE) at IIT Mumbai and a Solar lighting laboratory at The Energy and Resources (TERI), Delhi.

Summary remarks:

RE technologies are still more costly than the electricity produced from the fossil fuels (like coal, oil and gas).RE sector in India is still in the early stages of market development. RE programme development still needs a helping hand from both the government and public at large.

Chapter 2: Solar Radiation

2.1 The Sun

Would you like the following description to go along in this section?

The sun has got various layers each with its own characteristics. These mainly include temperature, density and process features. The interior of the sun includes the core, the radiative zone, and the convective zone. The matter in the core is at temperatures of around 15,000,000 K. The core density is around 160,000 kg/m3, which is 160 times as dense as water. It is more than 130,000 times as dense as earth's atmosphere at sea level. Each second, the sun converts around 5 million tons of mass into energy as per the well known equation E=mc2 (here m-mass and c is the speed of light). It produces energy to the scale of 4x1026 Watts. The radiative zone surrounds the core and it helps to maintain the high temperature needed to carry on the nuclear fission. In turn, the radiative zone is surrounded by the convective zone. It is known as the outermost layer of the interior and being cool too. The photosphere gives out the light which all of us can see. At the photosphere, the diameter of the sun is 1.39x106 km. It is nearly equal to 109 times the diameter of the earth. Photosphere is believed to be the surface of the sun and has the following few important features:
made of about 73.5% hydrogen, 25% helium & 1.5% (mainly oxygen and carbon)
one of the coolest layers of the sun at a low temperature of 6000 Kelvin
density of around 10-6 kg/m3
shines about 3,98,000 times as brightly as the moon.

2.2 What is Solar Radiation?

The sun emits radiation in the entire electromagnetic spectrum from gamma rays to radio waves. Thus the radiant energy is a combination of energy released by layers having different temperatures.This type of radiation is simply known as the solar radiation. The solar radiation spectrum is made of the following few components:

- about 6.4% of the total energy is contained in Ultra-violet (UV) region (λ< 0.38 μm)
- another 48% is contained in the visible region (0.38 μm < λ< 0.78 μm)
- remaining 45.6% is contained in the Infrared region (λ>0.78 μm)

The amount of solar radiation present is not the same everywhere as you will know below.

It is quite important to understand the following few terms in respect to this radiation.

Beam radiation

It is that part of solar radiation that reaches the earth's surface without any change in direction. That is why it is also known as the direct radiation.

Diffuse radiation

It is that part of radiation whose direction gets changed before touching the earth's surface. This happens as it gets scattered i.e. here and there.

Total solar radiation

The sum of the beam and diffuse components of solar radiation is called total solar radiation. Total solar radiation on a horizontal surface is commonly known as global radiation.

Irradiance

The solar irradiance G is the rate at which the radiant energy is incident on a unit area of a surface. It is marked in terms of W/m2.

Insolation

The incident solar radiation is also known as insolation. Generally, the insolation for a specific time period (commonly one hour) is represented by symbol I. While as, symbol H is used to give insolation for the day. The H and I values are indicated by W-h/m2/day and W-h/m2/h respectively. In case, both H and I values are measured on an hourly basis; I numerically becomes equal to G.

2.3 Variations in solar radiation

Solar radiation is present on nearly each and every place on earth. However, it may or may not be present for the whole year. The amount of such radiation received can change due to the following few things:

- location (like for example Ladakh, Delhi, Rajasthan)
- time of the day (morning, noon, afternoon)
- season (Spring, summer, autumn, winter)
- local landscape (means mountains, trees, rivers and forests etc.)
- local weather conditions (air temperature, humidity, wind etc.)

The sun rays strike the surface of earth at different angles. It ranges from 0 degree (just above the horizon) to 90 degrees (directly overhead). In simple words, the earth gets all the energy possible when sun rays are just straight down. However, it may not always be like that. Think about the following few facts as well:

- sun rays may take more time to pass through the earth's atmosphere. Thus, these can break up here and there and get dim too.

- the earth moves around the sun in an egg-shaped orbit. The surface of earth gets a little more solar energy when the sun is closer to the earth.
- the earth is nearer the sun when it is summer in the southern hemisphere and winter in the northern hemisphere.
- the earth's axis of rotation has a tilt of 23.5°. It also plays a part in knowing the amount of sunlight that hits the earth at a given location.
- sunlight changes from one hour to the other due to earth's rotation.
- the sun is low in the sky during the early morning and late afternoon. The sun is at its highest point at noon.
- on a clear day, earth gets the maximum possible amount of solar energy around noon.

2.4 Types of solar radiation

Sunlight moves through the atmosphere. It does not reach us in a full amount. Some amount of it is absorbed, scattered and reflected due to the following few things: *Figure 2.1* shows the effect of these things on the solar radiation as it makes its way into the earth's atmosphere.

- water vapours
- air molecules
- clouds
- dust
- pollutants
- forest fires
- volcanoes

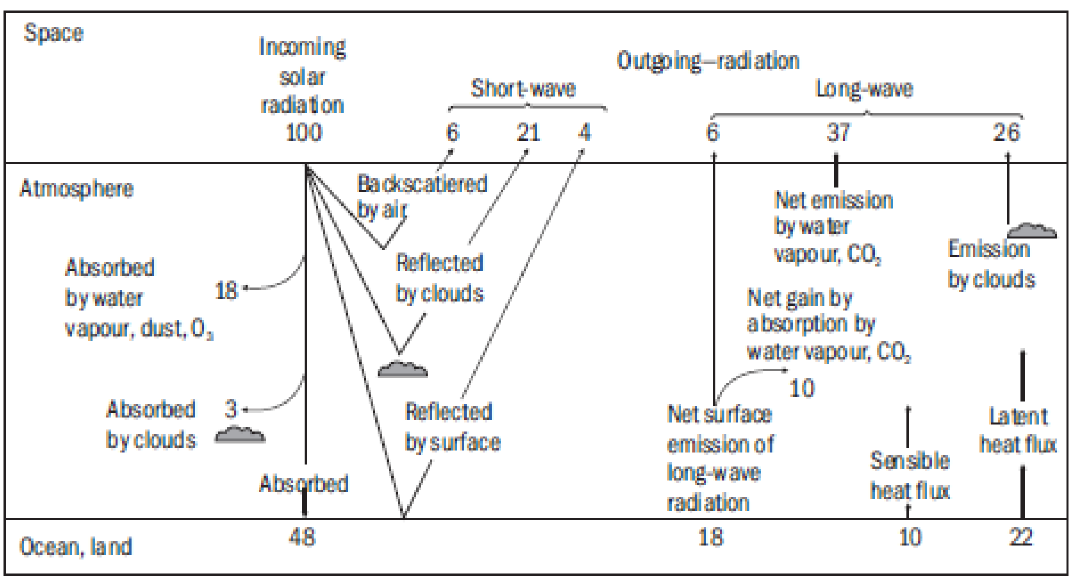


Figure2.1: Effect of atmosphere on solar radiation

However, even then, a large amount of energy still reaches the earth's surface. It can be used to produce some useful electricity via solar cells for example. Some of this radiation is direct and some of it is diffuse. The sum of direct and diffuse radiation is commonly known as Global solar radiation. Brief features of these types of radiation are given in Table 2.1 below: Figure 2.2 shows these components of solar radiation.

Figure: 2.2: Components of solar radiation

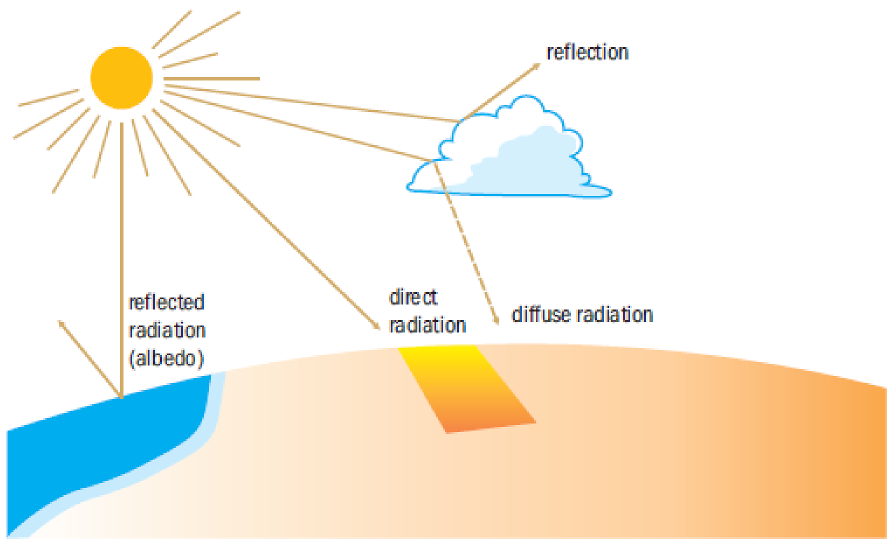


Table 2.1: Components of solar radiation

Type of Solar Radiation	Key features	Solar technology applicable	Remarks
Direct/Direct Normal radiation	Comes directly from the sun Does not get reflected off the clouds, dust, the ground or other objects Strikes the plane of a solar module at a 90 degree angle	Flat plate collectors (non-concentrating type)	Majority of the solar collectors (including solar modules) do not use concentrators to focus light onto solar cells for example Solar concentrator systems can not make use of diffuse sunlight
Diffuse radiation	Reflected off clouds, ground or other objects Takes a longer path than a direct light ray to reach solar collector	Flat plate collectors	

Figure 2.3 presents the percentage amount of solar radiation lost due to the absorption and scattering etc. Simply put, just around less than half (47%) of the solar radiation finally makes its way on the earth's surface.

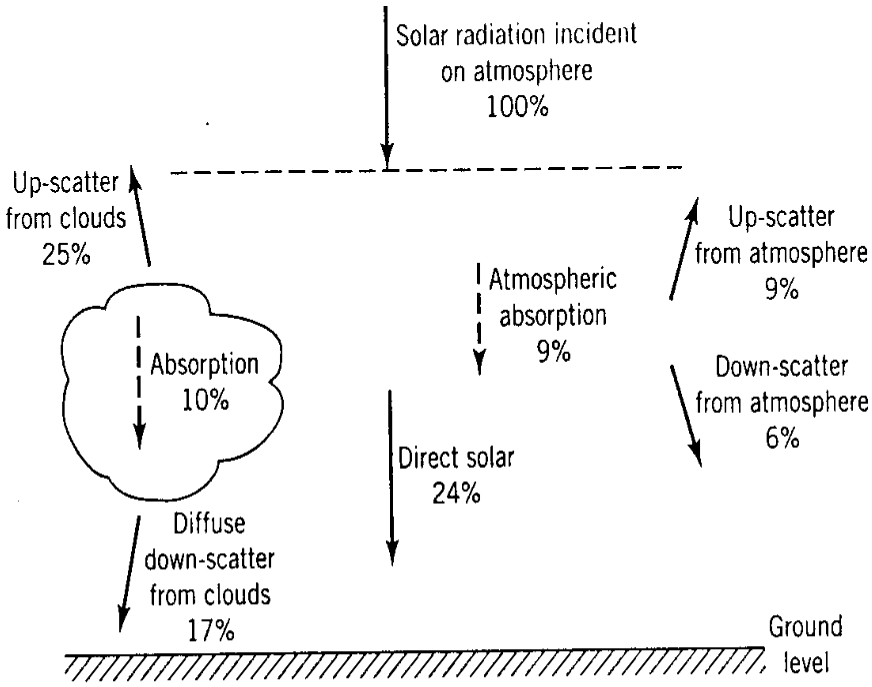


Figure 2.3: Percentage of solar radiation lost due to different phenomenon

2.5 Solar Geometry

The earth revolves around the sun in an elliptical orbit with the sun being at one of the foci. The distance between the sun and earth, therefore changes continually during its revolution around the sun in about 365 days. The average or the mean Sun-Earth distance is 149.6×10^6 km. At its perihelion position i.e. when the earth is nearest to the sun on January one, the distance of earth is about 98.3% of the mean distance. On the other hand, it is farthest on the aphelion position i.e. on July 2, which is about 101.7% of the mean distance. Because of these variations in the sun earth distance, the radiant energy cut by the earth also varies by about +_3% of its normal energy value. *The radiant energy falling on a unit area, termed irradiance, at normal incidence outside the earth's atmosphere at mean sun earth distance is termed as solar constant(S).* Thus value of the solar constant varies from day to day depending on the actual distance from the sun. The present accepted value of solar constant as derived from the space based measurements is 1367+_7 W/m^2.

The fact is that all rays received from the sun can be thought of as being parallel to one another. It is because the sun is at a very large distance from the earth. Figure 2.4 shows the different angles at which the solar radiation is received on earth.

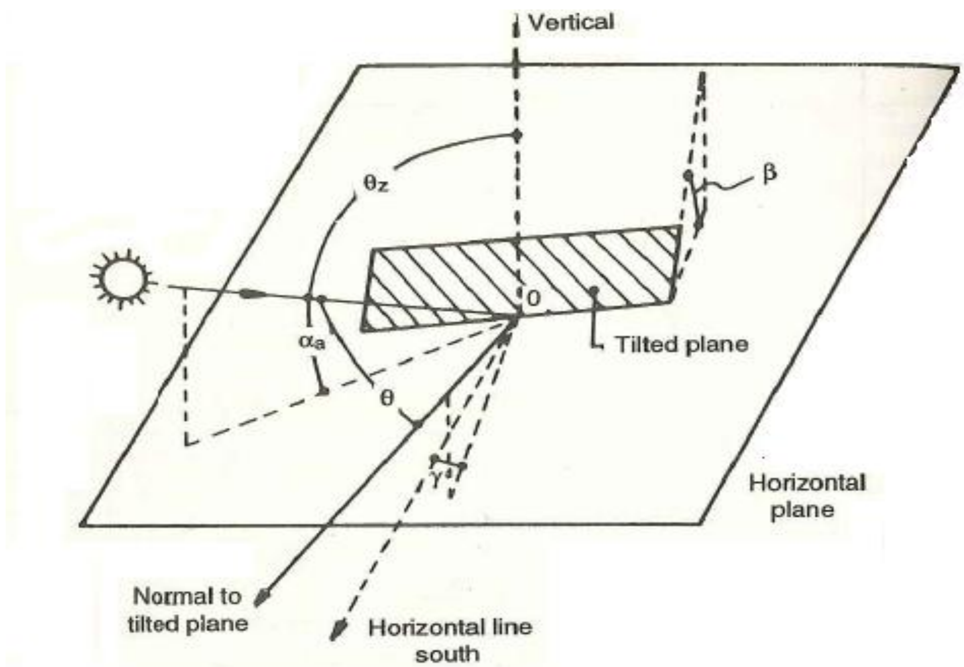


Figure 2.4: Angular path of the solar radiation

It is quite interesting to know few things about a wide range of solar geometry related angles as shown below

Solar Geometry-Angle definitions

Type	Symbol	Name	Description	Sign	Range
Location	Λ	Latitude	Angular location north or south of equator	North positive	-900<-1<-+ 900
Location	Δ	Declination	Angular position of the sun at solar noon with respect to equatorial plane	North positive	-23..450<-d +23..45023..450
Location	Ω	Hour-angle	Displacement of the Sun E or W of due S	East negative West positive	150 per hour
Solar position	Β	Solar altitude	Angle of the sun above horizon	Positive	00 at Sunrise, sunset 00<- β +900

Type	Symbol	Name	Description	Sign	Range
Solar position	θs	Solar zenith	Angle of the sun from the normal of earth's surface, 90 0- β	Positive	00<- θs<-900
Solar position	Φ s	Solar azimuth	East or west position of the sun from due S	East negative West positive	00 at due south Φ can be greater than 900
Wall-orientation	Φ p	Wall azimuth	1. East or west position of the wall from due S	East negative West positive	00 at due south 00 <- φp<-+/- 1800
Wall-orientation	θp	Surface tilt	Angle of the surface relative to the horizontal	Positive	00 horizontal 900 vertical 1800 upside down
Wall-sun orientation	Δ φ	Wall-Solar azimuth	Angle between the solar azimuth and wall azimuth	Positive	00, when wall and solar azimuth coincide
Wall-sunorientation	θi	Solar-incident	Angle between the surface normal and the sun	Positive	Cos θi is the fraction of surface projected in the insolation direction

Source: www.uidaho.edu

2.5.1 Sun's path in different seasons

The movement of earth around the sun gives rise to seasons. The earth's axis of rotation is tilted at 23.45 degrees. Thus it is not perpendicular to the plane of its orbit. The path of sun, as seen from a point on the earth changes from month to month. The northern pole is tilted towards the sun during the northern summer. It is tilted away from the sun in the winter season. This tilt causes the sun to appear higher in the sky in the summer. It thus results in more hours of daylight. Also, there is a quite bright sunlight i.e. hotter condition on the surface of earth. The same is not true of the winter time. The sun's rays strike the earth at a low angle. Thus these rays are more spread out. It also results in lower amount of energy at any spot. That is not all; as winter nights are longer and days remain short. Thus the earth does not get warmed up properly. *Figure 2.5* shows the sun path in three different situations

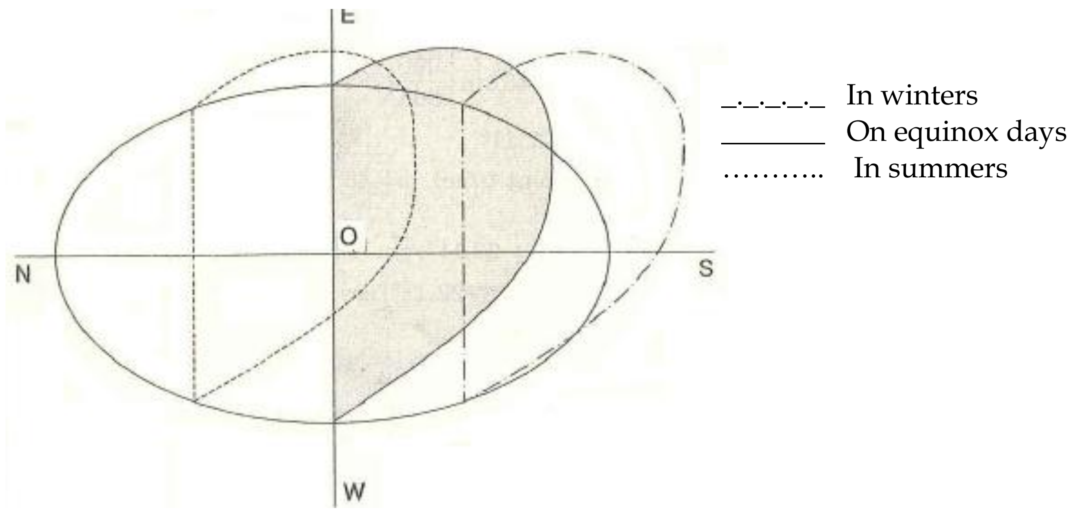
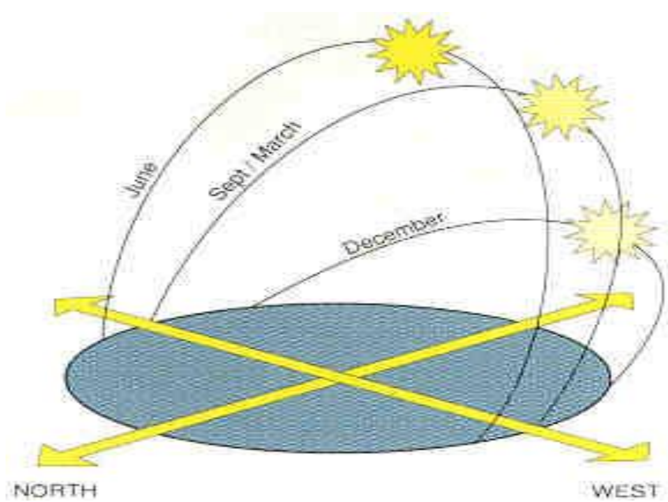


Figure 2.5: Sun Path in three different situations

Figure 2.6 below shows the apparent plane of motion of sun for a location in the northern



hemisphere. It is quite Interesting to note the relative position of sun under different seasons of the year. Earth is closest to the sun in December, which is the winter time in the northern hemisphere.

Figure 2.6: Apparent Planetary motion of the sun

2.6 Solar radiation measurements

Solar radiation is received nearly on all geographical regions of the world. For those who simply like to bask in the sun may just be able to distinguish between a strong sunshine and a weak sunshine as per the season. However, in fact, there are a large number of factors which need to be recorded so as to judge the sunshine availability at different places properly. These factors mainly include the following few:

- latitude, Longitude and Elevation of the site
- monthly and yearly averages of solar radiation
- minimum/maximum monthly & yearly average insolation
- daily Sunshine hours
- monthly and yearly average temperature
- average daily minimum and maximum temperature
- record minimum and maximum temperature
- average heating and cooling degree days
- average relative humidity and Average wind speed

It is now interesting to take a close look at the graphical representations (Figures 2.7 &2.8) of monthly global insolation and the daily insolation in terms of time versus the solar radiation availability in W/m^2 right through the morning hours to late afternoon.

The incoming solar radiation is not equally distributed over the planet due to the spherical shape. At each instant, the sun lights up only half of the planet's surface. The maximum radiation comes out at local noon and less in other times of the day. Daily variation in the solar output is also due to passage of sunspots across the face of the sun. This is as the sun rotates on its axis about once a month.

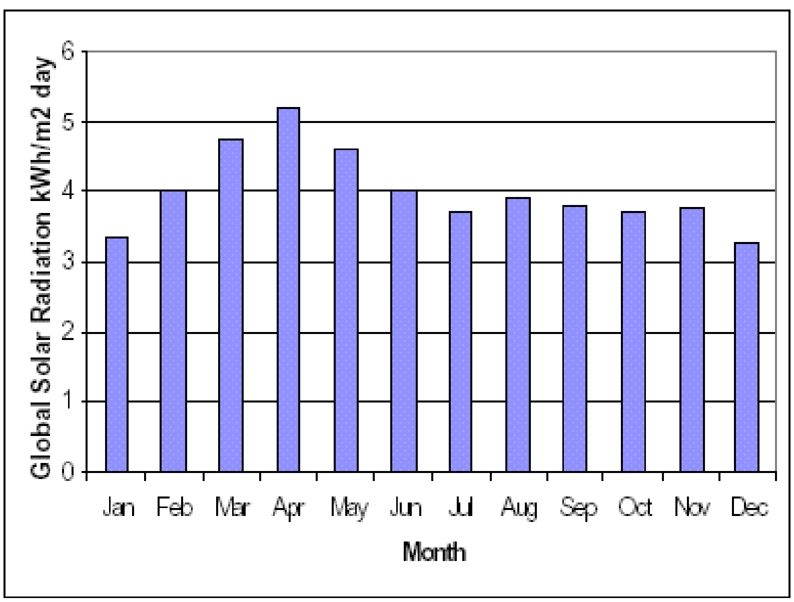


Figure 2.7: Monthly Global Isolation

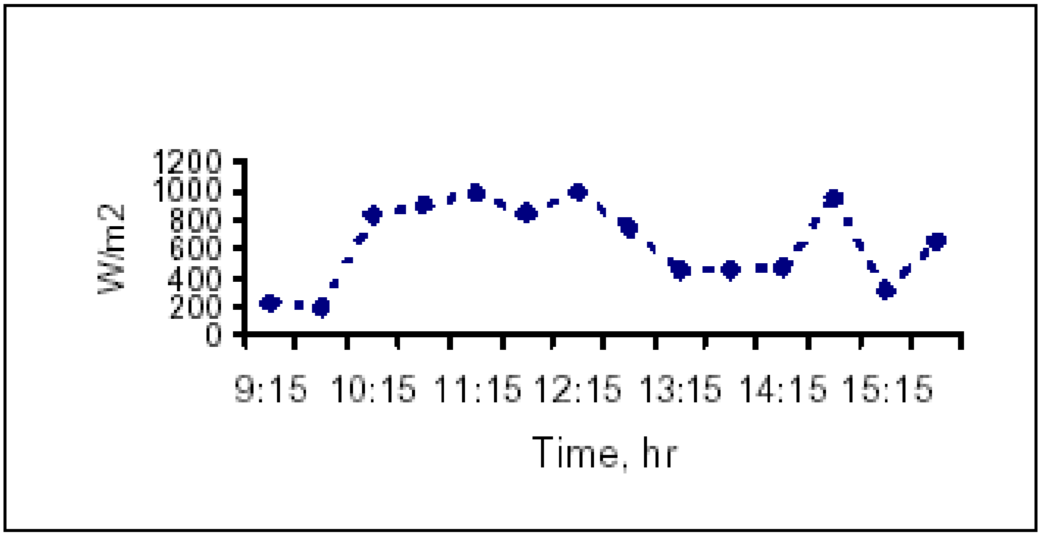


Figure 2.8: Daily Isolation

2.7 Empirical equations for predicting the availability of solar radiation

Ideally, solar radiation should be a known value for a large number of sunny regions. However, it is not normally available due to one reason or the other. Of course, there are several types of solar radiation measuring instruments available today. Attempts have been made by many investigators to establish relationships linking the values of radiation (global or diffuse) with meteorological parameters like the following few:

- number of sunshine hours
- cloud cover
- precipitation

2.7.1 Monthly average global radiation

The first attempt at estimating solar radiation was made by Angstrom. He suggested that it could be related to the amount of sunshine by a simple equation of the form:
$H_g/H_c=a+b\ (S/S_{max})$

Where, H_g=monthly average of the daily global radiation on a horizontal surface at a location (KJ/m^2/day)

H_c=monthly average of the daily global radiation on a horizontal surface at the same location on a clear day (k J/m^2/day)

S=monthly average of the sunshine hours per day at the location (h)

S_{max}=monthly average of the maximum possible sunshine hours per day at the location i.e. the day length on a horizontal surface (h)

a, b= constants obtained by fitting data

The definition of what a clear day means was not quite clear then. Page suggested that Hc be replaced by Ho. It is the monthly average of the daily extra-terrestrial radiation which would fall on a horizontal surface at a given location

$H_g/H_o = a + b\,(S/S_{max})$

Values of a and b have been obtained for many cities in India as given in Table 2.2 below. H_o is the mean of the value (H_o) for each day of the month.

Table 2.2: Constants and b in the equation for the Indian Cities

Location	a	b	Mean error (%)
Ahmedabad	0.28	0.48	3.0
Bangalore	0.18	0.64	3.9
Bhavnagar	0.28	0.47	2.8
Kolkata	0.28	0.42	1.3
Goa	0.30	0.48	2.1
Jodhpur	0.33	0.46	2.0
Kodaikanal	0.32	0.55	2.9
Madras	0.30	0.44	3.5
Mangalore	0.27	0.43	4.2
Minicoy	0.26	0.39	1.4
Nagpur	0.27	0.50	1.6
New Delhi	0.25	0.57	3.0
Pune	0.31	0.43	1.9
Shillong	0.22	0.57	3.0
Srinagar	0.35	0.40	4.7
Thiruvananthapuram	0.37	0.39	2.5
Vishakapatnam	0.28	0.47	1.2

2.8 Simple measurement of solar radiation

As mentioned in Section 2.5, around 1367 Watts per square meter (W/m^2) of solar radiation reaches the earth's atmosphere. This is also known as the solar constant. The total energy emitted by the sun does not change by more than 0.1%, no matter at which point the sun is. A typical solar cycle lasts for around 11 years. On a clear sunny day, solar radiation is in the range of 1000-1300 Watts at midday. This depends on the altitude, latitude and time of the year. It is very useful to collect solar radiation data to know the following:

- solar radiation values (at different times of the day)
- number of hours of sunshine (on a daily basis)
- total number of sunny days in a year

2.8.1 Common units of solar radiation measurement

The values of global Solar radiation **on a horizontal surface** are generally expressed in kWh/m²/day. It is the amount of solar energy that strikes a square meter of earth's surface in a single day. This value is averaged to account for differences in the day's length. There are different units that are used across the world. The conversions based on a surface area are as under:

1 $kWh/m^2/day$= 317.1 $BTU/ft^2/day$=3.6 $MJ/m^2/day$
(BTU= British thermal unit; MJ= mega Joules)

The raw energy conversions are as:
1 kWh =3412 BTU=3.6 MJ=859.8 kcal
(kcal is kilo calories)

2.8.2 Radiation measuring instruments

Solar radiation is made of several components like direct and diffuse. It is quite important to make use of different types of measuring instruments much in accordance with the type of solar radiation. Following few choices of instruments may be mentioned below:

- Pyranometer-for measurement of total and diffuse radiation
- Pyrheliometer-for measurement of beam radiation
- Pygeometer-for measurement of night-time solar radiation
- Suryamapi-for measurement of total and diffuse radiation
- Sunshine recorder- to know the duration of sunshine

Brief description of these types of instruments to measure different types of solar radiation is as under:

Pyranometer

It measures the global solar radiation. This instrument is more in use while dealing with the setting up of flat plate system such as solar modules etc. A Pyranometer is an instrument which measures either global or diffuse radiation over a hemispherical field of view (refer to drawing of section A for schematic diagram). Following few are its most important design cum working features:

- it has a black surface, which heats up when exposed to solar radiation
- temperature goes on increasing till the rate of heat gain equals the rate of heat loss by convection, conduction and radiation
- hot junctions of a thermopile are attached to the black surface
- cold junctions do not receive the solar radiation due to their position.
- electromotive force i.e. emf is thus created. It lies within a range of 0-10 milli volts.
- it can be read, recorded and even summed up over a period of time.

Figure 2.9 shows the view of a commonly used pyranometer in India. Its main design features are as under:

Figure 2.9 : Pyranometer

- hot junctions arranged in the form of a circular disc of diameter 25 mm.
- special lacquer coating which absorbs the solar radiation very well
- two concentric hemispheres of 30mm and 50 mm diameter exist
- hemispheres are made of optical glass with very high light passing properties

The optical glass assembly also keeps the disc surface safe from any weather related effects. This pyranometer is also used to measure the diffuse radiation. It is done by mounting it at the center of a semicircular shading ring. This ring is put up such that its plane is parallel to the plane of the path of sun's daily movement across the sky. It shades the thermopile element. Two glass domes of the pyranometer also remain shaded from the direct sunshine. In this way, the pyranometer measures just the diffuse radiation received from the sky.

Brief construction features of the shading ring

(Refer to drawing of section A for schematic diagram of shaded ring pyrenomter). ABCD is a horizontal rectangular frame 35 cmx80cm. Its long sides are in an east-west direction. There are two angle iron arms EF and GH pivoted to the sides AB and CD of the frame. These are around 70 cm long with slots along their length to carry sliders. The purpose is to place the semicircular shading ring on these ss sliders. The arms are pivoted around a horizontal axis passing through the centre of a rectangular frame. It can be adjusted at an angle to the horizontal. This angle is roughly equal to the latitude of a given station. The movement of the ring up and down the arms can change the sun's declination. Few other design features of the shading ring are given as under:

- it is made of aluminium 50 mm broad and is bent to a radius of 450 mm
- inner side of the ring is painted dull black and the remaining part is painted dull matt white
- a thick plate P is fixed with a circular slot to the bottom of the frame ABCD
- frame can be adjusted in its proper position by rotation about a vertical axis
- pyranometer is mounted on another metal plate P fixed on the top of frame

Pyrheliometer

It measures the intensity of direct solar radiation. This instrument is more in use when planning the installation of concentrated solar power systems. Key design cum working features of this instrument (Figure 2.10) are as under:

Figure 2.10: Pyrheliometer

- hot junction of a thermopile is attached to a black absorber plate
- black absorber plate is placed at the base of a tube
- tube is put in the path of the sun rays by a two-axis tracking mechanism/alignment indicator
- black plate receives just the beam radiation along with a very small amount of diffuse radiation

The daily average solar energy incident over India varies between 4-7 kWh/m^2. It depends on the location. The annual average global solar radiation on a horizontal surface over India is about 5.5 kWh/m^2/day. Our country is very lucky to have around 300 sunny days in a year.

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. A track is burnt along the strip.

This corresponds to the time when the sun is shining. Sunshine Recorder records the actual duration of sunshine (Figure 2.11).

Figure 2.11: Sunshine Recorder

The time period for which the bright sunshine is present is measured by a sunshine recorder.

The sun rays are focused by a glass sphere to a point on a card strip. The card strip is held in a groove in a spherical bowl mounted concentrically with the sphere. During the bright sunshine, a powerful image is formed. 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 the sky. Traces of burning form in this way. The length of these traces is proportional to the time period of the sunshine.

Suryamapi

Suryamapi is a simple hand-held device to measure the solar radiation. It uses a silicon solar cell to sense the incoming radiation (Figure 2.12). This cell simply acts as a photo or light sensor. The unit of measurement in this case is mA/cm^2.

Figure 2.12: Suryamapi

Figure 2.13 gives a quick glimpse of the impressions marked by a sunshine recorder.

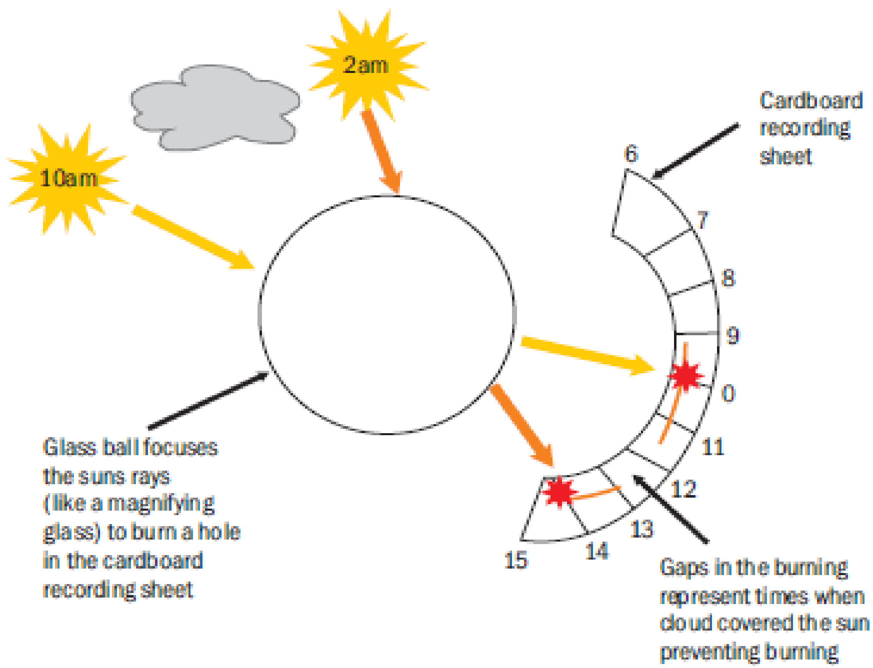


Figure 2.13: Working of a Sunshine Recorder

2.9 Solar map of India

A large number of solar radiation measurement stations have been set up in the country so far. Valuable field data collected in this way has helped to prepare a solar map (Figure 2.14) of India. It shows the solar radiation across the country. Several organisations have played an important role in recording the solar radiation present at different stations across the country. These mainly include the following few:

- Indian Meterological Department
- Indian Institute of Sciences, Bangalore
- Centre for Wind-Energy Technology (C-Wet), Chennai
- Solar Energy Centre (Ministry of New and Renewable Energy)

Solar energy drives nearly all processes on the earth, including the formation of wind too. Thus solar radiation availability at a given station is of importance for a wind farm developer too.

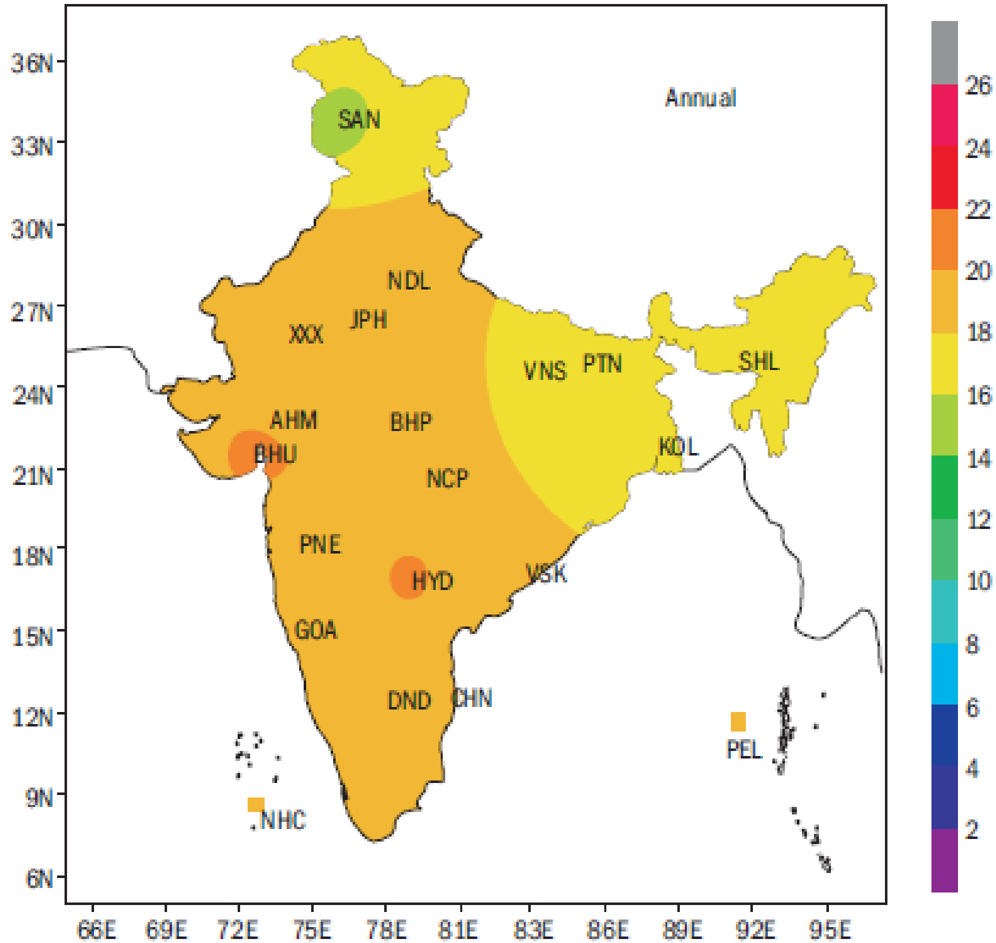


Figure 2.14: Solar map of India

2.10 Solar energy Technologies related to such radiation use

Solar radiation makes several practical uses possible. The heat and light available to us can be used through the following four types of solar energy technologies:

- Solar Photovoltaic (PV) systems-these change sunlight directly (single step) into electricity by means of solar cells made of semiconducting materials like silicon.
- Solar water heating systems-these have a solar collector which faces the sun. It heats the water directly or heats a working fluid. The fluid then transfers its heat to water.
- concentrating solar power systems-these focus the sun's energy using reflective devices like lenses and mirrors. Heat thus produced is used to make electricity.
- passive solar systems-these use non-mechanical components to control the collection of sunlight for various uses like heating, lighting, cooling or ventilation.

2.10.1 Advantages and Limitations of solar technology

Use of solar technology is unique in one way or the other. Following few are its main advantages and limitations:

Advantages

- it runs on a freely flowing fuel (1.8 x 10^{11} MW) which is there as long as sun lasts
- it is available nearly everywhere and to everybody at no cost
- it can be used to produce heat or electricity without a by-product (i.e. a residue)
- there is no burning of any combustible material (like coal for example in a thermal power plant)
- there is no risk of any radioactive exposure (unlike the one in a nuclear power plant)
- it can produce electricity or heat without any noise level
- it is quite safe to use

Limitations

- it is a dilute form of energy
- it has a high initial capital cost
- it varies throughout the day (daily, seasonal and local variation)
- it still needs an expensive storage like a deep cycle battery for night time use

2.10.2 Solar radiation on a different surface

There is a geometrical relationship between a plane of any special orientation relative to the earth at any time and the incoming beam radiation.

Latitude

It is the angle made by the radial line joining the location to the centre of the earth, with the projection of the line on the equatorial plane. By convention, latitude is measured positivefor the northern hemisphere. It varies as $-90^0 <- \varphi <-90^0$.

Solar declination

Since the earth's axis of rotation is inclined at an angle of 23.45^0 to the axis of its orbit around the sun, this tilt causes the seasonal variations in available solar radiation at any location. The angle between the earth-sun line (through their centres) and the plane through the equator is called the solar declination. It varies between -23.45^0 on 21 December to + 23.45^0 on June 21. Further, declinations towards the north of the equator are positive, whereas those to the south are negative.

Surface Azimuth Angle

It is the angle made in the horizontal plane between the line due south and the projection of the normal to the surface on a horizontal plane. As per the convention, due south is taken as zero, east of south is positive and west of south is negative. Hence it varies as $-180^0 \leq \gamma \leq 180^0$

Slope

It is the angle between the plane of the surface concerned and the horizontal plane. It varies as $0 \leq \beta \leq 180^0$. $\beta > 90^0$ means that the surface has a downward facing component.

2.11 Simple calculations on solar radiation

Some easy to do calculations have been included in this section. The simple idea is to make the concepts of solar radiation quite clear. Following few parameters/relationships are being covered here:

- extra-terrestrial radiation
- effect of earth-sun distance
- declination of the sun
- equation of time
- relationship between solar time and local time
- relationship between hour angle and time
- cosine of the zenith angle
- solar radiation on the tilted surfaces

Mean sun-earth distance

The solar radiation which is present outside the earth's atmosphere is commonly known as the extra-terrestrial radiation. Its average value is around 1367 Watts/m^2. This value changes by ±3% as the earth orbits the sun. The earth's closest approach to the sun takes place around 4th January. This distance is the maximum from the sun around 5th July.

The extra-terrestrial radiation is given by

I_0=1367*(R_{av}/R) 2 W/m^2
Here Rav=mean sun-earth distance
R=actual sun-earth distance depending on the day of the year

Approximate equation for the effect of sun-earth distance

It is generally given by the equation
$(R_{av}/R)^2$= 1.00011+0.034221*cos(β)+0.001280*sin(β)+0.000719*cos (2β)+0.000077*sin (2β)
Here β=2 πn/365 radians, n is the day of the year

Take for example, January 14 is year day 14 and February 16 is year day 47. As is well known, there are 365/366 days in a year. The earths axis is tilted at around 23.45 degrees with respect to the earths orbit around the sun.

Declination of the Sun

It is the angle between a plane perpendicular to a line between earth and the sun and the earth's axis. The estimated formula for declination of the sun is
$\delta = 23.45\,\pi/180 * \sin(2\pi*(284+n)/365)$

Equation of time

There is a small change in the solar time with respect to the local standard time. It takes place due to the movement of earth around the sun. This time difference is commonly known as the equation of time. It is useful to know while trying to find out the sun's position for any solar energy related calculations. The approximate formula for equation of time in minutes is as under:

$E_{qt}* = -14.2 \sin(\pi(n+7)/111)$
(it is for year day n between 1 and 106)

$E_{qt} = 4.0 \sin(\pi(n-106)/59)$
(it is for year day n between 107 and 166

$E_{qt} = -6.5 \sin(\pi(n-166)/80)$
(it is for year day n between 167 and 246

$E_{qt} = 16.4 \sin(\pi(n-247)/113)$
(it is for year day n between 247 and 365)

Relationship between solar time and local standard time

There are two important ways of telling time when calculating sun angles. "Clock time" is the time that we use in everyday life. Local solar time (or simply solar time) is time as per the position of the sun in the sky relative to one specific location on the ground. In solar time, the sun is always due south (or north) at exactly noon time. The local solar time is calculated in the following way:

LSoT = LST + 4 minutes * (LL - LSTM) + ET
where:
LST (local standard time) = Clock time
LL = The local longitude; positive = East, and negative = West.
LSTM = The local standard time meridian,(it can be calculated by multiplying the differences in hours from Greenwich Mean Time by 15 degrees per hour. Positive = East, and negative = West.
ET = The equation of time adjustment in minutes

(note earth rotates one degree every four minutes)

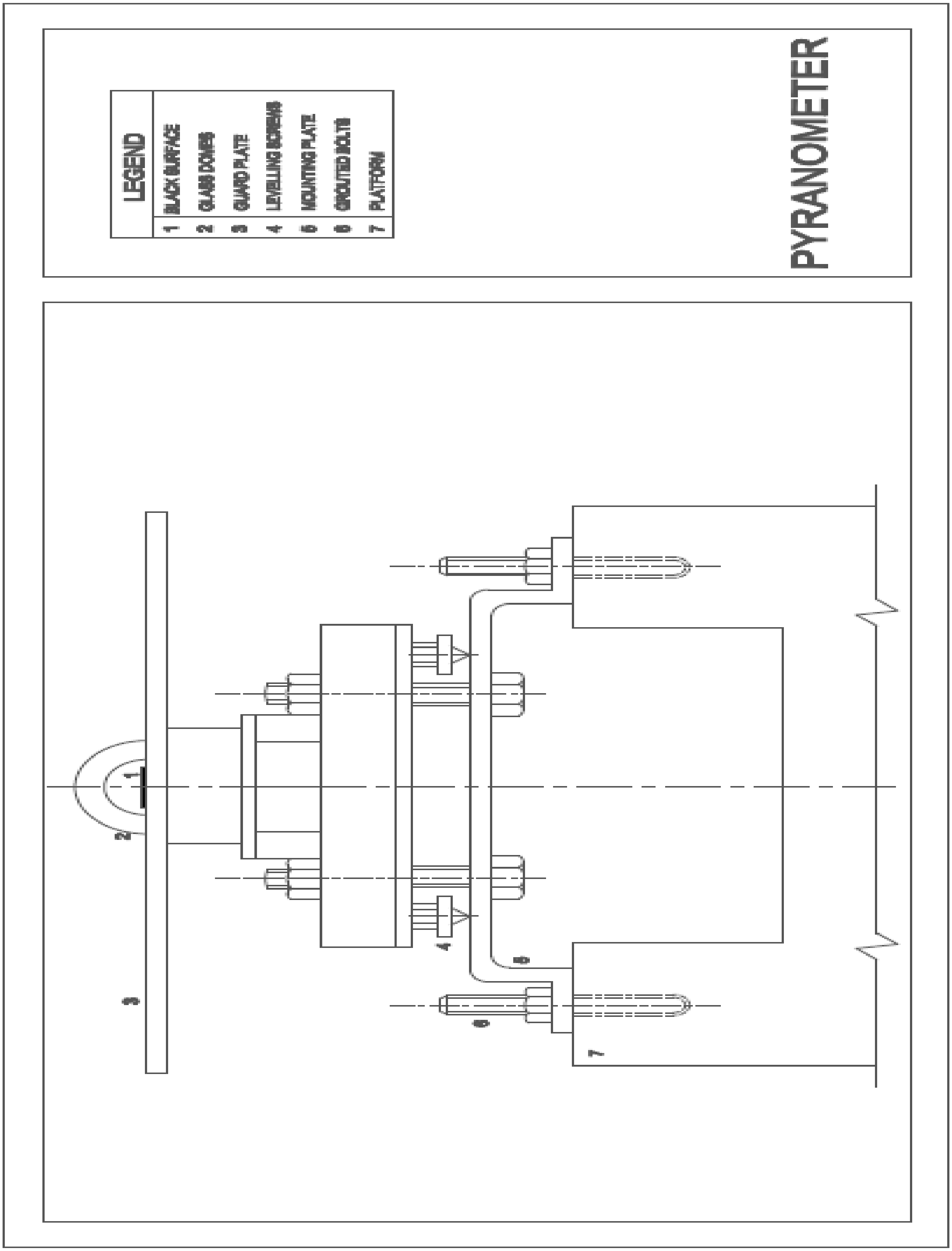
Relationship between hour angle and time

The hour angle is simply the difference between local solar time and solar noon. It is expressed in angular units (degrees). The hour angle measures time after solar noon in terms of one degree for every four minutes, or fifteen degrees per hour. The hour angle is calculated as:

- time after solar noon is expressed using a positive hour angle
- time before solar noon is expressed as negative hour angle

So, at two hours before solar noon, the hour angle is -30 degrees, and at two hours after solar noon it is +30 degrees.

Drawing


LEGEND
1 BLACK SURFACE
2 GLASS DOME
3 GUARD PLATE
4 LEVELLING SCREWS
5 MOUNTING PLATE
6 GROUTED BOLTS
7 PLATFORM
PYRANOMETER
1
2
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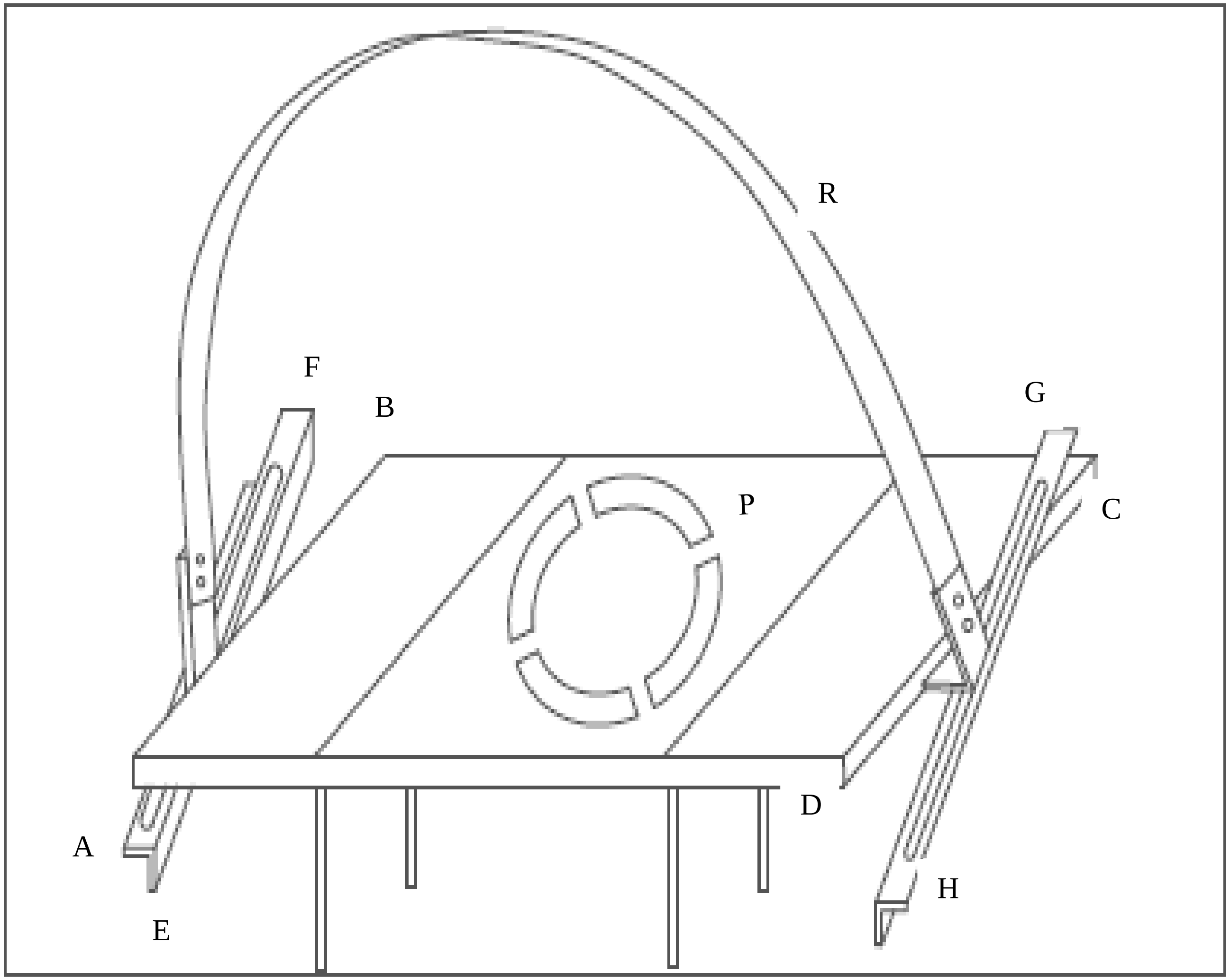
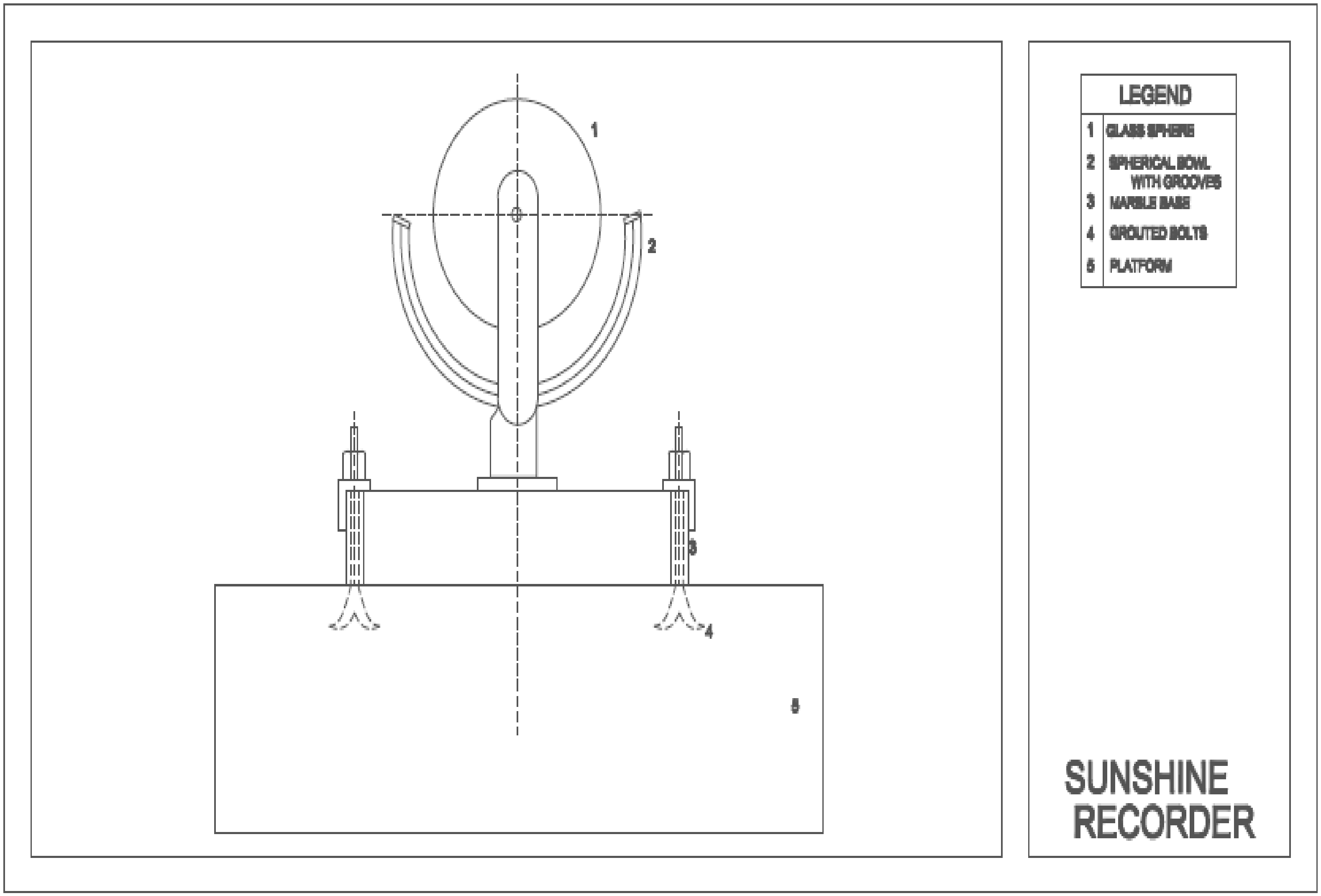


PYRANOMETER SHADED RING


1
2
3
4
5
LEGEND
1 GLASS SPHERE
2 SPHERICAL BOWL WITH GROOVES
3 MARBLE BASE
4 GROUTED BOLTS
5 PLATFORM
SUNSHINE RECORDER

Section B: Solar Photovoltaic

Chapter 3: Solar Photovoltaic

3.1 What is Solar Photovoltaic?

Well, photo simply means light. It has come from a Greek word phos. Voltaic means producing an electric current. This word has come from the name of Alessandro Volta. He worked on electricity during the seventeenth century. Thus Photovoltaic (PV) in a combined way means producing electricity under light (sunlight in this case). A solar cell is a device which does this simple trick. The photons or energy packets as these are known energise cell material i.e. a semiconductor made generally of silicon. Figure 3.1 illustrates this simple looking but highly complex process of solar energy conversion into some useful electricity via this device only.

A solar cell works like a simple flashlight battery. It also has a negative and positive terminal.

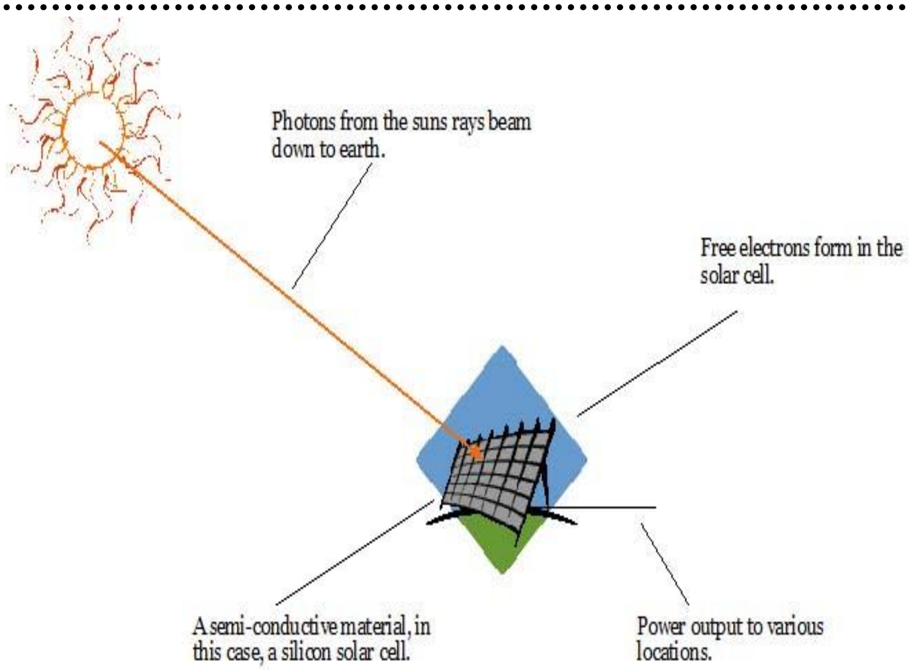


Figure 3.1: Solar Photovoltaic flow

3.1.1 Energy band gap

Two types of energy bands are generally present in a semiconducting material. These are more commonly known as the valence band and the conduction band. The valence band has electrons at a lower energy level. Also, it is fully occupied. The conduction band has electrons at a higher energy level. It is not fully occupied. The difference between the energy levels of the electrons in the two bands is called the band gap energy Eg. Now think of photons in the sunlight striking a semiconducting material. The photons having more energy than the band gap energy will be absorbed in the cell material. This will excite some of the electrons. These electrons will then cross over to the conduction band. Thus electron-hole pairs will be created. The electrons in the conduction band and holes in the valence band are mobile. These can be separated and made to flow through an external circuit. Simply put, it can then run a load too.

Table 3.1 below gives the band gap energy values in respect of the most commonly used solar cell materials as under

Table 3.1: Band gap energy values

Material	Eg (eV)
Crystalline silicon	1.1
Amorphous silicon	1.4 -1.8
Cadmium Telluride	1.55
Copper indium diselenide	1.05
Gallium Arsenide	1.43

Simply assume if, energy band gap is zero, then what happens? Well, all photons can contribute to the photo current. It will then gain a maximal value. However, the photo-voltage will be zero in that case. A bigger gap stops some photons from producing electron-hole pairs. It simply means a reduced photo-current too, while the photo-voltage goes up. Thus between the limits for the conversion efficiency (η=0 for Eg=0 and η=0 as Eg tends to infinity), there must be lie a value of Eg, for which η is maximal).Lower bandgaps generally yield higher currents. This is because they absorb a large part of the spectrum. Typical materials to fall in this category are silicon (1.1 e V and Germanium.

In a way, energy band gap is just like a boundary wall. Ideally it should neither be cake walk nor a tedious one. It too would then welcome all friendly interfaces.

3.2 Simple working of a solar cell

The first solar cells were made in the fifties from single crystal silicon. A solar cell is made of a semiconductor. Most of the solar cells today are made of crystalline silicon. Remember the first solar cell was made of selenium and not silicon. A little bit of boron and phosphorus are added into silicon. This creates holes and extras so that electrons can flow. A solar cell generally has two layers. One layer has the silicon/boron semiconductor and is known as the p-type. The other layer is the silicon/phosphorus semiconductor and is known as the n-type (electrons in excess). The point at which the p and n type layers meet is known as a p-n junction. Metal electrodes are attached to the front and back of the cell. The electrode is in the form of a metal grid with fingers. It allows the sunlight to pass through it. An anti-reflection coating is used to decrease the amount of light reflection. A typical cell develops a voltage of 0.5 volts and current density of 20-40 milli amperes/cm2. To get more voltage and current, individual cells are joined in a series and parallel fashion. This takes the shape of a solar module. In turn, a number of modules are joined together to form a solar array. Thus cell, module and array come into shape. These can be used for running of various products like a calculator, lantern or a water pumping system etc.

Figure 3.2 demonstrates the simple principle of solar photovoltaic effect.

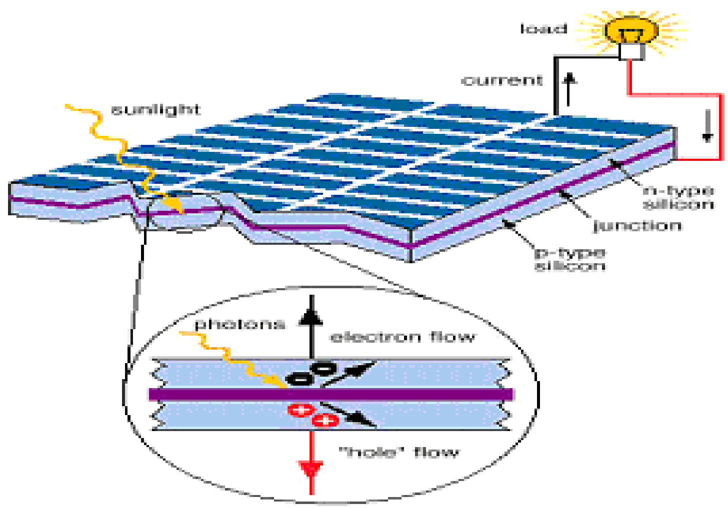


Figure 3.2: Principle of Solar Photovoltaic effect

A solar cell does not store electricity. Instead it keeps on producing electricity as long as sunlight falls on it. Thus it is different from an ordinary torch cell which stores the charge.

It is thus clear that a cell must be made of a light absorbing material. In this case, it is the sunlight, which is made of energy packets like the photons. The energy (E) of a photon is related to the wavelength λ by the simple equation:

E=hc/λ
Here h= Planck's constant=6.62×10^{27} erg-s
and c=velocity of light=3×10^{8} m/s
Putting these values in the above equation, we get E=1.24/λ
Here E is in electron-volts (eV) and λ is in microns

3.3 Important steps in commercial solar cell fabrication

Perhaps it may sound interesting as to how a solar cell is really made. There are five clear steps to make a crystalline silicon solar cell as mentioned below. *Figure 3.3* shows the building blocks of solar PV supply chain as under:

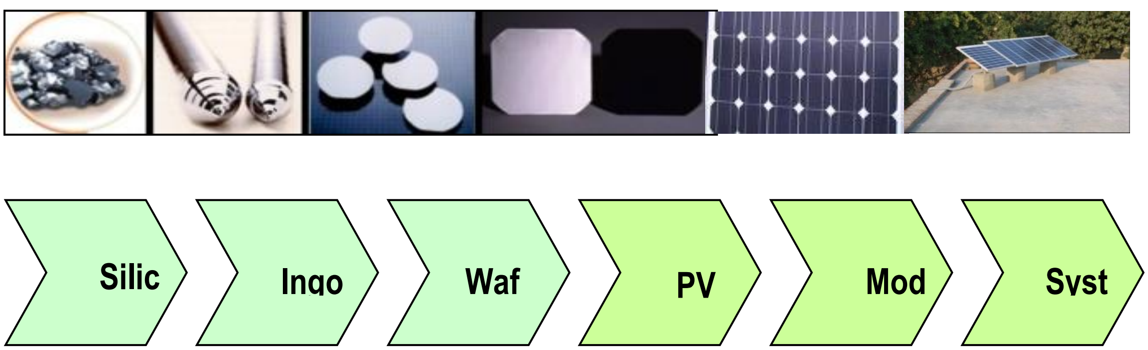


Figure 3.3: Start to end of PV Material supply/product chain

Material processing

The journey of a solar cell begins with silica (sand). Silica is nothing but Silicon dioxide. It is treated in a blast furnace thus giving metallurgical grade silicon. This form of silicon is not very pure. So, it is cleaned further to make it very pure. Silicon got in this way is better known as electronic grade. It is also called feedstock from which a wafer is then made.

Wafer development

The above feedstock is melted in a crucible. It is either pulled/grown as a cylinder (single crystal) or as a polycrystal. A small quantity of boron is mixed during the melting process. It thus produces the p-type silicon material. The end product is called ingots or bricks and is shaped/cut in the way required. These are then sawn into thin slices better known as wafers by the blade saws. Single crystal is also known as mono-crystalline, while polycrystal is also known as the multi-crystalline.

> Sand is an ordinary material. But, to make solar cell is no ordinary job. It needs modern pieces of machines to make it. Thinner the solar cell becomes, more difficult it becomes to work on it.

Etching and Texturing

Use of a blade saw may have caused some damage to the silicon wafer. It is generally set right by using a simple chemical solution of sodium hydroxide. Next these are dipped into a hot solution of sodium hydroxide and isopropanol to form square shaped pyramids. It is also known as a texture and helps to reduce the reflection of incident sunlight

Diffusion

The wafer at this stage is p-type. An n-type material (phosphorus) is now diffused into the wafer. The simple idea is to create a P-N junction.

Anti-reflection Coating

Silicon nitride and titanium oxide are generally used on the surface. This helps to bring down the surface reflection of the sunlight further

Metallization

It is required to make a contact between the front and back surface. The simple idea is to collect the electricity that a cell is now able to make. Silver is the most commonly used material to develop such contacts. Silver in the form of a paste is screen printed onto the front and back surfaces. The last step is to heat these pastes so as to form good quality ohmic contacts.

How much electricity can a solar cell produce?

The amount of electricity produced by a solar cell generally depends on the following few factors:

Surface area of the cell- it is the area that is exposed to the sunlight

Strength of the Sun- it means how bright the sun is (and the brightness depends on the time of day, weather, latitude etc.)

Length of sunshine- i.e. the number of hours for which cell gets the sunshine

3.4 Commercially available solar material technologies

Following few technologies are now commonly available to make a solar cell/module.

3.4.1 Crystalline silicon

These types of cells are made from thin slices cut from a single crystal of silicon (mono-crystalline). It can also be made from a block of crystals (polycrystalline). Their efficiency ranges between 14-19%. Importantly, this technology represents around 80% of the solar cell market today.

3.4.2 Thin film technology

These types of modules are made by depositing very thin layers of light-sensitive materials onto a low cost substrate or backing. Such substrate materials can be glass, stainless steel or even plastic. There are four different types of thin film modules being sold in the market now:

- amorphous Silicon (a-Si)
- cadmium Telluride (CdTe)
- copper indium/gallium diselenide/disulphide (CIS, CIGS)
- multi-junction cells (a-Si/m-Si)

Figures 3.4-3.6 present a view of both the crystalline silicon and thin film technologies

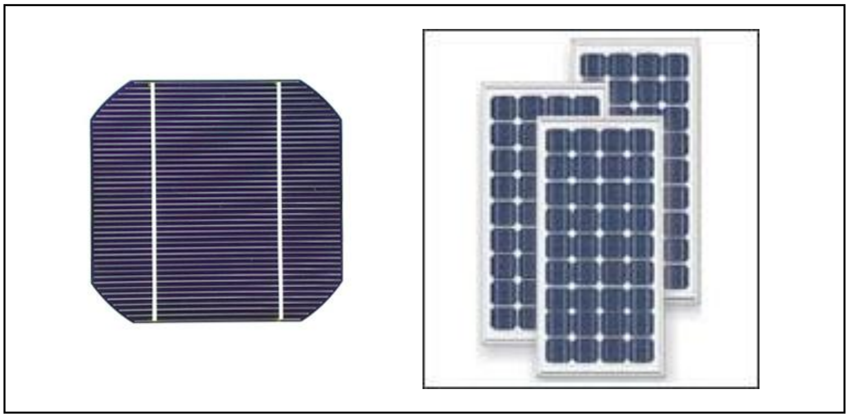


Figure 3.4: Single crystal silicon modules

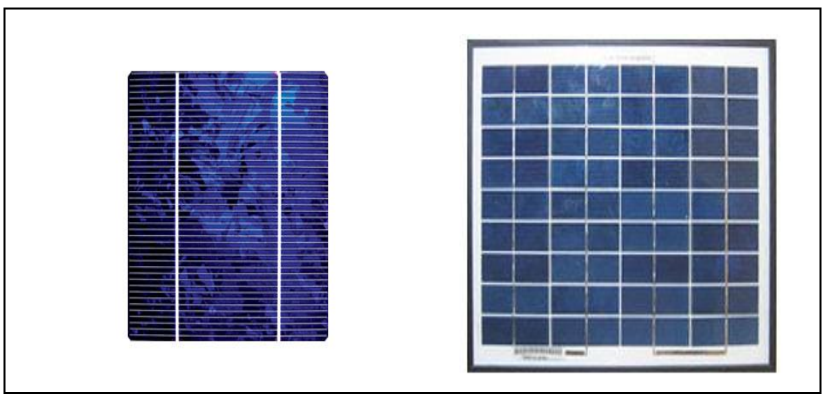


Figure 3.5: Polycrystalline silicon modules

Figure 3.6: Left hand and right hand view of a thin film Cadmium Telluride

3.4.3 Concentrated Cells

Semiconducting PV material is quite costly. The simple idea is to use very little of this material while collecting the maximum possible sunlight. The light is concentrated by using cheap plastic lenses or mirrors. These type of solar cells known as concentrator cells are around 20-30% efficient.

3.5 Advantages and limitations of solar PV systems

Advantages

Solar power offers the following few advantages:

- sunshine is totally free- i.e. there is no fuel cost
- produce no harmful gases- i.e. it is totally safe for our environment
- last longer- i.e. these systems work well
- running cost is very low- i.e. very low maintenance is needed
- very suitable for remote area lighting-i.e. improve the quality of life in such areas
- system is modular-i.e. small capacity system can be set up to begin with, then more such systems could be added to it later on
- flexibility of shape-i.e. thin film modules like those made of amorphous silicon can be moulded into many different shapes
- building worthy- i.e. it can be a part of the building itself and produce power too
- cost is coming down-i.e. technology is getting better (that also means producing more power)
- high job potential-i.e. it uses people with many different skills such as that in science, engineering, finance & management etc.

However it has some limitations like:

- high cost of the products/systems (to begin with)
- depends on the sunshine which may or may not be present always
- depends on battery storage to run any load at night

3.6 Current and Voltage relationship of a solar module

Solar radiation varies all through the day. At times, the sun shines too bright. While as, sunshine simply fades due to a thick cloud cover. So, one should know the effect of this changing radiation on the current (I) and voltage (V) of a module. I-V feature presents the basic picture (Figure 3.17) of a solar PV device performance. There are two important parameters to describe a solar module. These are known as the Open circuit voltage (Voc) and Short circuit current (Isc).

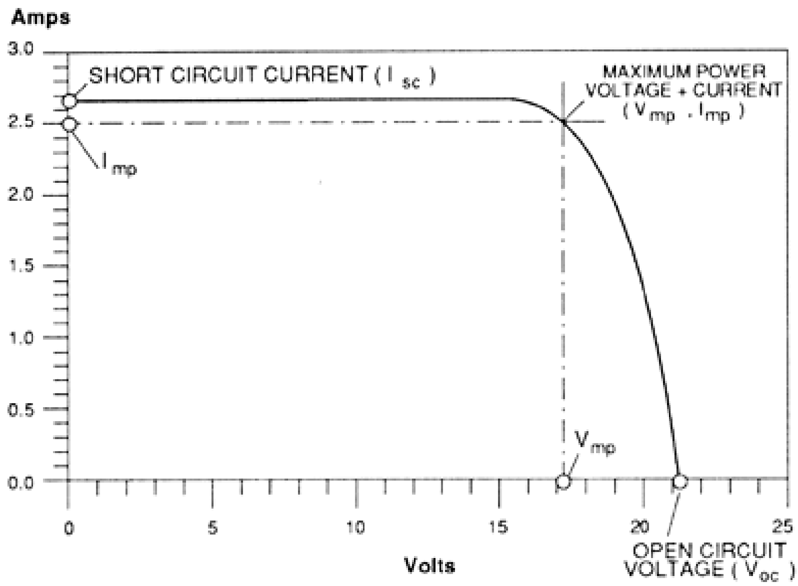


Figure 3.17: Current-Voltage Characteristics of a Solar Module

- Voc is the voltage between the positive and negative terminals when no current is drawn (i.e. unlimited load resistance)
- Isc is the current when the positive and negative terminals are connected to each other (i.e. zero load resistance). The short circuit current increases with the intensity of sunlight. More the intensity more is the number of photons produced. In turn, it means more number of electrons too.

The above I-V curve may be understood in terms of the following few steps:

- voltage is shown on the X-axis
- current is shown on the Y-axis
- specific operating point is found by the electrical load (device or appliance) connected to a PV system.
- I-V points are plotted between the short circuit current point (Isc). At this point, the device produces maximum current and zero voltage.
- the other point is the Open circuit voltage (Voc), where the device produces maximum voltage and zero current.

- the point at which a PV device delivers its maximum power output and operates at its highest efficiency is known as its maximum power point.
- the voltage and current values at the maximum power point are referred to as maximum power voltage (Vmp) and the maximum power current (Imp).

The module short circuit current goes up with bright sunshine. On the other hand, the module open circuit voltage decreases slightly instead of going up too. Thus a bright sunshine has its negative side too.

3.7 Conversion efficiency

A solar cell is best judged by its current-voltage characteristics. The intercept of the curve on the x-axis is known as the short circuit current (I_{sc}). Similarly, the intercept of the curve on the y-axis is called open circuit voltage (V_{oc}). The values of current and voltage giving the maximum power are known as I_{max} and V_{max} ($P_{max}= I_{max}*V_{max}$). The maximum useful power can be traced to a point on a I-V curve. The thing is to observe the rectangle with the largest area. Another important parameter is known as the fill factor or simply FF. It is more as the area under the curve becomes more. Mathematically, FF can simply be calculated as:

$FF= (I_{max} *V_{max})/(I_{sc}*V_{oc})$
The value of FF lies between 0 and 1.
Maximum conversion efficiency
The conversion efficiency of a solar cell η is calculated as the ratio between the generated power (P_{max}) and the incident power Pin.
$\eta = P_{max}/P_{in}$
$=(I_{max}*V_{max})/P_{in}$
The cell area related expression for the cell efficiency is as under:
$\eta =(I_{max}*V_{max})/(P_{in}*A_c)$
here A_c is area of a solar cell.

3.7.1 Key factors to have an efficient cell

A solar cell must have a high short circuit current. The open circuit voltage too must be high. Simply put, a solar cell should have a high fill factor. It is possible to meet these conditions by:

- choosing low band gap materials to get high value of Isc
- choosing high band gap materials to get a high value of Voc

It is clear from above that the maximum theoretical efficiency may be obtained at some value of energy band gap. (Detail is beyond scope of this curriculum for details refer to books mentioned for supplementary reading material).

3.7.2 Actual efficiency values

The theoretical maximum efficiency and practical efficiency of a solar cell are not the same. It is so because of the following few reasons:

- solar insolation under the Standard test conditions is 1000 W/m^2. However, its value changes every now and then under the field conditions
- the cell temperature at which the maximum efficiency is obtained is 25^0 C. However, the cell temperature generally goes much higher than 25^0

3.7.3 Standard Test Conditions

Solar modules are being produced across the world. There is now an industry standard to rate and compare these modules. It is commonly known as the Standard Test Conditions or simply STC. STC is a set of laboratory set conditions to test a module. STC mainly includes the following three factors:

irradiance (sunlight intensity) in Watts per square metre falling on a plain surface. The measurement standard is 1000 kW/m2

air mass is simply the thickness and clarity of air-through which the sunlight passes to reach the module (s). The standard is 1.5

cell temperature-it is different from the air temperature. STC defines cell testing temperature as 250 C

module efficiency- the ratio of output power to the input power is known as module efficiency. Module uses the photons in the sunlight to produce DC electricity. Note the following values of efficiency as under:

- normally 1000 W/m2 of sunlight strikes 1 square meter area of a module. In case 100 Watt of power is produced from that square meter, then a module has an efficiency of 10%
- in case 50 Watt of power is produced from that square meter, then a module has an efficiency of 5%

Tables 3.2 & 3.3 sum up the efficiency values as well costof these technologies as under:

Technology	**Thin film**			**Single Crystalline**	**Poly Crystalline**
	Amorphous Silicon	Cadmium Telluride	CIGS		
Cell efficiency at STC*	5-7%	8-11%	7-11%	16-19%	14-15%
Module efficiency				13-15%	12-14%
Area needed per kWp (for modules)	15 m2	11 m2	10 m2	~7 m2	~8m2

Table 3.3 : Indicative cost estimates of commonly used PV cell/module technologies

Technology type	**Efficiency feature**	**Cost Consideration**	**Whether manufactured in India (Y/N)**	**Indicative cost per peak Watt for Module**	**Indicative System Cost**	**Key cost determinants**
Mono-crystalline silicon	Most efficient cells/module	Most expensive	Y	Rs. 110	Rs. 270 for system with batteries	Silicon grade used Technology type Physical and Technical Specifications Source of Purchase Volume of purchase to be procured
Polycrystalline silicon	Less efficient cells/modules (in comparison to mono-crystalline silicon)	Less expensive than mono-crystalline silicon	Y	Rs. 100	& Rs. 190 for system without any batteries	
Amorphous Silicon	Far less efficient than both mono-crystalline and poly crystalline silicon	Less expensive than crystalline silicon (i.e. mono + poly)	N	Rs 90/Wp		
Cadmium Telluride	More efficient than amorphous silicon	Least expensive of all	N	Manufacturing cost of under $1/Wp		

3.8 Basic idea of a solar module, array and balance of system (BOS)

Solar cells are made in various shapes and sizes. The smallest of the cells can be seen in devices like an ordinary calculator. These type of devices use very little amount of power. However, some other devices like a home lighting system needs more power to run on. A single cell will not work in that case. Thus a number of cells are put together to produce more power. This group of cells is packaged together (like a pack of pasteries) in an enclosed space known as a module. In doing so, main benefits are:

- cell voltages of each cell add up to give a higher voltage
- higher voltage also means more amount of power (Power= Voltage x Current)
- Cells will be safe from rain, snow and wind etc.

Remember voltage and power output of a module depend on the size and number of solar cells used.

Figure 3.7 gives an illustrated view of a crystalline silicon based solar module.

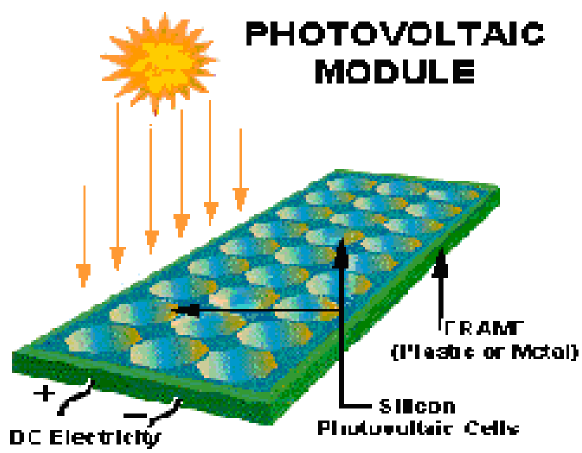


Figure 3.7: Crystalline silicon based solar module

Few more applications may need more than a single module. So, a number of modules are to be connected. Such a simple assembly of modules is commonly known as an array. Figure 3.8 shows a collective assembly of a solar cell, module and array.

A solar cell which has more efficiency needs less space to keep it. While as more space is needed to keep a low efficiency cell. Big cities and towns often have very limited land/roof space. Thus it would be more useful to put up high efficiency solar cells there.

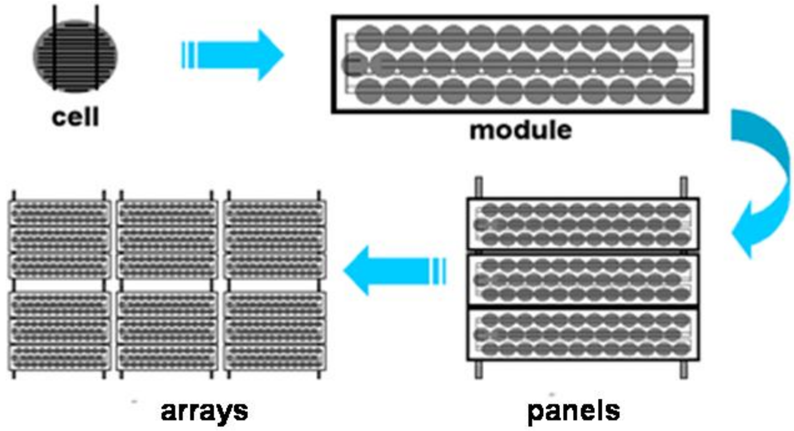


Figure 3.8: View of a Cell, module and array (Collective Assembly)

A solar cell, module and array are much like the members of a same family. These come together in times of need much like we humans.

3.8.1 Balance of System

The cells, modules or arrays are the power producing part. Small devices like a radio etc. need small amounts of power. So, these can be directly connected to a cell or even a small module. However, most of the consumers may want power to be available when sun is not shining. Simply put, a storage battery would be needed. It can supply power to various appliances like lights, fans or television at any time moreso at night. This assembly of module, battery and an appliance is a simple form of a PV system. However, a module should not be connected directly to a battery. So, a charge controller also known as a charge regulator is used in-between the module and battery. Inverter may be needed for running the AC appliances. In short, any thing excepting the solar module is known as the Balance of System or simply BOS. A BOS assembly (Figure 3.9) is mainly made of the following few components:

- storage battery
- charge Controller
- inverter
- support structure
- junction boxes
- wires, cables & fuses
- connectors and switches

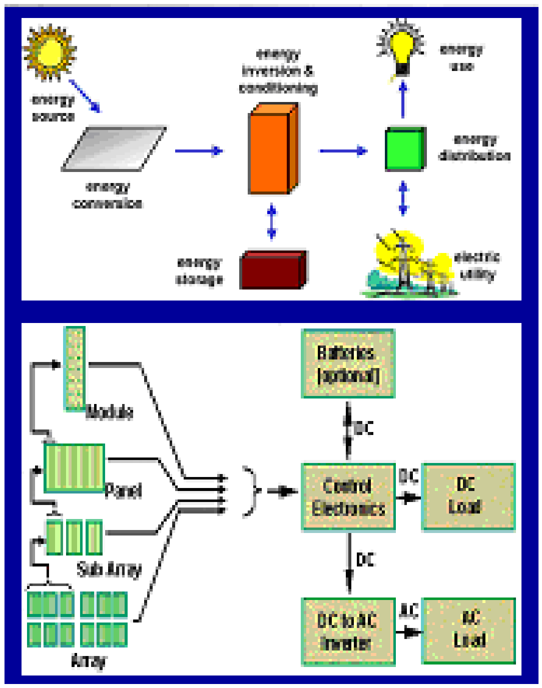


Figure 3.9: Basic components of a Solar PV System (BoS assembly)

Balance of System is mainly a storage cum control unit. It may thus be more or less thought similar to an Inverter unit at home. The major difference is that it gets charged by solar power unlike the normally used AC power.

3.8.2 Basic idea of these sub-components is given here as under:

Storage battery

Lead-acid batteries are found in most of the solar systems. These may be thought of just like the automobile batteries. However, there is a very important difference between a solar and an automobile battery used in cars etc. *A high current (for a short time) is needed to start the car engine for example. But, a solar system needs a stable current for a long time.* Most small systems like the one's used for lighting use 12V batteries. Larger systems like refrigerators often use 24 V batteries. These help to keep the wire size small and system losses to a minimum.

Charge controller

A battery needs to be handled with great care. It can get damaged if, we try to put more charge into it. Taking out more charge from it is equally harmful for a battery. These two stages are better known as overcharging and deep discharging. A battery is not able to control charge on its own. This work is done by a simple automatic device known as a charge controller in the following way:

- it senses the battery charge and switches off the charging current. Thus no damage to the battery can take place.
- it disconnects the appliances when battery charge goes below a set limit.
- prevents reverse current
- a fast blow glass fuse is also provided to save electronic circuit from damage under short circuit or any other load conditions

Small is beautiful in this case too. Very small PV systems may not need a charge controller at all. Small currents are not likely to damage good-quality batteries. However, it is not the same case while dealing with slightly large systems.

Inverter

A solar system produces DC power. However, our home appliances generally run on AC power. So, one needs a device to change DC power into more usable AC power. A simple example is that of a compact fluorescent lamp or a CFL. The device which does this trick of conversion from DC to AC is known as Inverter. These are of many different types and capacities too.

Support structure

A solar module is a very sensitive piece of equipment. It can not be simply placed either on ground or roof. It also needs to collect the sunshine at an angle. There is one more need here i.e. of keeping a module safe from any strong winds. The support structure generally takes care of all these needs.

Junction boxes

It is a meeting point for many wires. These may be from a row of modules or from modules to a battery bank. A junction box is made of an un-breakable material i.e. polycarbonate. It makes use of copper connectors for a high current flow. This way, wires remain safe from any moisture etc.

Wires and fuses

Solar systems generally carry a low voltage but high current. That is why a large diameter wire is needed. Fuses keep the solar equipment safe against the short circuits.

A solar system uses the freely available sunshine. It does not cost even a rupee to buy it unlike the petrol and diesel. Sun will continue to shine, but same can not be said about the petroleum products like these. However, sunshine once changed into electricity needs a set of efficient components to run different types of appliances.

Several combinations of systems can be made using these key components. Figure 3.10 gives a schematic view of four different types of Solar PV systems. A direct coupled system does not make use of a battery. One of the best examples of this system use is a solar water pumping system. The quantity of water that does not get used during the day is stored in a storage tank. Stand-alone systems continue to meet the lighting demand for example in the rural areas. Some of the most common examples are the solar lantern, home lighting system and street lighting system etc. The grid connected systems are now being installed to feed the solar power directly to the grid. These type of systems generally do not use the battery storage. Hybrid power systems are mainly designed to keep down the cost of a solar PV system. PV-diesel and PV-wind hybrid power systems are the most common examples of a hybrid power system.

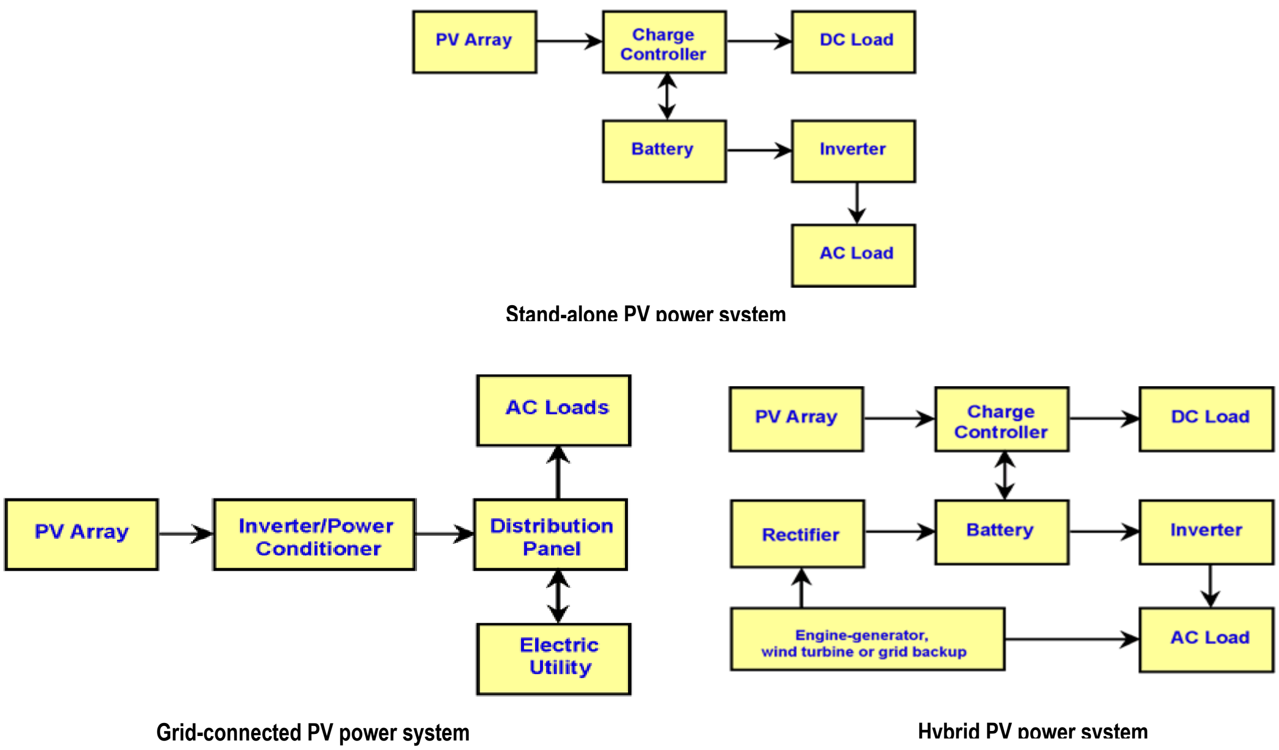


Figure 3.10: Different types of PV System arrangements

It is interesting to note here that Sun trackers are quite useful to increase the power output in case of large capacity power systems. The output power can go up by as much as 25% via use of single-axis/dual-axis tracking units.

3.8.3 Current, Voltage and Power value of a solar module

A solar module is made up of a number of cells. These cells are generally made of silicon. *A single cell (big or small) produces a voltage of 0.5 Volts under sunlight*. *Solar systems normally work on a 12V battery. So, a number of cells (usually 33 to 36) are connected in series to form a module.* These give out a combined voltage of around 18 V. It is thus good enough to charge a 12V battery. The charging current of these cells does not add up in a series connection. The manufacturers of the module generally rate a module in terms of Watt Peak. It is the most common unit of measure and represents the following:

- identifies the power output of a cell, module or array at mid day under a clear-sky sun.
- this power output is defined at a sunlight intensity of 100 mW/cm[2].
- actual power output of a PV system changes with the brightness of sun

Just think of a clear sunny day. The power given out by the module will move up from zero in the morning to its maximum near midday (noon). Then it will decrease as night comes. The same is more or less true with many other forms of human activity too.

3.8.4 Series and Parallel connection of modules

Series wiring of modules adds voltage and parallel wiring adds current. Most of the 12V solar modules are made up of crystalline silicon solar cells. Here each cell produces 0.5 Volt. The panel is designed with 36 cells so that it can produce 18 Volts. It is enough to go through a charge controller to charge a 12 V battery. Solar modules made to charge a 12 volt battery can be series connected in pairs of modules to charge a 24 volt battery. Simply connect the plus of one to minus of the other module. The remaining terminals, minus of the first and plus of the second are the 24 volt output connections. Together the pair functions as one 24 volt module though with the same ampere rating as a single module. Four solar modules can be connected in series the same way. This way it is possible to charge a 48 volt battery. Now think about the parallel connection of solar modules. Here all the negative terminals are connected together. In the same way, all the positive terminals are connected together. Remember parallel wiring does not change the voltage. However, it gives more current capacity. Adding more solar modules with parallel connection charges the same voltage battery. But it now charges it faster. Figures 3.11-3.12 show the series and parallel connection of the solar modules.

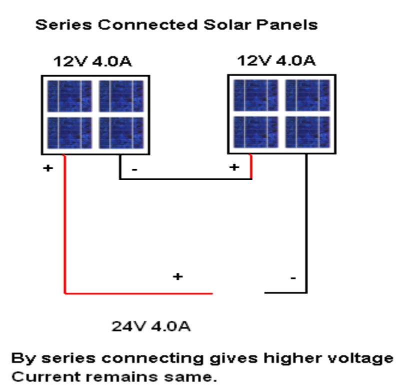


Figure 3.11: Series connected solar modules

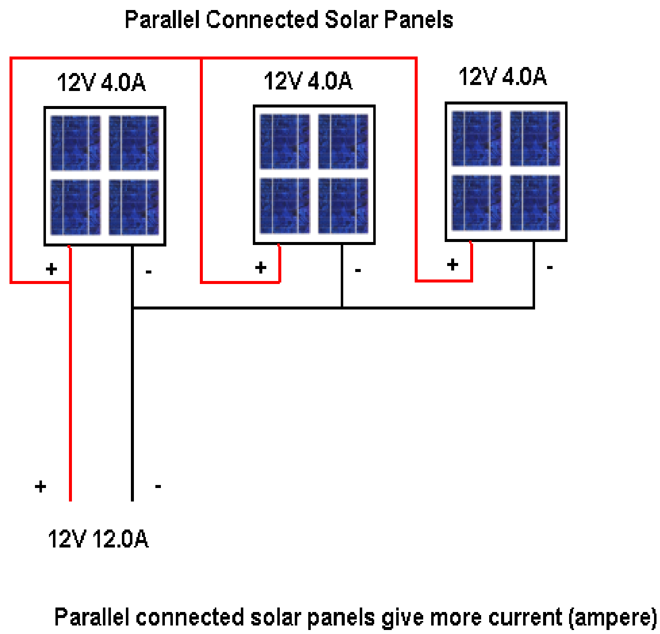


Figure 3.12: Parallel connection of solar modules

Figure 3.13 gives a graphical representation of the resultant gains in current and voltage via series and parallel connection of solar cells.

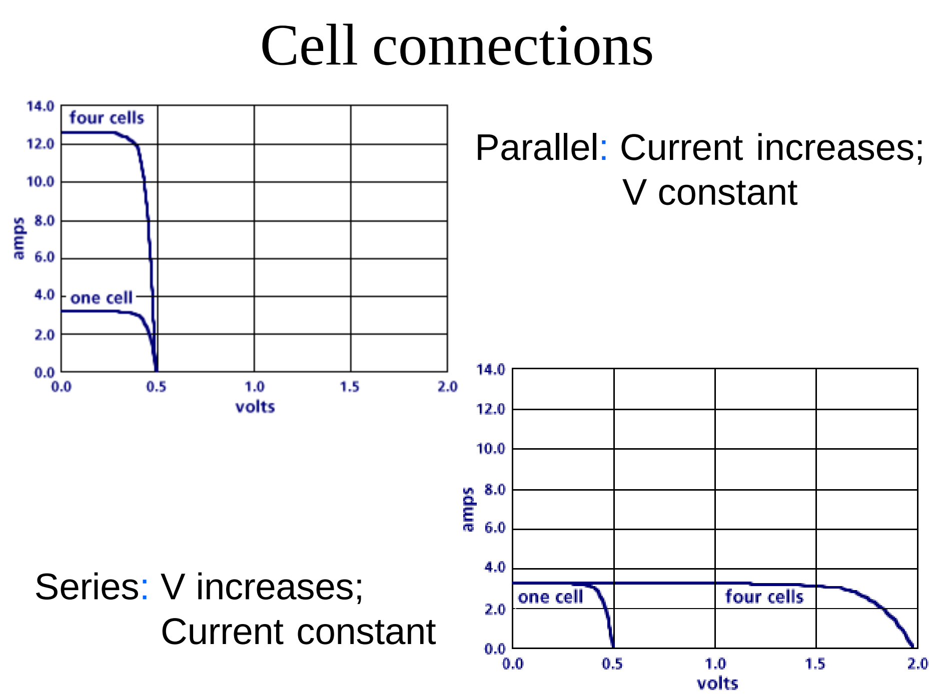


Figure 3.13: Current and Voltage gains via series and parallel connection of cells

3.9 Parameters influencing the performance of Solar PV systems

Sunlight is the basic fuel for a solar module. Any loss of sunlight means a sure loss of power too. This also means that our means of collecting the sunlight should be perfect. There is one more side of the story. A PV module can suffer loss of power loss due to some other reasons too. It may keep working for around 20-30 years. Ideally, nothing goes wrong with it. Perhaps the best thing about a module is that it has no moving parts. So, nothing will wear out with time.

Crystalline silicon modules now come with 20 to 25 year warranties. Even the thin film panels made of amorphous silicon etc. offer warranties ranging between 10-20 years. Sunshine is enough to keep the modules going. But, the environment around the modules has some effect or the other on their working.

Following few factors can have some effect or the other on the working of a solar system.

Tilt angle

A solar module should be put up in the proper path of sun. Thus module is tilted at an angle. It is roughly equal to the latitude of the place where a module is put up. Any error in the tilt angle will lead to loss of some amount of power.

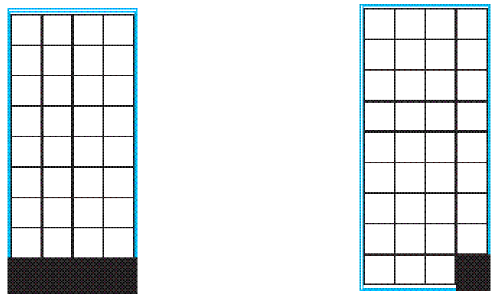
Dust

The modules need to be kept as clean as possible. The dust settles on the module surface mostly in the dry season. So, proper care should be taken to clean the glass surface of a module regularly. Remember, dust may cause energy losses as high as 5-10%

Shading

Solar module faces the sun all day long. There should be no shade present on it. So, keep on looking for any extended tree branches, plants and TV anteenas etc. Thus, place the panels where they won't be in the shade. Figure 3.14 shows the net effect of shading on the power output expected from a solar module.

A solar module is made of a string of individual solar cells. These are connected in series with one another. The current output from the whole module is limited to that passing through the weakest link cell. Take for example one cell from 36 cells in a module. In case, it is fully shaded, the power output from the module will come down to zero. However, if, one cell is 50% shaded, then the power output from the module will reduce by 50% only.



Example of full-cell shading that can reduce PV module power to zero

Example of full-cell shading that can reduce PV module power by ½

Figure 3.14: Shading effects on Solar Modules

The simple solution is to make use of a bypass diode. It can be connected between modules in a system or between groups of cells in a module. The idea is to ensure that power loss takes place from just the shaded unit (cell). Now think of a partially shaded module. The current from the unshaded part of module passes through a diode. It thus bypasses the shaded group of cells.

A shaded cell becomes like a high resistance. It can even result in overheating of the cell. This is so as the unshaded cells try to force current through this high resistance cell. Is this not like a totally opposite case of a human being trying to lie down in shade to feel a cooling effect without any force at all?

Light Intensity

The brighter the sunlight the more power the panels will produce. So, if, there is 1000 watts/m^2 of sunlight, you will see almost the full rated output of the panel. But, if there is 500 watts/square meter only, you will see half the rated power of the panel. Figure 3.15 shows a clear effect on the module current as a result of changing values of solar insolation. It goes up in direct proportion with the increasing solar insolation. The same is not the case with the module voltage.

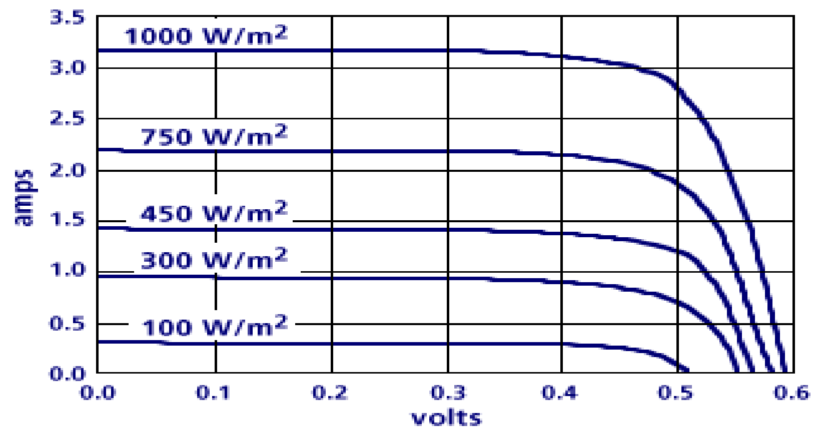


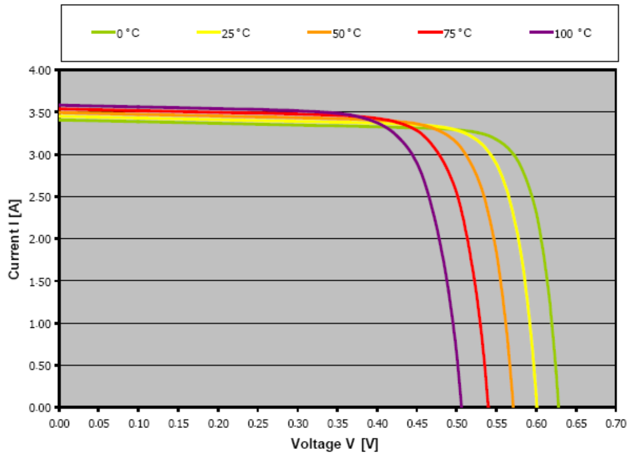
Figure 3.15: Influence of solar isolation on current and voltage

Temperature

Modules are tested at a standard temperature of 25^0C . The higher the temperature, the lower is the power output of a module. Simply put, a module loses power at higher temperatures. The cell temperature can reach around 70 degrees C under the bright sunlight. The power in case of crystalline silicon cells decreases by about 0.4 to 0.5% per degree C of temperature increase above 25 degree C. Amorphous silicon modules have a lower temperature coefficient of about 0.2 to 0.25% per degree C of temperature increase.

Some may quickly think about solar modules producing more power at higher temperatures. However, it is just not true, moreso in case of crystalline silicon modules. These type of modules lose as much as 16% of the available power at air temperature of around 35^0C. Thin film modules on the other hand lose just half the power at high temperatures.

Figure 3.16 presents the effect of increasing temperature (s) on the module voltage. The voltage reduces as the temperature goes up. The same is not the case with module current. Thus it can be said that power output of a module comes down with reducing values of solar insolation and increasing temperatures.



Temperature coefficients

$$\frac{dI_{SC}}{dT} = 0.1\,Am^{-2} \deg C^{-1}$$

$$\frac{dV_{OC}}{dT} = -2.2\,mV \deg C^{-1}$$

$$\frac{dP_{MAX}}{dT} = -0.5\% \deg C^{-1}$$

Figure 3.16: Effect of temperature on module current and voltage

Losses inside the battery

The chemical energy gets converted into electrical energy inside a battery. Some amount of power is lost in this process. This energy loss depends on the age of a battery too.

Energy consumption in the charge regulator

The charge controller continuously draws a small current of about 5 mA to 25 mA. It may amount to a system power loss of around 1%.

Semiconductor energy loss

The charge controller contains components like the metal oxide semiconductor field-effect transistors (MOSFET's) and blocking diodes etc. Both these convert a certain amount of energy into heat

Cabling losses

Some loss of power can take place through cables. The solution lies in choosing a large diameter wire size to bring down the loss

Improper connections

Poorly made electrical connections produce resistance. It can thus result in less power going to the batteries. Make them tight and keep them clean too.

Table 3.4 sums up the estimates of total system losses as under:

Loss factor	Normal Range	Typical Value	Remarks
Shading of the Module	0-20%	0%	Battery losses happen to be the second highest. Improved designs of batteries may help to reduce these losses
Orientation not proper	5-10%	5%	
Dust on the module	5-10%	5%	
Temperature effect on the module	0-20%	16% (at 60 degrees C)	
Cable losses	5-10%	5%	
Semiconductor energy loss	5-8%	7%	
Charge regulator energy consumption	1-5%	2%	
Losses inside the battery	10-20%	15%	

The back surface of solar modules often gets very hot in places like Gujarat and Rajasthan. This means presence of heat. Efforts are now being made to transfer this wasted heat to a liquid. Experimental systems of this type are better known as PV/T (thermal) systems.

3.10 Working principle of a battery, charge controller, inverter

Charging a battery

A solar system commonly makes use of deep cycle batteries. These are designed to be discharged and then re-charged hundreds or thousands of times. A lead-acid battery can generally be charged at any rate. While doing so, it should not lead to the following conditions:

- excessive gassing
- overcharging
- high temperatures

The sealed or valve regulated batteries should ideally be charged at a constant voltage. The deep cycle batteries can not follow this condition. This is because the charging time in this case is much longer. In a PV system, the energy source is not uniform at all times. So, special charging considerations are needed to charge solar batteries.

Think of a battery being charged at a very high voltage. Quite true, it will get charged fast. But, it will fail to live for long.

Table 3.5 shows various steps in the battery charging process as under:

Type of Charge	Charging need	Remarks
Main Charge	Watch for gassing to start Voltage increases in the process	Voltage limit-2.39 V at 25 degrees C 2.33 V at 40 degrees C
Top-up Charge	To reach 100% state of charge from a level of 90-95%	Keep the same voltage limit by reducing the current
Equalisation Charge	Used for making the capacity of individual cells equal	Voltage is increased to 2.5-2.6 V for a short time (30-60 minutes) at regular intervals once a week Life of the battery increases by doing so
Maintenance Charge	Used for maintaining the full capacity in a battery (in an already fully charged battery; but not used regularly for some time)	Approximate voltage of 2.20-2.25 per cell

Remember the size of a solar battery depends on:

- storage capacity needed
- maximum discharge rate
- maximum charge rate
- minimum temperature (at which the battery will be used)

Charge Controller:

It is a simple device to keep a watch on the battery state of charge. It decides as to when a battery needs a charging current. It also makes sure that a battery does not get overcharged. Thus it is important to connect a solar module via a charge controller to a battery. A charge controller is also known as a charge regulator. It is rated on the amount of current that comes from the PV array. Take for example a controller rated at 20 amps. In simple words, it means that we can connect up to 20 amps of solar panel output current to this single controller. Following few types of controllers are being used in a solar system at present:

PWM

The most advanced charge controllers make use of a charging principle known as Pulse-width-Modulation or simply PWM. Two of its key features are:

- it allows a battery to be charged very efficiently
- battery life is increased in the process

MPPT

This is one more type of controller, which also includes the maxiumum power point tracking or simply MPPT. Two of its key features are:

- maximizes the amount of current (going into a battery from the solar array)
- output voltage from a panel is reduced.

Few more features of Charge controllers:

Low Voltage Disconnect (LVD)	• allows connecting loads to the LVD terminals (which are then voltage sensitive) • loads are disconnected in case of very low battery voltage
Battery Compensation Feature (BTC)	• batteries are sensitive to temperature changes above and below 27 degrees C • adjusts the charge rate based on the temperature of the battery

Inverter

A Solar power system produces DC current. It is usually stored in a lead-acid battery. Inverter is a device which changes this stored power into standard AC electricity. Nearly all lighting, appliances, motors, etc., are designed to use AC power. In an inverter, direct current (DC) is switched back and forth to produce alternating current (AC). Then it is transformed, filtered, stepped, etc. The clear goal is to make the inverter output (waveform) acceptable to all types of loads. Two basic output designs of the inverter are as under:

- Sine wave-can run almost anything
- Modified sine wave-changes DC to AC very efficiently; cheaper than sine wavinverters.

Most inverters produce 120VAC. However, these can be provided with a step-up transformer to produce 120/240VAC.

3.11 Current, Voltage and Ampere-hour capacity of a battery

A battery is generally made of number of cells. The voltage of a battery thus depends on the number of these cells. Each lead acid cell is capable of giving 2 Volts. A 12 V monoblock battery is made of 6 cells. However, a 2V tubular battery is still called as a battery even though it is made of a single cell only.

The capacity of a battery to store charge is commonly expressed in ampere-hours. 1 ampere-hour is equal to 3600 Coloumbs. Take the case of a battery which may give 1 ampere of current flow for one hour. Then its ampere-hour capacity is taken as 1 Ah. Now, if, it can give 100A current for 1 hour, then its ampere-hour capacity will be 100 Ah.

Those producing batteries generally rate their batteries as per a standard method. The battery is discharged at a constant rate of current over a fixed period of time. This time period is taken either as 10 or 20 hours. Thus a 100 Ah battery is rated to offer 5A for 20 hours at room temperature. It is interesting to note the following few points:
Rate in Amperes = capacity in Amp- hours / Time in Hours (i.e. C/T)

- battery capacity will decrease as temperature comes down but life is increased
- battery capacity will increase as temperature goes up but life is decreased
- battery charging voltage also changes with temperature

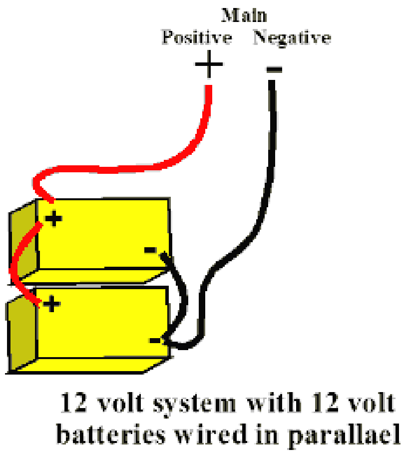
3.11.1 Series and parallel connection of batteries

Series

The batteries of equal voltage and ampere-hour capacity are joined together. The idea is to increase the voltage of the battery bank. In this case, the positive terminal of the first battery is connected to the negative terminal of the second battery and so on. The idea is to get the desired voltage. The final voltage is the sum of all the battery voltages together. However, the ampere hour capacity remains unchanged.

Parallel

The batteries of equal voltage and capacities are joined together. The idea is to increase the ampere-hour capacity of the battery bank. In this case, the positive terminals of all batteries are connected together. Similarly, all the negative terminals are connected together. The final voltage remains unchanged. However, the capacity of the battery bank is now the sum of capacities of individual batteries. *Figures 3.18-3.21* show the series and parallel arrangement of different capacities of batteries.



Figures 3.18: Same voltage
battery in parallel

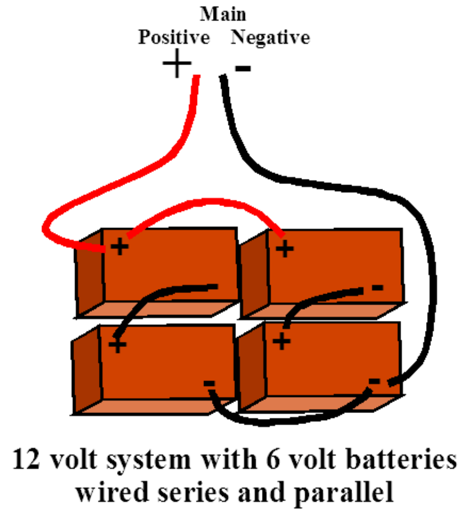


Figure 3.19: Same voltage
battery in series and parallel

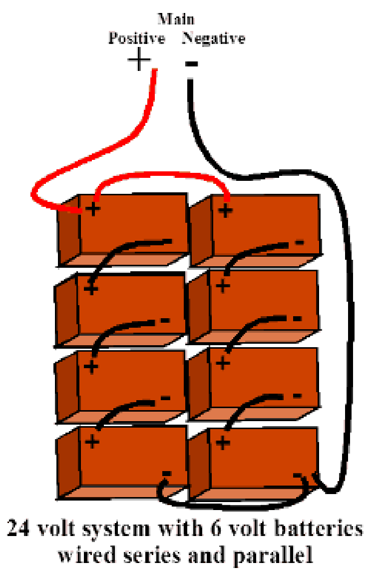
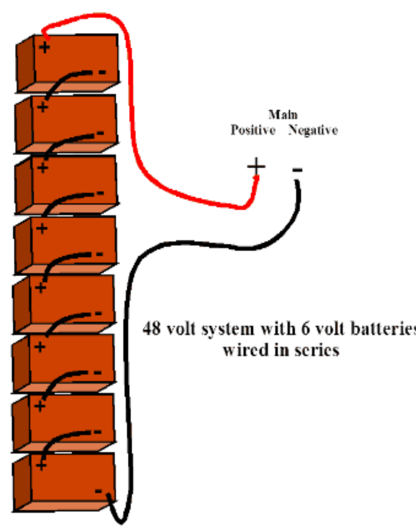


Figure 3.20: Same voltage
battery in series and parallel



Figures 3.21: Same voltage
battery in series

At present, batteries of the following few types mostly are being used in the solar systems (*Table 3.6)*

Table 3.6 :

S.No.	Type of battery	Voltage of battery	Recommended Depth of discharge
1.	Lead acid battery (SMF)	6 V / 12V	15-25 %
2.	Lead acid battery (Positive tubular plate)	2V/12V	Up to 80 %
3.	Nickel Cadmium (Ni-Cd)	1.2 V	100 %
4.	Lithium-Ion (Li-ion)	3.6V/3.7V	Up to 90 %

Sulphation

Sulphation normally occurs in lead acid batteries. It results from longer time operation at part state of charge. This effect reduces battery life.

3.12 Most common types of commercially available PV products and systems

Solar system is of many different types too. The choice of a system depends on the following few things mainly:

- type of application (i.e. capacity of system)
- type of load to be powered (i.e. whether an inverter is needed or not)
- availability of any other alternate energy source like wind etc.(i.e. a hybrid system)
- availability of the grid (i.e. a grid connected system)

The most common one's are as under:

Off-grid systems for rural electrification

There are many areas in our country where electricity is not available. In this case, the system is connected to a battery via a charge controller. Rural electrification generally means small solar home systems covering basic electricity needs in a single household. It could also be larger solar mini-grid enough to power many homes together. Following few types of PV products/systems are amongst the most widely installed:

- Solar Lantern
- Home lighting system
- Street lighting system
- Water pumping system
- Battery charging system (for many different needs)

Hybrid systems

It is possible to mix a solar system with another source of power like wind turbine or a diesel generator etc. This type of system can be a stand-alone system or even connected to the local grid. The most important advantages of putting up a hybrid system are as under:

- uses not just one but two naturally occurring renewable energy sources like sun and wind at one place
- helps to keep the cost of a solar PV system down by increasing the capacity of the other source. Remember it costs far less to put up a wind energy system

Grid connected systems for domestic use

A solar system produces DC power. It is fed to the local grid with two clear advantages etc.:

- AC power can be drawn from the grid when there is no sunshine
- Any DC power that remains unused (excess solar power) can be supplied to the grid

These types of systems are mostly used in homes and businesses in the developed countries like Germany and USA. In this case, an Inverter is used to change DC power into AC power. A bi-directional meter is at work to record the amount of power going in and out of the system.

> Solar power is not just needed in rural areas only. Urban people too need it in some measure. The inverter too seeks charge from AC supply. But, when it fails to switch on for long, solar power may well be the solution to charge it. This type of system is better known as a PV-AC hybrid power system.

Grid connected power plants

These systems also known as grid-interactive systems produce a large amount of PV electricity at a single point. Generally, the size of these systems may range from several hundred kilowatts to several megawatts or even more. In India, Jawaharlal Nehru Solar Mission (JNNSM) is aiming to put up a large number of grid connected solar power plants in the next few years.

Off-Grid industrial applications

Solar power is also being used to connect remote rural areas to the other parts of the country. Some of the most common applications are as under:

- mobile telephony
- remote lighting (at factories etc.)
- highway signs etc.

Chapter 4: Solar Lantern and charging station

4.1 Need for a solar lantern

The most common source of artificial lighting is the kerosene lamp. It is being used by more than 1.5 billion people living in many different parts of the world. The quality of light offered by these oil lamps is very poor. That is not all as it has some effect on the health too. A simple solution at hand is to use a solar lamp. Solar lighting did not begin with the first hand development of a solar lantern. Solar torches came into being much earlier while using the off-specification cells generally produced in the solar cell production lines. However, these torches did not fit into a bare minimum power availability category for a typical rural household. Thus further development followed on having a solar lighting device much resembling a kerosene oil lantern. Several design configurations were developed, which finally evolved into a solar lantern. Today a large number of solar lantern models are available in the marketplace depending on the choice of an end-user.

It is more commonly known as the solar lantern. It gives cool white light good enough for doing household work at night. School going students too find it useful.

Nearly 77 billion liters of kerosene oil are burnt in kerosene lamps every year. It amounts to the use of 1.3 million barrels of oil per day. In India alone, nearly 67.6 million rural households use kerosene oil for lighting as per the National Sample Survey Organisation (NSSO) figures for 2008. Is this not enough to make the whole world think much more seriously about the use of solar lanterns?

Table 4.1 gives a comparative cost figures for various lighting sources

Lighting system	Typical cost (US$/klm per hr)	Remarks
Candle	2.00	The running cost of kerosene oil lamp and solar lanterns may be the same. However, a solar lantern has got many advantages over the oil lamp
Kerosene lamp	0.10-100	
Solar lantern	0.10-4.00	
Solar home system	0.04	
AC electricity	0.01	

Klmhr-kilolumens per hour

Source: GTZ

4.2 What is a solar lantern?

It is a hand held lamp working on the freely available sunlight. The most common lighting source used in this lamp is the compact fluorescent lamp (CFL). Recently, more efficient light emitting diodes or LED's have become more common for such a use. Key features of a solar lantern are:

- good quality light (i.e. much better light than what a kerosene lamp gives)
- light-weight design (i.e. easy to carry from one place to the other)
- pollution free (i.e. emits no smoke)
- *fire & shock proof (i.e. safe to use)*

LED based lights are more efficient for a few good reasons. Firstly, these convert nearly all the available electrical energy into light. Moreover, LED lighting is focused in one direction. It simply means that there is very little light scatter unlike the ordinary light bulbs and the compact fluorescent lamps (CFL's) too. These two later types of lamps are omni-directional. These light up such areas too as are not to be lit up. However, in case broader lighting is needed, multiple LED units can be angled to produce 360 degree lighting. Typical consumption of LED lamps ranges from 1-8 Watt. Currently, modern residences and offices alike etc. make use of LED's for task lighting such as reading.

Basic operation

Sunlight falls on the module during the day to make electricity. This electrical energy passes through the electronic circuitry to the battery. In turn, the battery gets charged and stores energy. This energy is then available for lighting the fluorescent lamp/light emitting diode in the lantern at night. A single charge can operate a CFL for 3-4 hours and LED for a longer duration of 5-6 hours.

Major applications

This lamp can be used both indoors and outdoors. However, it has been designed keeping in view the following few applications:

- room lighting (in the non-electrified remote areas)
- emergency lighting
- as a table lamp
- camping
- patrolling streets and farms
- hawker/vendor stalls
- adult education centers/health Centres

4.2.1 Commonly used lamps/lanterns available in the market

The very first model of solar lantern looked much like a kerosene oil lantern. Since then, several designs of solar lantern have become available in the market. More recently, LED based lanterns have been developed. These use lesser amount of power and work for more number of hours as well. The Ministry of New and Renewable Energy (MNRE) is encouraging the use of both the CFL and LED type lanterns. Solar manufacturers are trying to bring down the cost of lanterns.

Physical form/layout diagram

a. CFL Lantern

Solar module is a separate part of a solar lantern. The other two main components i.e. battery and CFL are housed inside the body (plastic or fibreglass) of a lantern. **Figure 4.1 show the front view of a CFL based lantern. The solar module is connected to the battery via

Figure 4.1 : CFL Lantern

a charge controller whenever needed. The LED indications are easy to follow.

b. LED lantern

The physical form of this model is nearly similar to a CFL model. The major difference is that it has a number of small LED's in place of a single CFL. **Figure 4.2 presents a front view of the lantern. It has an additional feature of brightness control. The simple idea is to save power while making the desired use of a lantern.

Figure 4.2: LED Lantern

4.3 Major components of CFL and LED lamps

Table 4.2 shows the major components of both the CFL/LED type lanterns for an easy understanding/comparison

S.No.	CFL Model	LED Model	Remarks
1.	Solar Module (crystalline Silicon (X-Si)/Thin film)	Solar Module (X-Si/Thin film)	Generally X-Si modules are in use
2.	Battery (sealed maintenance free)	SMF , Li-ion	Generally, lead-acid type batteries are in use
3.	Compact Fluorescent Lamp	Light Emitting Diodes	LED's are costly, but use less power, thus cost effective
4.	Charge Controller (on a PCB assembly)	Charge Controller (on a PCB assembly)	
5.	Fuse	Fuse	

4.3.1 Ratings of the major components

There are several models of CFL lanterns available in the marketplace. These use the same type of major components as mentioned above. However, the key difference is in terms of their capacities. In turn, each one of these designs runs for varying number of hours at night. Tables 4.3&4.4 show the comparative ratings of different CFL/LED based lantern models:

Table 4.3: Comparative Ratings of CFL based solar lanterns

Model No.	Module capacity (Wp)	Battery Capacity (Ah)	Lamp Wattage	Fuse rating	Charging Cable/ length	Charging Time per day (hours)	Average Working Hours Per day	Operating temperature (0C)
1.	3Wp (6V)	4 Ah, 6V	3W	1 A	2-core (5m)	7-8	2-3	0-50
2.	5Wp (6V)	4Ah, 6V	5 W	1 A	2-core (5 m)	6-8	3-4	0-50
3.	10 Wp (12 V)	7 Ah, 12V	7 W	1 A	2-core (5m)	6-8	4-5	0-50
4.	10 Wp 12 V	7 Ah, 12 V	9 W	1 A	2-core (5m)	6-8	2-3	0-50

Table 4.4: Comparative features of LED based Solar Lanterns

Model No.	Module Capacity (Wp)	Battery Capacity	LED Wattage	Fuse rating	Charging Cable/ length	Charging Time Per day (hours)	Average Working hours Per day	Operating temperature (0C)
1.	2.5-5	4.5 Ah, 6V	0.75 W	1 A	2-core (4m)	6-9	8	0-50
2.	2.5-5	4.5 Ah, 6V	1.50W	1 A	2-core (4m)	6-9	4	0-50
3.	2.5-5	4.5 Ah, 6 V	2.25W	1A	2-core (4m)	6-9	3	0-50
4.	3.0	4.5 Ah, 6 V	2.25 W	1A	2-core (4m)	6-9	3	0-50
5.	2.5-5	4.5 Ah, 6V	4.50W	1 A	2-core (4m)	6-9	5	0-50

4.4 Major components

The basic operation of the major components is presented below:

Solar Module

It collects the sunlight and changes it into useful electricity. This electricity is then stored in the battery for running the lamp source (CFL/LED) at night.

Battery

The battery gets charged/discharged via an efficient electronic circuit. It thus keeps the battery safe both against the overcharging and deep discharging too.

CFL/LED

CFL is an energy efficient lamp. Like for example, a 7W-CFL gives light equivalent to that of a 40-Watt ordinary incandescent bulb. On the other hand, LED is a special type of diode. It emits light when connected to a DC power supply.

Electronics/PCB card

In a CFL lantern, the electronics used with the lantern is made of charge controller/inverter circuit. While as, the driver circuit takes the place of an inverter circuit in a LED lantern.

Protective indications

These are incorporated in the Printed Circuit Board (PCB) in case of both the CFL/LED based lanterns.

4.4.1 Charging techniques of a CFL/LED Solar Lantern

It is a simple task to charge a solar lantern. The lantern battery gets charged for use at night. Following few steps demonstrate a simple charging method:

- there is a charging cord provided with each lantern. Connect this cord to a solar module
- connect the red wire of the cord to the positive terminal of the solar module
- connect the black wire of the cord to the negative terminal of the module
- put this cord into the charging socket of the lantern for charging
- keep the solar module out in the sun.
- tilt it at a correct angle so as to collect the maximum possible sunlight
- take care that no part of the module is shaded

- keep the ON/OFF switch in the OFF position while charging the battery in the lantern
- The battery starts getting charged and green LED glows
- The battery gets fully charged and green LED stops glowing
- Take care to disconnect the module from the lantern during the night time

4.5 Need for a solar lantern charging station

There are a number of solar lantern technologies available now. The simple idea has been to use them for lighting in places without any electricity at all. However, the lanterns have at times not worked properly due to the following few reasons mainly:

- use of low quality components
- increasing concern to bring down the cost
- battery failure on account of irregular charging
- user's wrong practice to run other appliances on the battery

Various solutions have been thought of till now. The basic issue is to find a scheme for the lanterns that can:

- make use of the best quality charging equipment (that can not be opened at will)
- control the use and charge status of the batteries
- Keep a watch on the life cycle of the major components used
- bring down the cost of lighting to be competitive with the kerosene lanterns on a household level

The centralized mode of solar charging seems to be a better solution.

4.5.1 Simple concept of a solar charging station

The solar lantern charging station (SLCS) is a facility to charge a large number of lanterns together at one place. The owner of the lantern need not buy the costly module. The person who runs the charging station charges these hand-held lamps daily. In return, he collects small fees from each household. It is mostly equal to the amount spent on buying the kerosene/candles. Thus an individual user does not feel the trouble of paying for the charging of lantern. Key components of a SLCS are as under:

- solar module (s)
- junction boxes
- lanterns
- electronic system control unit

Taking power to the rural remote areas of India is a big challenge. The solar charging stations now charge a large number of solar lanterns together. It is as good as selling hours of solar lighting to poor people at a cost just equal to that of kerosene.

The SLCS is designed to charge both the CFL and LED type lanterns.

However, two different types of junction boxes are set up. Key advantages of a solar charging station are:

- cost of charging the lantern is lower for a poor user
- it runs with lesser number of problems too

Technical specifications of a SLCS

LED's use just a small amount of power in comparison to the CFl's. It thus helps to keep the cost down too. Table 4.5 below gives an idea about the capacities of all major components.

Table 4.5: Component ratings of lanterns

	Module Capacity	**Lamp Wattage**	**Battery Type**	**Junction Box**	**Charging Cord**	**Remarks**
CFL Lantern	1x80 Wp	10x7 W	12 V storage battery	10 ports	10 (around 2 mtr.length)	In both these cases, 10 lanterns can be charged per port at one time
LED lantern	1x30 W_p	LED's	6V storage battery	10 ports		

4.5.2 Key components of a SLCS

The major components used in a typical solar charging station are as under:

Module

It is the power producing part and charges the battery every day. The capacity of a module is worked out on the basis of following:

- lamp wattage (whether CFL or LED)
- capacity of the battery (used in a lantern)
- number of lanterns to be charged together

Junction box

It serves as an important link between a solar module and the lantern. There are 10 ports (or slots) in each junction box for collective charging of 10 lanterns. A junction box has got the desired protections and control circuits as well. The CFL and LED based lanterns should be used in the respective junction boxes marked for them. It is quite important to know the battery voltage so as to match it with the same voltage for a junction box. Like for example, a 6V lantern battery should be coupled to a 12V-6V (JB), whileas a 12 V lantern battery is to be adapted to a 12V-12V JB only. In both these cases, the solar panel voltage is assumed to be 12 V. There are a few vital reasons to have this type of matching combination (s). Failing which, it will result in a lower efficiency of charge conversion/availability too

Lanterns

Solar module charges the lantern battery via a junction box. Once fully charged, lantern is removed from the junction box. It is then free to be used a mobile source of lighting. The full description of lanterns has been given in the last section.

Figure 4.3 shows a view of the solar lantern based centralized charging station

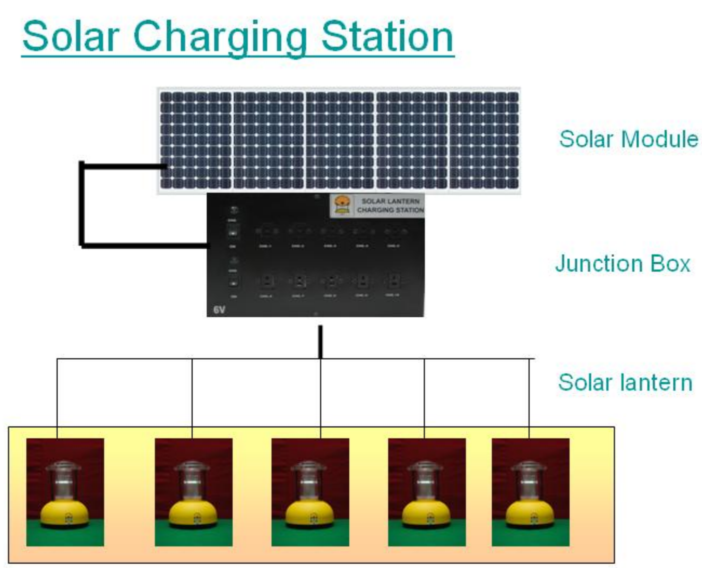


Figure 4.3: Solar Lantern Charging Station

4.6 Important Steps to install a Solar Lantern charging station

The design of a SLCS is not difficult at all. The number of components in a charging station is kept low. Solar modules are kept on the rooftop of a charging station. The remaining items like junction boxes, lantern racks and the lanterns are put up in a room. Following few are the component wise steps of a typical SLCS installation:

Module

- use a Mariners compass to find the southern direction
- place the solar modules towards south for receiving the maximum possible sunlight
- check if, any object like a tree, tall building or a television anteena is casting any shadow on the modules

- see if, any of the modules is stopping the sunlight from reaching the other module
- grout the modules to the roof (concrete/tiles/slates etc.) with bricks, cement and sand
- use a four pole mounting structure to position the panel on pitched roofs (wood/thin metal sheet/rough tiles etc.)
- keep the modules bolted with such a structure at a height of 6 feet above the ground
- make the modules secure by fixing with anti-theft screws
- always use a metallic frame of MS flat/angle iron to fabricate the mounting structure for modules
- it must allow to tilt a module to horizontal between 0-45 degrees

Installation and operation of the Junction box:

- choose a clean space for the mounting of five junction boxes (for charging of 5x10 lanterns)
- it should be just above the top of the rack on which the solar lanterns are kept
- fix the junction box on the wall using a proper screw arrangement
- connect the lanterns to the respective junction boxes by wires tied together by a spiral wire
- use a proper polyvinyl conduit (PVC) to connect wires/cables between the solar panel and junction boxes
- connect the red wire (positive of the solar module) with the positive terminal in the junction box
- connect the black wire (negative of the module) to the negative terminal of the junction box

Indications: Connection (s) between a module and the junction box is alright, if, the green LED of the junction box glows.

Physical inspection of the solar lantern:

- check the lantern for any type of damage from outside
- check if, the fuse is in its place
- if, not, unscrew the cap of the fuse holder
- put the fuse inside the fuse holder
- close the fuse cap by giving it a reverse twist

Checking the lantern operation:

- remove the gummed tape, if, put on the ON/OFF switch (two position facility)
- press down the switch to the on position & watch the CFL glow
- CFL may not glow but the red LED glows
- it means the battery is low, charge it quickly
- check the fuse in case both the CFL and red LED fail to glow
- contact the system installer/supplier in that case

Connecting the lanterns with junction boxes.

Charging the lantern:

- keep the lanterns on the racks designed for the purpose
- connect each lantern with the junction boxes via a charging cord
- put one end of the charging cord in the charging socket (lantern)
- put the other end in the socket provided in the junction box
- check the LED indications to see if, each lantern is getting charged properly
- green LED in the lantern will begin to glow
- red LED will not glow at all
- keep the on/off switch on the lantern in the off position during charging
- allow the full charging of a lantern
- if, green LED fails to glow, it may be due to poor sunshine
- switch on the lantern after unplugging it from the junction box
- check if, the lantern is glowing now
- plug back the lantern in the port (junction box) for charging
- green LED will begin to glow in just a minute or two
- once charged, disconnect the lanterns from the junction box
- these lanterns are now available for renting by the people in need

4.6.1 Emerging concept of Solar Multi-Utility Stations

Solar power still does not come cheap. That is why it becomes all the more important to maximise the use of a solar power system installed in remote rural environs. Such type of systems are more commonly known as the solar multi-utility stations. Solar lanterns are not the only devices to be charged. A number of other appliances like the following few can well be charged via this facility:

- Water purification units
- Laptops
- Mobile phones etc.

The idea at large is to make use of the locally available solar or any other renewable energy resource. It is also possible to make use of other renewable energy sources like wind and biomass in tandem with solar so as to extend the scope of SMU's further.

Chapter 5: Solar Home Lighting System

5.1 What is a Solar Home Lighting System

A solar lantern meets a simple need for lighting. Solar home system (SHS) in comparison offers more facility of lighting. Simply put, it is defined as a small independent system. It is commonly made of one or more solar module (s), a battery, charge controller and a few loads. Such loads could be in the form of light (s), television or even a fan. The demand for such systems is rising. In India alone, there are more than 6 lakh solar home systems at work moreso in the remote areas. These systems are generally working well. However, there are still a few technical and non-technical problems to deal with worldwide. In short, SHS is a fixed source of lighting unlike a hand held lantern. However, it works on nearly the same principles as a lantern. Figure 5.1 shows the basic model of a solar home lighting system alongwith a few demonstrational loads as well.

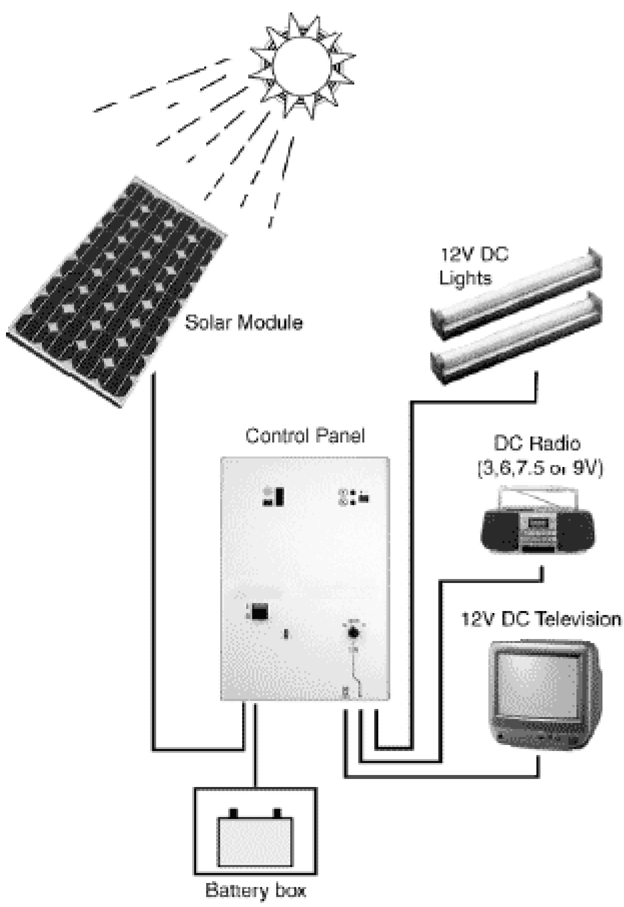


Figure 5.1: A solar home lighting system assembly with loads

5.2 Components of SHS

A solar home lighting system works on its own. It is generally made of the following few components:

Solar Module

It is mainly made of crystalline silicon cells. At the most two modules of 37 Wp are needed to run models III&IV

Battery

It is a flooded electrolyte positive tubular plate battery. Simply put, it needs very low but regular maintenance

Luminiare with electronics

It is made of ABS plastic body or any other suitable material. The luminiare and holder are a part of this lamp assembly. The acrylic cover is generally less foggy. The reflector ensures the maximum possible sunlight. Further, the luminiare is designed for the indoor use only. The compact fluorescent lamp or the CFL is placed in the base up position

Compact fluorescent lamp

Solar power does not come cheap. So, a system designer takes care to include the energy saving features in various forms within a PV system. Use of CFL is one such measure. It not only lasts long (8000 hours) but also gives out less heat. The light output of CFL (s) commonly used with a CFL is as under:

- 5W-235 lumens
- 7W-370 lumens
- 9 W-600 lumens
- 11W-900 lumens

Inverter

It is a transistor based on push pull operation. A push-pull is a type of electronic circuit which can drive either a positive or a negative current into the load. The inverter has an input voltage of 120 V and operates at more than 80% efficiency

Charge controller

It is just possible that solar module may be producing more electricity. A battery may not be needing all of this electrical charge. A charge controller just does that and much more as mentioned below:

- stops the excess charge from going into the battery
- stops the flow of more charge from within a battery to power the load (s)
- adjust to 12 V or 24 V system voltage on its own
- adapts automatically to the ambient temperature
- highlights the battery state of charge
- beeps on battery load and overload

Table 5.1 gives the key features of a solar charge controller used in a solar home system as under

Nominal Voltage	**12/24 V, Auto Recognition**
Boost charging	15/30 V (25 degrees)
Float charging	14/28 V(25 degrees)
Low voltage disconnect function	11.1 V to 11.4 V/22.2 V to 22 V
Load reconnect voltage	12.7 V/25.4 V
Temperature compensation	-3 mV/cell/degree centrigrade
Maximum solar charging current	5/10 A max
Maximum load current	5/10 A max
Dimension	100x170x40 mm
Weight	270 gm
Self consumption	6 mA
Maximum wire size	4 mm2 single core
Ambient temperature range	-500C to + 500C
Case protection	IP22
Efficiency	> 80 %

Inverter

Type: transistor based push pull type
Input voltage 12 VDC
Efficiency > 80%

Module mounting structure

It is mainly made of hot dip galvanized iron. To stop corrosion, white paint is used.

5.3 Emerging use of LED based Solar Home Lighting Systems

LED's made a sound beginning in the case of solar lanterns. From there flowed the idea of using LED's in the home lighting systems too. Key consideration is to bring down the cost of this type of system too. The simple trick seems to be the use of a low power consuming lamp instead of a CFL. Following few are some of the most important advantages of a LED system over the conventional CFL based lighting unit:

- LED lamps give high amount of brightness at a low power consumption
- LED based systems thus need very small solar panels as compared to the higher capacity panels in case of a CFL system
- Likewise, small capacity battery (ies) too come into the charging frame
- LED lamps have a life of more than 50,000 hours as compared to around 10,000 hours for a CFL. In turn, this reduces the cost of lamp replacement too
- LED based systems are available at a lower cost than the CFL based systems thus indicating its higher market potential too.

5.4 Commonly used types of SHSModels approved under MNRE

It is quite possible to design a solar home system as per our need. However, a good system design takes many things into account. The most important thing is to know the number of lights really needed in a household etc. The Ministry of New and Renewable Energy (MNRE) has specified four different models (I-IV) of the solar home lighting systems as per Table 5.2 below:

Table 5.2:

S.No.	Item	Mod-I	Mod-II	Mod-III	Mod-IV	SHS 1	SHS II	SHS III
1	**Solar Module (Wp)**	18	37	2X37/ 1X74	2X37/ 1X74	30	40	50
2	**Battery (Ah) 12 V LMLA/SMF (dry charged)**	20	40	75	75	40	60	75
3	**Charge Controller (12 V)**	5A	5A	5A /10A	5A/10A	5A	1OA	10A
4	**Luminiare with electronics and CFL (W)**	1(9/11)	2(9/11)	2(9/11) Fan (<20 W)	4(9/11)	3(7)	4(7)	6(7)
5	**Module mounting structure**	1	1	1	1	1	1	1
6	**Battery box**	1	1	1	1	1	1	1

S.No.	Item	Mod-I	Mod-II	Mod-III	Mod-IV	SHS 1	SHS II	SHS III
7	**DC Fan 14 W**	-	-	1	1	-	-	-
8	**Interconnecting cable (set)**	1	1	1	1	1	1	1
9	**Installation kit and accessories (set)**	1	1	1	1	1	1	1

- battery type is low maintenance lead-acid battery (dry charge)
- Models (I-IV) will have a socket to provide power for a 12 V DC TV set
- Models (I, II and IV) work for an average duration of 3-4 hours daily
- Model No. III (2 lights and 1 fan) work for an average duration of 2-3 hours daily
- Model Nos. shown above as SHS I, SHS2 and SHS III are a few more choices of a solar home system

5.5 Physical form/layout diagram of HLS Models

Figures 5.2-5.3 gives a schematic diagram of Model nos. I-IV and SHS 1-3 respectively. The key difference is in terms of the number/type of the loads to be operated. The PWM charge controller may be termed as heart of a solar home lighting system. The complete specifications of the MNRE approved models are enclosed in this report as Annexure I.

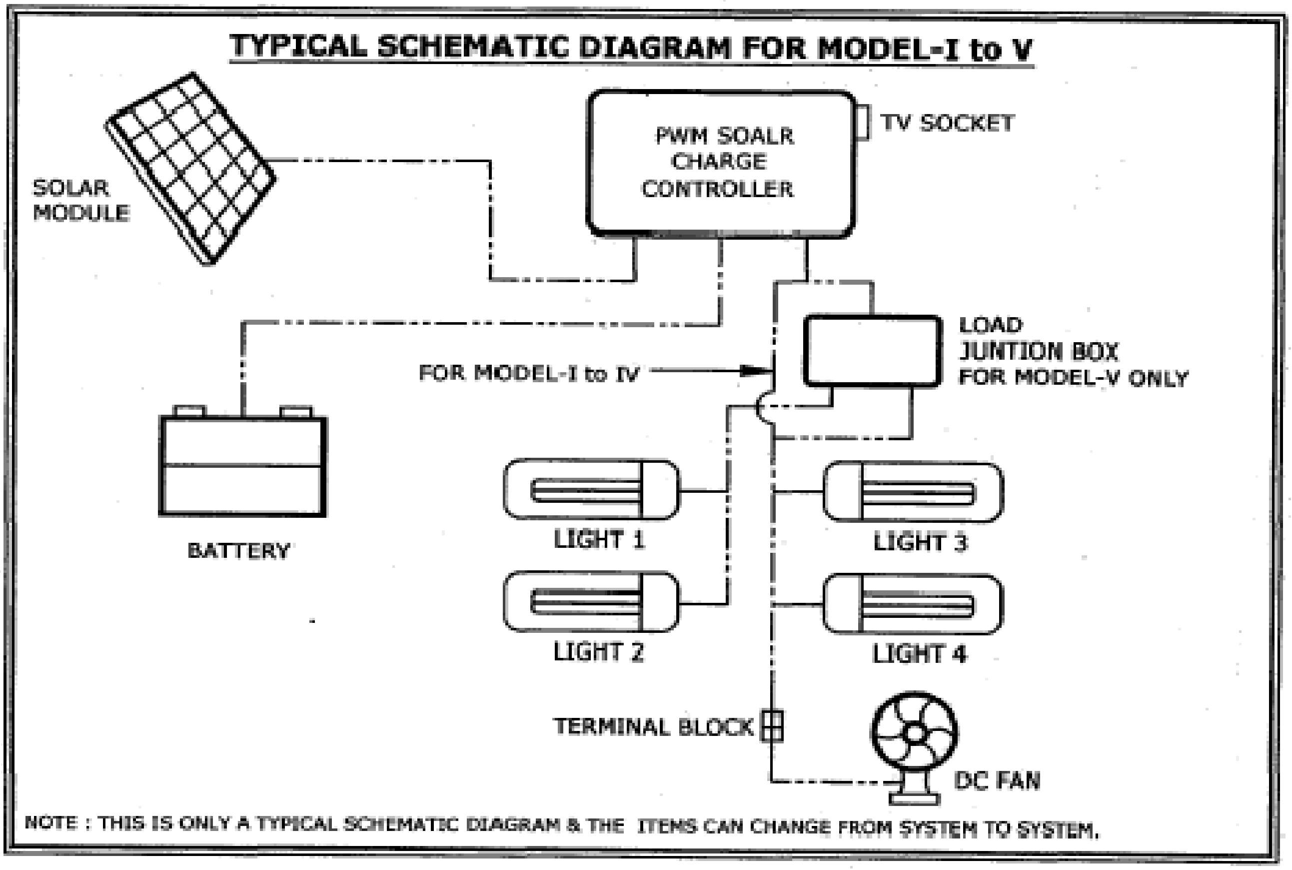


Figure 5.2: schematic diagram of Model nos. I-IV for Solar Home System

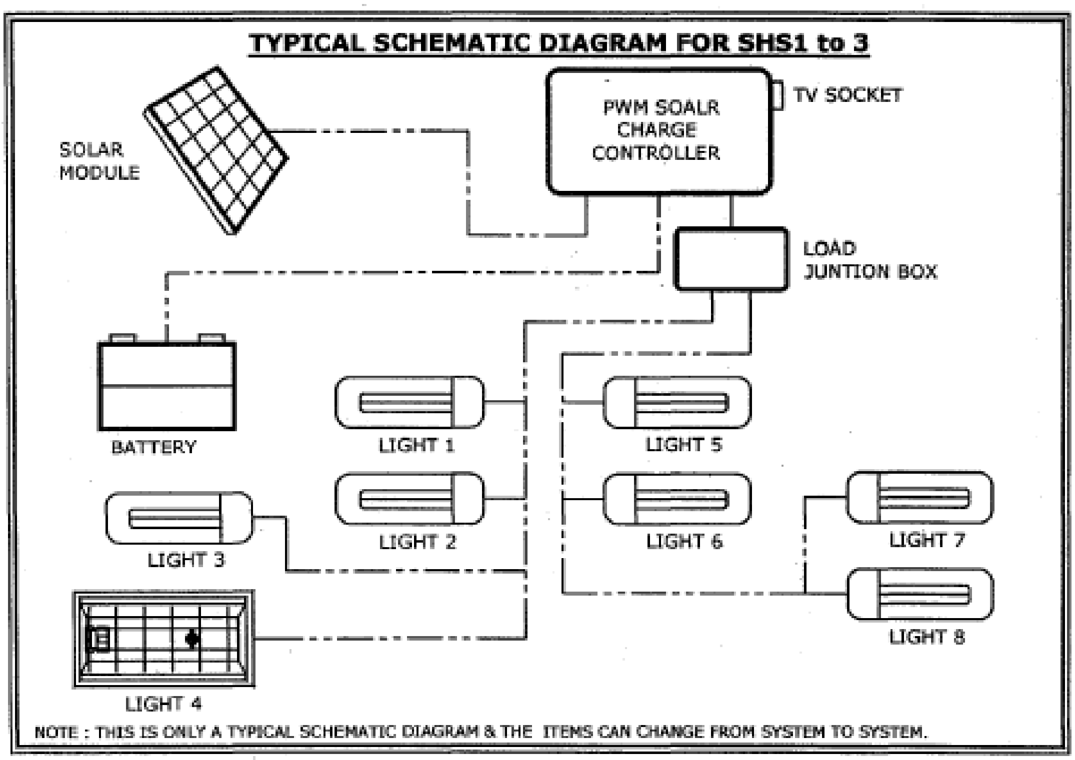


Figure 5.3: schematic diagram of Model nos. 1-3 for Solar Home System

5.5.1 Working principle of each major component

Module

It collects the sunlight available during the day. After which, it is changed into some useful electricity via solar cells. Electricity thus produced gets stored in a battery

Battery Charging

Lead-acid storage batteries are the most common type of batteries used in the solar systems. These are made of a number of matching cells. Also, these cells have two different lead plates. These plates are dipped in electrolyte. Electrolyte is a solution of sulfuric acid and water. As the battery cell gets electrical energy (charges), the other delivers (gives out) electrical energy (discharges). So, there is a change in the chemical composition of the battery plates. The strength of electrolyte also changes. The voltage depends on the following two parameters mainly:

- type of electrode materials used
- type of electrolyte used

In general, the voltage per cell in a lead-acid battery is 2.1 Volts per cell. The electrical energy is produced by the chemical action between the electrode materials and the electrolyte. The chemical actions start and electrical current flows from the battery. This takes place as soon as there is a circuit connection between the positive and negative terminals. The electrical current flows as electrons via the outside circuit.

Discharging

The battery begins to discharge as soon as any load i.e.an appliance is switched on. The discharge actually begins when sulphuric acid in the electrolyte acts on lead peroxide in the positive plates. Similarly the lead acts on the negative plates to form a new compound i.e. lead sulphate. The moment the sulfate in the electrolyte is used up, the battery stops producing electricity. That means it simply discharges.

CFL

A CFL tube is flled with a noble gas like argon, neon, helium. It also contains a small amount of mercury. On heating it the mercury becomes a vapour. The inside of the tube is coated with a phosphorescent material (mostly phosphorus). There is electronic ballast in the base of a bulb. It boosts the line voltage up high enough to ionize the gas inside the bulb. With this the mercury also vapourises inside the tube. The ionized gas and the ionized mercury vapour give out ultraviolet light (UV). The UV light strikes the phosphorus. In turn, it produces white light good enough to light a room. Table 5.3 gives a comparative luminous efficacy of different categories of lighting sources.

Table 5.3: comparative luminous efficiency

category	Type	Overall luminous efficacy	Overall luminous efficiency
Incandescent	100-200 W tungsten incandescent (220 V) 100-200-500 tungsten glass halogen (120 V) 5-40-100 W tungsten incandescent (120 V)	13.8-15.2 16.7-17.6-19.86 5-12.6-17.5	2.0-2.2% 2.4-2.6-2.9% 0.7-1.8-2.8%
Fluorescent	9-32 W Fluorescent	46-75	8-11.45%
Light Emitting Diode	White LED 4.1 W (120 V) White LED 6. 9 W (120 V) White LED 8.7 W (120 V)	58.5-82.9 55.1-81.9 69.0-93.1	8.6-12.1% 8.1-12.1% 10.1-13.6%
Gas Discharge	Metal halide lamp Low pressure sodium lamp High pressure sodium lamp	65-115 100-200 85-150	9.5-17% 15-29% 12-22%

Charge Controller

It is an important part of nearly all power systems that charge batteries. The purpose is to keep the batteries properly charged and safe. The basic functions of a controller are very simple:

- stop overcharging of the battery
- block the reverse current
- protect from electrical overload
- show the battery status
- indicate the flow of power

Stopping overcharge

A battery may reach its full charge at some time of the day. It means that it can no longer store more energy coming in from a solar module. The battery voltage will get too high, if, more charge is put in a fully charged battery. Water breaks into hydrogen and oxygen and bubles out fast. It looks as if, it is boiling. This way lot of water is lost. It may thus lead to a small explosion in the battery. That is not all as it may degrade quickly. Overheating of the battery can also take place. Such a condition may also lead to shutting down of inverter. Simply put, stopping overcharging is a matter of decreasing the flow of energy to the battery after it reaches a certain voltage. The voltage may come down due to lower sunshine. Then again the controller may allow the battery to obtain the full charge. This is what is commonly known as voltage regulating. Simply put, the controller looks at the voltage and in turn regulates the battery charging. Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. It is called on/off control. Some more type of controllers bring down the current slowly. It is typically known as the pulse width modulation (PWM).

A controller with a PWM feature holds the voltage more constant. If, it has a two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach fullcharge. Then, it will drop the voltage lower to sustain a trickle charge. A two-stage process maintains a full charge but brings down the water loss.

Blocking reverse current

A solar module works by moving current through the battery in one direction. At night, the module may pass a small amount of current in the opposite direction. Thus battery gets discharged a bit. In most controllers, charge current passes through a semiconductor (transistor). It works like a valve to control the current. Thus it stops the reverse current without any extra effort. In some controllers, an electromagnet coil opens and closes a mechanical switch. It is more commonly known as a relay. The relay switches off at night to stop the reverse current.

Set points

The voltage at which the controller changes the charge rate are known as the set points. The value of these points depends upon the following few parameters:

- expected type of battery use
- type of battery
- choice of the system designer

Interestingly, some controllers have adjustable set points. While others may simply have fixed points only.

Effect of temperature on the control set points

The ideal set points for charge control change with a battery's temperature. The controllers used in a solar home system have a feature commonly known as temperature compensation. It simply senses the battery temperature. If, it is low, it will increase the set points. The batteries get exposed to high temperatures often.

Control Set Points vs. Battery Type

The ideal set points for charge control depend mainly on the battery design. Solar systems often use deep cycle lead-acid batteries of either the flooded or sealed type. Flooded simply means that these are filled with liquid. Sealed batteries make use of saturated pads between the plates. These are better known as valve regulated or absorbed glass mat. These need to be regulated to a slightly lower voltage than the flooded batteries. There is a risk that these may dry out

Low Voltage Disconnect (LVD)

Solar batteries also known as the deep cycle batteries are designed to be discharged by about 80%. It is important that the battery does not lie in the discharged state for days together. If so, it will get damaged. The simple solution is to disconnect the loads (lights etc.). Then these may be reconnected only when battery voltage has recovered due to longer hours of charging. Take for example a 12 V battery. It may reach 11 V only to get disconnected thereafter. All the modern day inverters used in a solar application have a built-in low voltage disconnect or simply LVD. The inverter will turn off to save itself and the loads besides the battery.

5.6 Step by step procedure for Installation of a Solar home system

Components:

- take out the system from the factory packing
- check if, there is any damage from outside on the different parts of system
- connect one end of the load cable to load junction box
- connect the other end of the load cable to charge controller
- connect one end of the load interconnecting cable to load junction box
- connect the other end to the luminiare
- connect all luminiares using load interconnecting cables
- place the charge controller on the battery box
- keep battery inside the box meant for it
- keep module in the south facing direction
- fix the module on the support structure using fasteners
- prepare a concrete plinth of ratio 1:2:4
- wire the system as per the drawing given by the system manufacturer
- take care to change the transit plugs of each battery with that of microporous vent plugs

Mounting of Charge Controller

- the charge controller has got two mounting holes
- it is designed in a key hole shape for wall mounting
- mount the controller to the wall with screws that fit to the wall material
- connect the battery cable assembly with fuse supplied along with the controller

- first connect the controller and then the battery to avoid any voltage on the wires
- connect the wire leading to the solar array with correct polarity
- first connect the controller and then the modules
- take care to see that positive and negative wires are placed close to each other
- connect the wires leading to loads with correct polarity
- first connect the wires to the load and only then to the controller

Electrical connection

- keep the battery on a full charge for 2-3 days
- connect the battery to the system only after getting fully charged
- do not switch on the loads for 2-3 days (when battery is on a full charge)
- connect the array cable to charge controller with proper polarity
- keep the switch in OFF position and connect the load cables and battery cables to the charge controller
- check if charging is proper-measure the charging current in series with array cable using current meter
- switch on the load i.e. lamps for their normal operation

Electrical disconnection

- disconnect the load cables by keeping the switch in off position
- disconnect the array cables

5. 7 Summary Remarks

Solar PV technology has made good progress since its early days. The processes to make wafers, cells and modules are definitely using lesser amount of energy now. The equipment i.e. the machines are also able to produce more number of these products on a per day basis. The number of PV products and systems is growing by the day. Urban areas are also finding its useful for a number of applications. However, the initial cost of the PV products is still on a higher side. These systems still need to be maintained like any other conventional products. That is where the role of trained solar technicians becomes important. They can assemble, install and importantly, maintain these systems. In this way, they will get a good work opportunity to connect with a sunrise technology.

QUESTIONS & ANSWERS-SOLAR PV

Q. Are renewable energy sources going to be every body's choice of use some day in future?

A. The conventional energy sources like coal, oil and gas are expected to be the frontline sources in the near future too. Renewable energy sources like solar, wind, biomass and small hydro etc. may find favour with lot more people if, their cost continues a downward trend?

Q. Which one amongst the popular solar Photovoltaic products has been sold in the largest numbers till date?

A. A large number of solar PV products and systems have been installed so far. However, solar lantern has outnumbered the rest of products.

Q. Name the solar mission which has just created the headlines in India recently

A. It is known by the name of recently initiated Jawaharlal Nehru National Solar Mission or JNNSM for short. Solar power capacity of 20000 MW is expected to come up by 2020 in the country

Q. Can solar radiation be available in the same measure in two different locations like Ladakh and Kanpur?

A. Solar radiation is usually not available in two different locations in the same measure. However, two neighbouring stations within a distance of 50 kms are expected to have almost the same representative value of radiation

Q. What percentage value of solar radiation is finally available on the earth's surface?
A. Around 47% of the solar radiation that makes its way to the earth's atmosphere is finally present on the earth's surface

Q Does measurement of solar radiation serve any useful purpose?

A. Yes, it is possible to know the amount of sunshine present in a given location. Further, one can also know the number of sunny days present on a year round basis. Both these values can then be used to arrive at the generation of solar power from a system designed for the purpose

Q. Is passive use of solar systems also possible in some way?

A. Yes, both the active and passive use of solar systems is possible. The latter use takes a good care of the available daylight making its way into a building envelope. This determines the final occupant comfort too.

Q. Do you see any matching between a solar cell and an ordinary dry cell battery?

A. Both the solar cell and dry cell battery carry charge across the positive and negative terminals

Q. Is strength of the Sun also related to the time of the day in any manner?

A. Yes, the intensity of the sun varies all day through, reaching its peak value at noon time

Q. Is it always true that a large area cell will produce more power than a small area cell?

A. Yes, it is generally so. However, the lone exception is the concentrator solar cell of a very small area but with a very high efficiency

Q. How many number of individual cells are joined together to make a thin film solar module?

A. Thin film module is a monolithic unit unlike a number of individual cells forming a crystalline silicon module

Q. Is it possible to produce the same amount of power from a) crystalline silicon module,

b) amorphous silicon module of same frame area?

A. No, that is not the case as the amount of power produced depends on the primary constituent of a solar module i.e. the cell (s)

Q. What is the best way to protect solar cells from rain and snow?

A. Solar cells in the case of a widely used crystalline silicon module are formed into a weather resistant assembly before it makes its way into the field.

Q. Does a solar module make up for a full PV system?

A. No, a solar module is not the full range of system by itself. It is supported by the balance of system components like a battery, charge controller, support structure and wiring etc.

Q. Does a solar battery store all the charge being produced by a solar cell?

A. No, it does not accept all the charge for a number of reasons

Q. If not, then which is the device at work to stop more charge from going into a battery?

A. The device which controls the amount of charge going in and out of the battery is commonly known as the Charge Controller or a charge regulator .

Q. Can solar power be used to run AC appliances directly without anything in between the battery and the load?

A. No, it it not possible as solar power is a DC source of power. An inverter would be needed to change the DC form into AC form.

Q. Is it okay to keep a solar module without any support on the ground?

A. No, it not a recommended practice. Generally, a solar module should be positioned at an angle, which is equal to the latitude of a given location. The idea is to collect the maximum possible sunlight.

Q. Name the parameters which show the highest value of voltage and current of a solar module.

A. These are commonly known as the open circuit voltage (Voc) and short circuit current (Isc).

Q. Is it possible to produce more voltage from two solar modules?

A. Yes, it is possible to add voltages by connecting the two modules in a series fashion. That means connecting the positive terminal of one module with the negative terminal of a second module and so on

Q. Is it possible to produce more current from two solar modules?

A. Yes, it is possible to add currents by connecting the two modules in a parallel fashion. That means connecting the positive terminal of both the modules together with the negative terminals of the two modules joined together too

Q. A solar module works best at a cell temperature of 25 degrees C. So, should it be kept shaded to keep the cell temperature down in a place like Rajasthan?

A. No, it is not at all suitable to allow any kind of shade on the module for possible loss of power

Q. Can the heat surrounding the solar module be used in any manner?

A. The back surface of a module gets quite hot in the summer months. This means surrounding availability of heat too. A PV/T system is capable of using this type of heat. Here T stands for a solar thermal system

Q. Does a solar battery work more efficiently at higher temperatures?
A. No, a solar battery works the best at 27 degrees centrigrade just like a solar module performance best suited to 25 degrees C

Q. Is it proper to light up any type of lamp with solar power?

A. Technically, it is possible to light up any lamp with solar power. However, it is always advisable to use energy efficient lamps i.e. which consume less power.

Q. Does combined charging of lanterns add more charge in one battery than the other?

A. No, it does not happen. Each and every battery gets charged as per its individual charge retaining capacity

Q Is it okay to take out all the charge from a battery on one day and then fill it up with the full charge the very next day?

A. No, it is not at all a healthy practice. A battery should be discharged according to its permitted depth of discharge or simply DOD. This value is generally up to 80% for a solar battery

Q. Sun shines for most parts of the year. Then is it really necessary to maintain a Solar PV system?

A. Yes, a solar system needs some simple maintenance too. Like for example, it is important to wipe the module surface clean of the dust etc. from time to time. Only then maximum amount of sunlight will pass through it.

Q. Does a solar system make any definite noise? If, not, then how do we know if, it is really working?

A. No, it neither makes any noise nor produces any smoke . In the modern day system, an electronic display is available which gives the value of voltage and current produced by a solar module all through the day

Q. Is it possible to switch off a solar PV system even when the sun is shining fairly bright during the day?

A Yes, a solar system is provided with operational and safety controls. So, it is quite possible to switch off a solar system for example during the repairing stages etc.

Simple calculations on Solar PV

1. Calculate the Module efficiency when:
Pin (Solar Insolation)=1000 W/m^2
Wp (Module)=55
am(area of the area) =1 m^2

Steps:
Formulae used is Efficiency $(\eta)=(100*W_p)/(P_{in}xa_m)$
=(100x55)/(1000x1)
=5.5%

2. Calculate the peak Watt of a solar module when:
Pin (Solar Insolation)=1000 W/m^2
Efficiency of the Module (η)=7.5%
am (area of the Module)=1m^2

Steps:
Formulae used is
Wp=(Efficiency/100) x P_{in}x area of the module
=(7.5/100) x1000x1
=75

3. A 0.5 m^2 module produces 35 W_p. How much power will the same module produce in case the area is doubled? Consider solar insolation of 100 W/m^2

Steps:
a) Calculate the efficiency first
$\eta=(100xW_p)/(P_{in}xa_m)$
=(100x35)/(1000x0.5)
=7%

b) Now calculate the Peak Watt by using the formulae
$Wp=(\eta/100)x(P_{in}xa_m)$
= (7/100)x(1000x1)
=70

4. Calculate the fill factor of a solar module when
V_{oc}= 11 V, I_{sc}=3 A
V_m= 10 V, I_m=2 A

Steps:
Fill Factor (FF)=$(V_m x I_m)/(I_{sc} x V_{oc})$
=(10X2)/(11X3)
=20/33
=0.60

5. Calculate the total Watt requirement of an office room in an ITI. It is using the following few loads:

Compact Fluorescent Lamp(CFL)- 2 nos. of 11 W + 1 no. of 20 W
Fans- 3 nos. of 20 W
Television-1 no. of 40 W

Steps:
Prepare the following type of Table:

Load type	**Number**	**Individual Wattage (W)**	**Total Wattage (W)**
CFL	2	11	2*11=22
CFL	1	20	1*20=20
Fan	3	20	3*20=60
TV	1	40	1*40=40
Total Watt requirement			=22+20+60+40 =142 W

7. Calculate the total Watt-hour requirement of the above load as per the following:

Hours of daily use (CFL's)= 4
Hours of daily use (Fan)=8
Hours of daily use (TV)=3

Load type	**Number**	**Individual Wattage (W)**	**Total Wattage (W)**	**Hours of use/ day**	**Load (Wh/day)**
CFL	2	11	2*11=22	4	=22x4 =88
CFL	1	20	1*20=20	4	=20x4 =80
Fan	3	20	3*20=60	8	=60x8 =480
TV	1	40	1*40=40	3	=40x3 =120
Total Watt-hour requirement			= 88+80+480+120 =768 Wh		

8. Calculate the Array load (as per the above) Wh/day when:
Battery efficiency=80%
Charge Conroller efficiency=90%

Steps:
Array load= Total daily load (Wh/day)/(Battery efficiency*Charge Controller efficiency)
= (768)/(0.8x0.9)
=1066 Wh/day

9. Calculate the Array capacity using the following formula
Array Size= Array Load/(Insolationxmismatch factor)
Here Insolation=5.5kWh/m^2/day
Mismatch factor=0.850

Array Size= 1066/(5.5x0.85)
= 1066/(4.25)
=250.8
= 250 W_p

10. A total solar capacity of 250 W_p is needed. Calculate the number of modules when:
a) 40 W_p modules are available
b) 50 W_p modules are available
b) 125 W_p modules are available

Steps:
Choose the total capacity as:

6 modules of 40 Wp
5 modules of 50 Wp
2 modules of 125 Wp

11) The daily load is 1066 Wh/day. Calculate the battery capacity needed

Steps:
The formulae used is :

Battery capacity= (Daily load x reserve backup)/(Nominal Voltage x Depth of discharge)

Here:
a) reserve backup is the number of days i.e. no-sunshine days, for which the extra charge in the battery is needed

b) Depth of discharge is the maximum possible charge that can be withdrawn from a battery without causing any damage to it

Assume reserve backup = 2 days

Depth of discharge (DOD)=60%=0.6

Using these values in the above equation gives

Battery capacity= (1066 x2)/(12 x 0.6)

= 296 Ah
= 300 Ah

12) Put down the final system design configuration

Steps:
a) Note down the module capacity (as worked out above)=
Modules= 6x40 W_p
Battery capacity= 12 V, 300 Ah
Load=2x 11 W CFL
1x 20 W CFL
3X 20 W Fan
1x40 W TV

This now becomes a standard PV system design configuration, which can be procured from a PV manufacturer and installed wherever needed

13) A solar battery is rated at a capacity of 100 Ah. Calculate the number of hours for which this capacity can be used

Steps:
Battery capacity= ampers x no of hours
So it depends on the current drawn and the duration for which it is drawn.
Thus a 100 Ah battery can be used in many different combinations such as

a) 5 hours (20 A x 5h)
b)10 hours (i.e. 10 Ax 10 h
c) 15 hours (i.e. 6.7 A x 15 h)

14) Calculate the total water head, if, water is to be pumped from a height of say 13 m using a solar water pumping system. It then has to be pumped to a storage tank placed at a height of 13 m. The dynamic head of the system (i.e. frictional losses of lifting water to the storage tank are included) is around 6m.

Steps:
Total water head= Static head + dynamic head + height of the storage tank
= 13 +6 +13
=32 m

15) Calculate the daily water demand in a village with a population of around 700 (around 140 households). Assume the per person water demand is around 35 ltrs per day

Steps:
Use the following formulae:

Daily water demand = Population x daily water demand
= 700 x 35
=24500 ltrs/day

16) Using the above values, calculate the daily water demand in m^3/day

Steps:
Daily water demand =24500 ltrs/day

Daily water demand in m3/day= 24500/1000
= 24.5 m^3/day

17) Calculate the energy required if, volume of the water that has to be pumped for a certain year say 2011 is 24.5 m^2/day. The total head is 32 m

Steps:
Energy required= mass of water x gravity x total water head (in Joules or kilojoules)
= 24.5 x 9.8 x 32 x0.28 (1 KJ=0.28 Wh)

= 2151 Wh/day

18) Calculate the array load as per the values mentioned in Q. 16 above

Steps:
Array load= Energy required/System Efficiency
= 2151/0.85
= 2530.5 Wh

19) Calculate the array size for the water pumping application as per Q. 18 above

Steps:
Array size= Array load/(Solar Insolation x mismatch factor)
= 2530.5/(5.5 x 0.85)
= 2530.5/4.67
= 542 W_p

20) Calculate the lumens per watt for in case of a a) 100 ordinary light bulb and b) 11 W CFL

Steps:
Lumens per watt is a simple measure of as to how much light is going to be produced for each watt of energy consumed

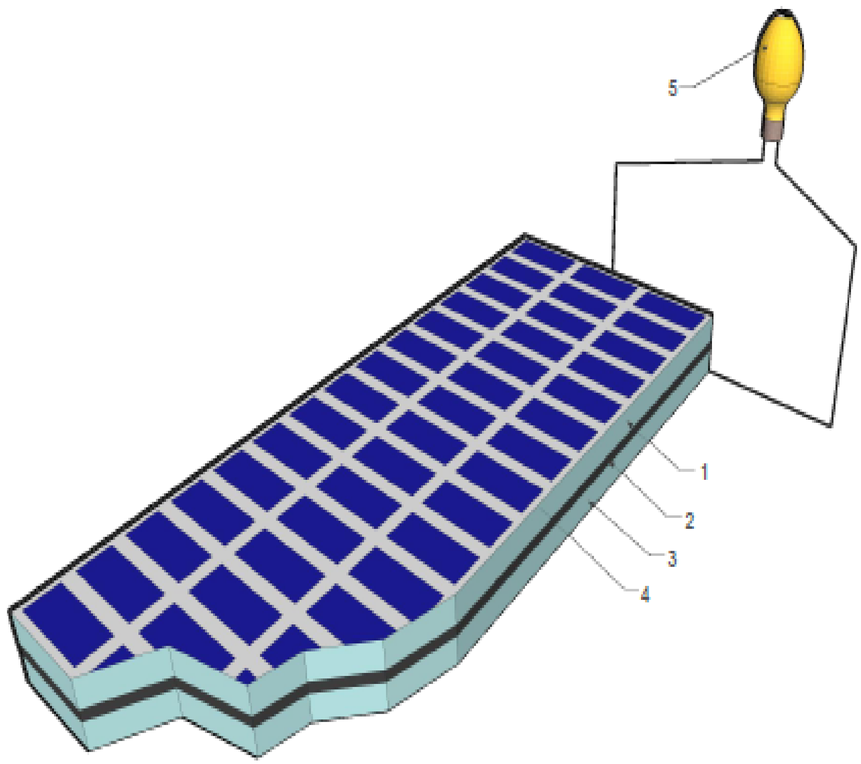
Using standard efficacy ratings, it is possible to know lumens per watt as under:

a) a 100 W bulb usually gives 1800 lumens
Thus lumens per watt is simply=lumens/lamp wattage
=1800/100
=18 lumens per watt

b) a 11 W CFL usually gives around 600 lumens
Thus lumens per watt is simply= 600/11
=54.5 lumens per watt

Thus it is quite clear that a 11 W CFL gives almost 3 times the light output as compared to an ordinary light. It means substantial energy saving too not to mention the long life span of a CFL

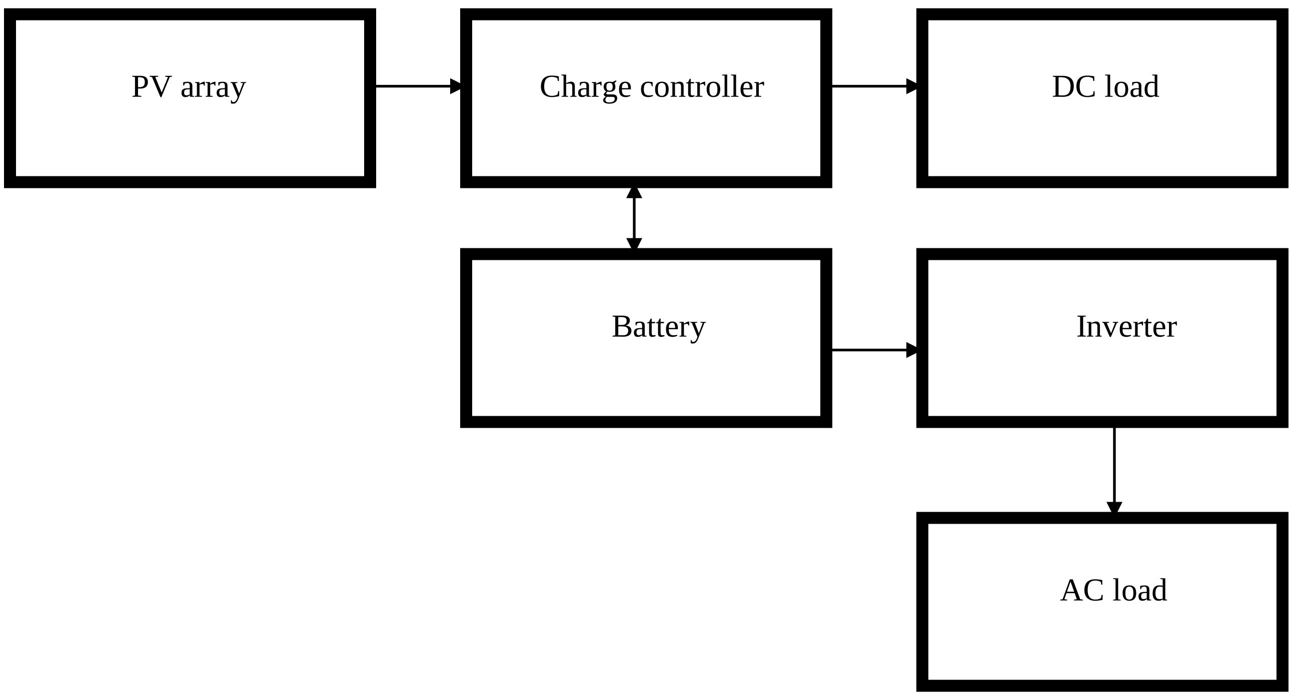
Drawing



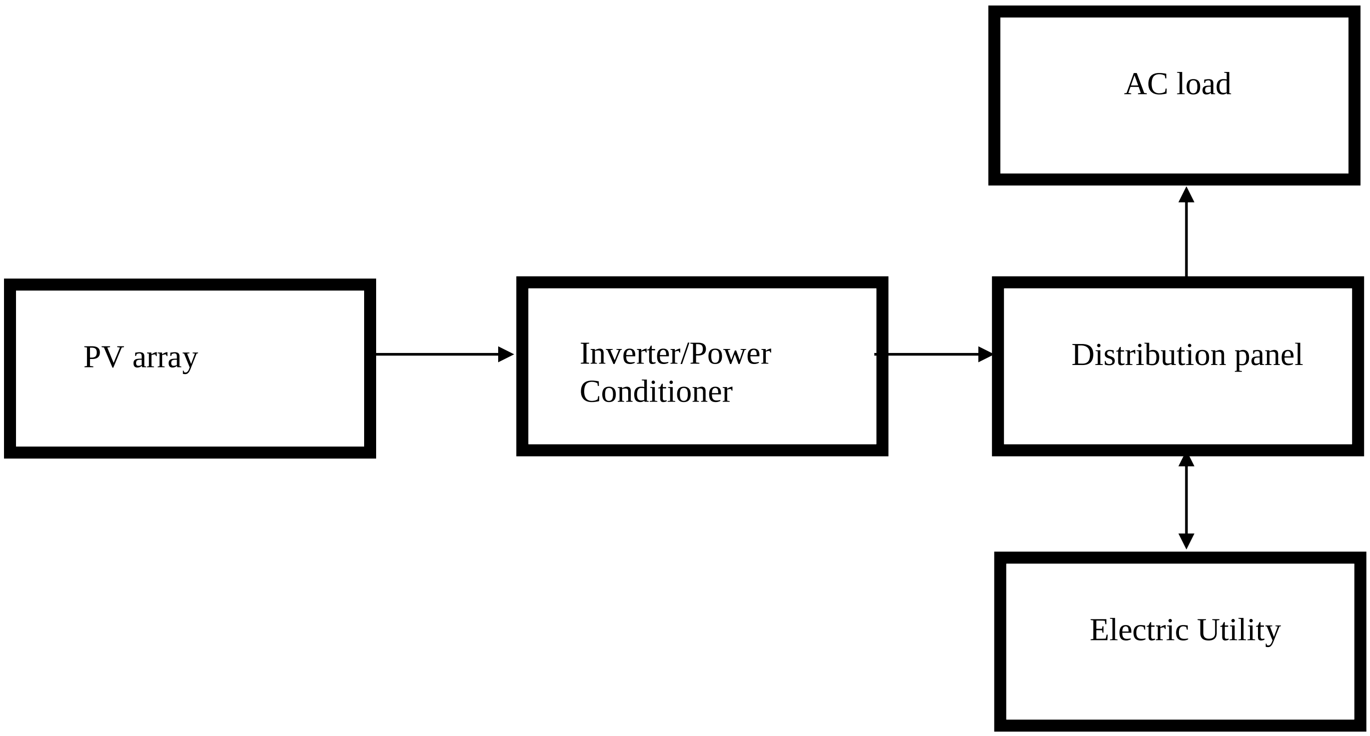
LEGEND	
1	N-TYPE SILICON
2	JUNCTION
3	P-TYPE SILICON
4	SOLAR CELL
5	LOAD

SOLAR CELL

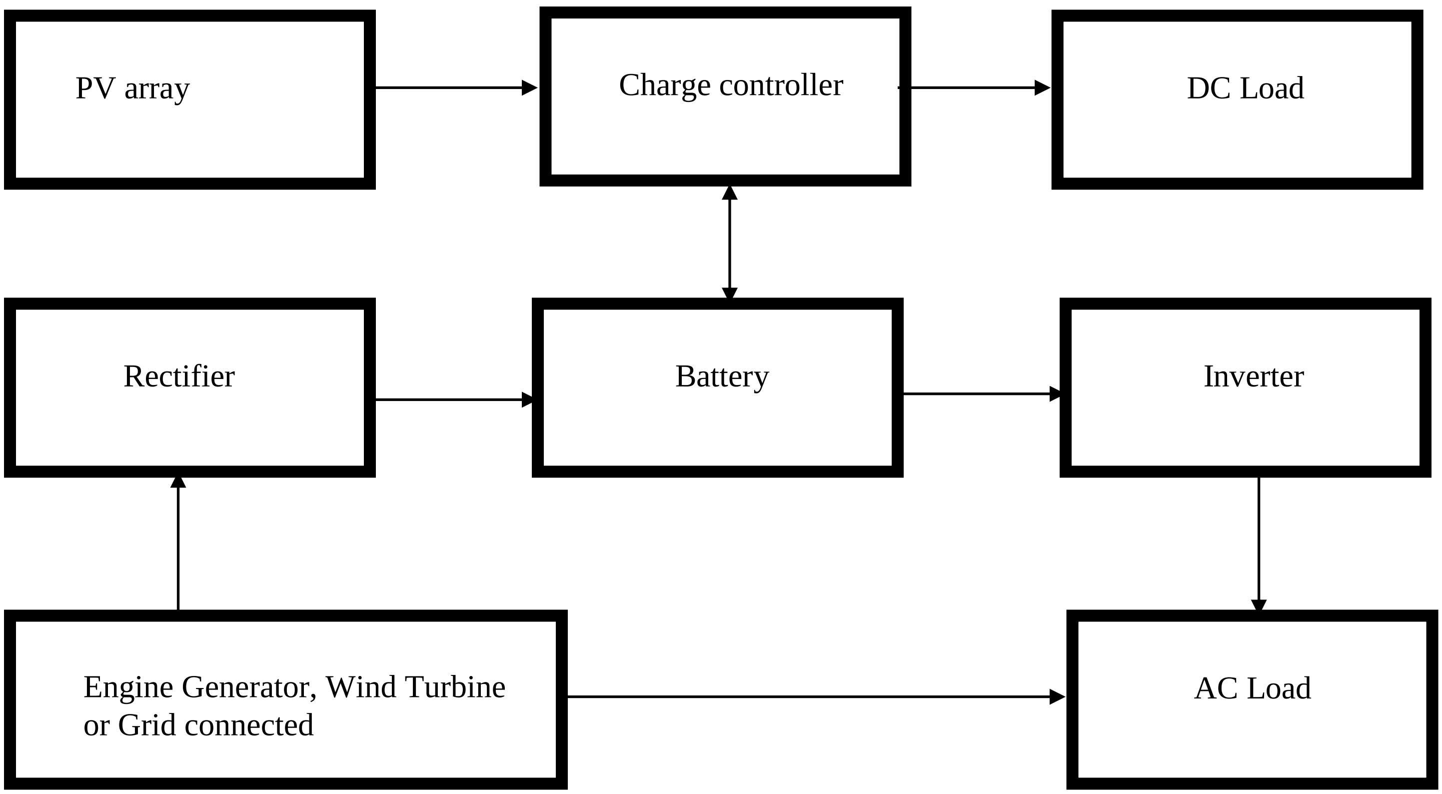
STAND ALONE POWER SYSTEM

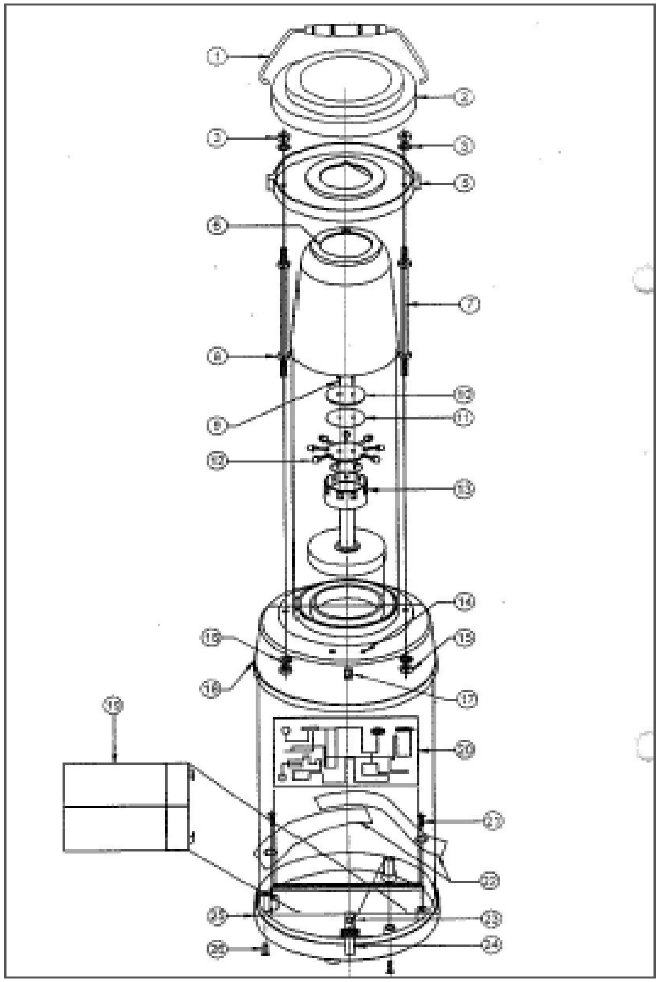


GRID CONNECTED PV POWER SYSTEM



HYBRID PV POWER SYSTEM





LEGEND			
1	HANDLE	17	ON / OFF SWITCH
2	TOP OUTER	18	MAIN HOUSING
3	M.S. NUTS	19	BATTERY
4	M.S. WASHER	20	P.C.B. PLATE
5	TOP INNER	21	SCREW
6	CHIMNEY	22	BATTERY FIXING ARRANGEMENT
7	M.S. ROD	23	CHARGING SOCKET
8	M.S. NUT	24	SLOT FOR CHARGING SOCKET
9	SCREW	25	BASE PLATE
10	HEAT SINK	2	SCREW
11	MICA		
12	U.B. WHITE L.E.D.		
13	L.E.D. HOLDER		
14	L.E.D.		
15	M.S. NUTS		
16	M.S. WASHER		

SOLAR LANTERN

Section –C: Solar Thermal

Chapter 6: Solar Thermal Technology

6.1 What is solar thermal technology?

Think of solar technology and you perhaps think of solar photovoltaic modules. However, there is one more way to use the energy of Sun. Solar thermal is a simple concept that uses the sun's energy to heat water, cook food and even dry crops etc. The technology which makes these things work is known as the solar thermal technology. This technology came into being in early 1960's. It is cheaper to produce, cheaper to install and easy to maintain. Take for example various fuels by which water can be heated. Use of solar thermal technology (solar water heater) can mean large savings of such fuels too.

Table 6.1: Savings possible via the use of a 100 liter per day solar water heating system at 60^0C

Type of Fuel	Calorific value (kcal/kg)	Efficiency (%)	Fuel saved (kg/annum)
Firewood	4708	17.3	2127
Kerosene	9122	50.0	380
Liquified Petroleum Gas (LPG)	10882	60.0	265
Charcoal	6940	28.0	891
Diesel	10004	75.0	231
Electricity	_	90.0	~1500 kWh

Just think of what you would gain by using a solar water heater. Well you would support technologies so good for our environment and gain some thing in monetary terms too.

6.2 Commonly available solar thermal technologies

There are many technology choices available today to do the following:

- heat water- for use in homes, buildings or swimming pools
- heat vessels-for cooking food
- heat spaces-inside greenhouses, homes and other buildings
- dry crops-for preservation

Applications like these are met at various temperatures These are also known as heat grades. Table 6.2 gives such temperature values along with a list of applications as under:

Table 6.2: Heat grades and applications

S.No.	Heat grade	Temperature range	Possible Applications
1.	Low grade	<100°C	• Water heating • Air heating • Drying • Refrigeration • Space heating • Desalination
2.	Medium grade	100-300°C	• Cooking • Steam generation for industrial applications • Drying • Refrigeration • Power generation • Water desalination • Water pumping
3.	High Grade	>300°C	• Power generation

Today, a large number of solar thermal products/systems are available in the marketplace. Out of these, solar water heaters and solar cookers are the most widely used systems so far. Given below is a brief introduction of these applications.

Is it not like getting worry free by handing over our every heat energy need to the care of mighty Sun? Only thing is that we need to give it a chance to do that for at least one of our most important needs.

Water heating

The most common use for solar thermal technology is for domestic water heating. Hundreds of thousands of domestic hot water systems are in use worldwide.

Solar cooking

A solar cooker is a device which cooks food on solar energy. The most popular solar cooker in India is a box type cooker. There is another type of solar cooker which uses a reflector. It is designed to concentrate (i.e. focus) the incoming solar radiation over a small area. This type of cooker is able to yield higher temperatures.

Solar drying

There are a number of agricultural and forest products around us. These contain some moisture i.e. water, which needs to be dried up. Using sun for drying of wood for example has been quite an old application. It is now possible to dry these things efficiently using solar dryers. These dryers are of two main types mainly i.e. passive means radiative (used to dry fruits, cash crops and fish etc.) and forced convection (i.e.using fan) dryers.

Solar desalination

Solar energy can be used to change the salty or sea water into clean water. Pure water thus obtained can very well find use in batteries, hospitals, laboratories and schools etc. In this process, water is first evaporated. It is then condensed as pure water.

Solar pasteurization

Water may not be always safe to drink. So, it is heated to a temperature of around 65°C for nearly 6 minutes. This way, germs and insects are removed.

Space heating, cooling and passive construction

Solar energy can be used for heating of buildings too. These buildings are generally located in the high altitude areas and face cold months. Heating can be done either by liquid or air collectors. It is also possible to use solar energy for space cooling applications. The passive construction helps to get maximum possible sunlight inside a building. The simple idea is to keep a building cool in summer and warm in winter. It is thus possible to save up to 90% of the energy otherwise needed to cool or heat a building.

6.2.1 Indian Solar Thermal Energy Programme

The Ministry of New and Renewable Energy (MNRE) has been encouraging the use of various solar thermal devices since a long time now. Under this programme, total solar water heating specific collector area of around 3.53 million square meters has been installed so far.

6.3 Sector-wise utilisation of solar thermal systems

Energy is used in many different ways in the domestic, institutional, industrial and commercial sectors etc. Table 6.3 highlights the above mentioned applications across these sectors:

Table 6.3: Applications of Solar Thermal Technology

Sector	Key uses
Domestic	Bathing, cleaning, laundry
Commercial (hotels, milk dairies etc.)	Laundry, washing, cleaning, bathing
Institutional (educational institutions etc.)	Bathing, cleaning, washing
Industrial	Washing, cleaning, bathing, pre-heated water for boilers

Solar collector is the basic element of a solar thermal system. It makes the above uses possible. The heart of a thermal system is commonly known as solar collector. It is made of headers (i.e. a pipe that runs across the edge of a solar collector), risers (i.e. the pipes that distribute the heat transfer liquid across an absorber) and absorber fins (made out of copper). The solar radiation is absorbed by the fins. It is then changed into a usable form of thermal energy by heating the water within it. This heated water is stored inside the solar tank.

6.4 Principles of Solar thermal equipments:

- low temperature thermal technologies rely on the scientific principles of GREENHOUSE EFFECT to generate heat
- short wavelength light radiation from the sun penetrates into the collector (covered by a transparent glass), which is absorbed by the surfaces inside the collector.
- once radiation is absorbed by the surfaces within the collector, long wavelength heat radiations are emitted but the transparent glass cover prevents the long wavelength radiation to pass through. This raises the temperature inside the collector.

Greenhouse effect

To some there are two meanings of the Greenhouse effect. There is a naturally occurring greenhouse effect, which keeps the earth's climate warm and worth living too. The other one is the manmade greenhouse effect. It is basically an increase in the earth's natural greenhouse effect due to addition of greenhouses gases like carbon dioxide. These type of gases mainly come from the burning of fossil fuels like coal, petroleum and natural gas.

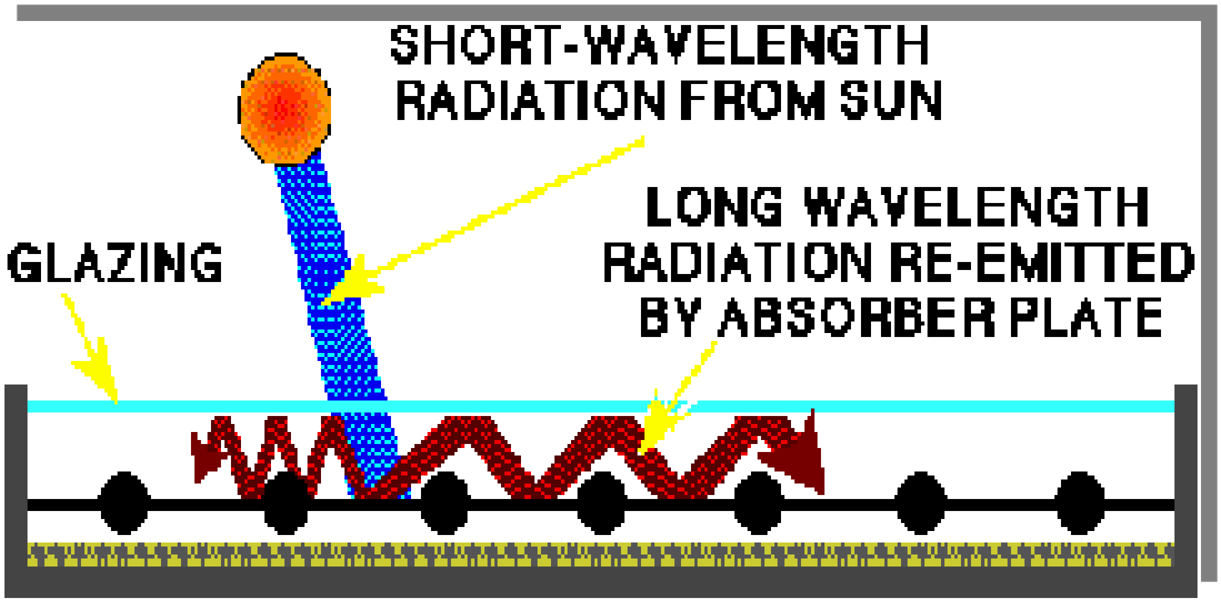


Figure 6.1: Greenhouse effect

The greenhouse gases absorb some of the infrared radiation that just escapes from the earth's atmosphere. It thus leads to warming of earth than it would be normally.

Just think of an ordinary blanket cover. Greenhouse gases act much like a blanket for the infrared radiation. It simply keeps the lower layers of the atmosphere warmer and the upper layers colder.

A black surface absorbs heat on facing sun. The same is true of a car parked out in the sun. Inside of the car gets quite hot, if, windows are left closed. The solar radiation passes through the glass window of the car, but can not come out of it. The simple reason is that it gets trapped inside. This heat trapping process is yet another common example of Greenhouse effect.

Absorption of radiation

A black body happens to be the most efficient absorber of radiation. That is why a black painted surface is used for this specific purpose in a solar thermal device. Solar radiations of different wavelengths get converted into heat. In general, a working fluid say water is in a close contact with the blackened surface. This way it can take this heat. Such a temperature increase can be put to use for heating water, distillation, cooking and for drying too. The temperature that is obtained in this manner will mainly depend on the following few things:

- mass of the working fluid
- heat absorbing capacity

It is quite possible to obtain a high efficiency of conversion for the solar thermal devices. Solar PV devices in contrast generally have modest conversion efficiencies.

Principle of reflection

Just think of the ordinary light rays. These change their direction when they reflect off a surface. So reflection takes place when light changes direction as a result of bouncing off a surface like the commonly used mirror. The rays move from one transparent medium to the other. The simple law of reflection states that on reflection from a smooth surface, the angle of the reflected ray is equal to the angle of incident ray. Thus this principle can be utilized for concentrating solar radiation at a point or on an area in solar thermal collector systems.

Conduction

It is one of the three routes in which heat is either transferred or simply lost.It basically takes place due to the temperature difference between two surfaces of the same material. Heat transfer is directly through the material

Convection

It is the second form of heat transfer. Within this, liquid, or gas such as air is heated. It then moves away from the source of heat and replaced by a cooler material. Take for example the natural convection. Here the heated fluid becomes lighter on account of expansion. It then moves away from the source and replaced by heavier cooler fluid. Now let us take the case of forced convection. In this case, the fluid is driven by some external force. It could well be a fan, pump or simply wind. It is then heated by coming in contact with the source of heat. Following which, it carries the heat away under the influence of an external force.

Radiation

It is regarded as the third route of heat transfer or loss. Radiation takes place via transfer of energy through an empty space. Remember the amount of heat transferred is proportional to the difference between the fourth power of absolute temperature of the radiating surface and the radiation receiving surface.

6.5 Basic knowledge about heat insulation & relevant pipes

Simply put, insulation is a material with a high resistance to heat flow. It is a process of stopping heat from leaving or making its way into a container. Thermal insulation can keep an enclosed area such as a building warm. It can also keep the inside of a container cold. Heat is transferred from one material to the other by conduction, convection and/or radiation. Insulators are used to reduce that transfer of heat energy. Polyurethane foam (PUF) is a material with very good insulation qualities primarily because of very low thermal conductivity and also due to its low moisture absorption capacity. The insulation is to be protected from rain water and solar radiation damage by covering with aluminium, GI sheet or fibre-glass cladding. Special attention must be paid to insulation if the hot water piping is inside the brick walls. The loss of heat to wall from pipe in the wall is many times more than the loss of heat from exposed pipe to air. Cold water piping and hot water piping must be kept separate

Table 6.4 below compares different types of heat insulation materials.

Table 6.4: Basic properties of insulating materials

Insulting Material	Density	Thermal Conductivity	Moisture absorption
Expanded Polystyrene 15	15	0.040	medium
Expanded Polystyrene 30	30	0.037	medium
Extruded Polystyrene	32	0.27	medium
Polyurethane Foam (PUF)	36	0.018	low
Phenolic foam	32	0.027	low
Cellular foam	125	0.41	low
Mineral wool	24	0.045	very high

Just think of when the air outside is cold; you may want to care for your skin by wearing a set of warm clothes. The simple idea is to keep the cold out and the body warmth intact. A thermal insulation in a solar water heater does almost similar by not allowing the warmth of hot water to go away.

Heat pipe is commonly made of copper material. It is hollow with the space inside evacuated. There is a small amount of purified water and some special additive inside the pipe. The simple idea is to change the state of such a liquid i.e. from a liquid state to a vapour. The heat pipes used in the solar collectors have a boiling point of only 30^{0}C . So, when the heat pipe is heated above this temperature, the water vaporises. This vapour moves up quickly to the top of a heat pipe transferring heat. As this heat is lost at the top, the vapour condenses i.e. becomes a liquid. It then comes back to the bottom of the heat pipe thus beginning the process once again.

6.6 Selection Criteria for specific technology use:

Table 6.5 gives a clear choice of the technology use much in accordance with the type of application under active consideration:

Table 6.5: Choices of Technology

Application	Technology
Low temperature application from 40-800c	FPC/ETC
Medium temperature application from 80-1200C	Heat pipe ETC
High temperature application from 120-250 0C	Solar Concentrator
Low temperature commercial applications (Swimming Pool)	FPC/ETC

Chapter 7: Solar Water Heater

7.1 Solar thermal Applications

Use of solar energy for heating water is not a new phenomenon. Or for that matter the drying of agricultural produce like rice and wheat etc. However, what has certainly changed between then and now is the use of modern technology based products and systems like a solar water heater and solar cooker etc. This chapter takes a close look at the solar water heating systems from a variety of end-use considerations. There are following three temperature ranges within which solar thermal systems as these are known work:

- Low temperature range: below 100^0C
- Medium temperature range: $100\text{-}400^0$C
- High temperature range: above 400^0C

Accordingly, it is now possible to group different types of applications on the basis of above mentioned temperature ranges:

Temperature range	**Common Applications**
Low temperature (< 100o C)	▪ Water heating ▪ Air heating (drying, space heating) ▪ Cooking ▪ Desalination etc.
Medium temperature (100-400o C)	Steam generation, industrial process heating, cooling, power generation
High temperature (> 400o C)	Power generation etc.

However, out of these many applications, the present course curriculum will deal with solar water heating and solar cooking technology uses only.

7.2 What is a solar water heater?

Solar Water Heater (SWH) is a cheap way to get hot water. It uses the free flowing solar energy and can be used in many different types of climates. The most important parts of a solar heater are as under:

- solar collector or a set of collectors (also called flat plate collectors)
- storage tank
- pipelines
- controls and instruments

In turn, the flat plate collector is made of:

- absorber plate
- fluid conducting pipes (consisting of bottom and top headers and riser tubes)
- glass cover
- insulation
- casing or a collector box

A solar water heater of 100 liter per day capacity can easily meet the hot water needs of 4-5 persons. It can pay for itself in 3-4 years when no electricity is used for water heating. That is not all, as it can even stop the emission of 1.5 tonnes of carbon dioxide per year. Still better is to know that it enjoys a long life of 15-20 years.

The collector box is in the form of an open top, shallow box. It has insulting fibre glass at the bottom and sides. Within the box lies the absorber plate. Above it like a window is the glass plate cover.

Why use solar water heaters

- 100 LPD SWH can replace an electric geyser for residential use and thus save 1500 units of electricity annually
- SWHs of 100 litres capacity each can contribute to a peak load shaving of 1 MW
- SWH of 100 litres capacity can prevent emission of 1.5 tonnes of CO_2 per year

7.3 Flat plate collector

A flat plate collector is the most common type of solar collector. It is used mostly for solar water heating in homes and in solar space heating too. The collector is made of an insulated metal box with a glass cover. There is a dark coloured absorber plate too. Solar radiation is absorbed by an absorber plate. It is then transferred to a fluid that circulates via the collector in the tubes. This type of collector is known as a liquid solar collector. It mostly uses water as a liquid. The other type of collector is air collector, which uses air as a circulating fluid. The flat plate collectors heat the fluid to a temperature which is less than that of the boiling point of water. Figure 7.1 gives a schematic view of a flat plate solar collector:

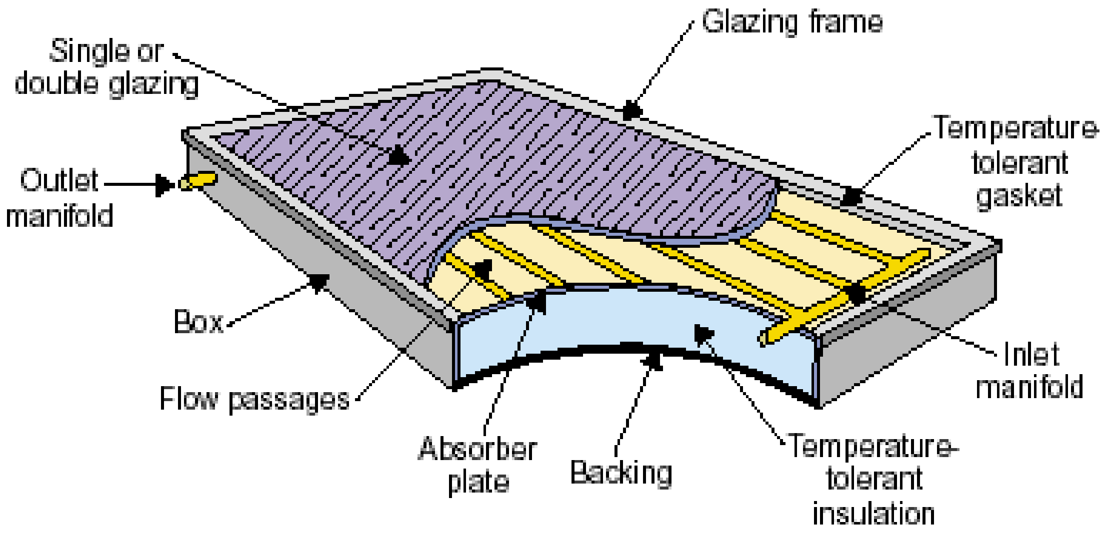


Figure 7.1: Schematic diagram of a Flat Plate Collector

Salient features of a typical solar collector:

- absorber is made out of high conductivity material like copper with selective coating on it for maximum absorption of solar radiation and minimum emission of infrared radiation
- the insulation must be able to withstand the maximum temperature of the absorber plate.
- the fluid that flows through the collector shall collect the heat for useful application.
- the transfer of heat shall take place mainly through conduction and convection process. The fluid that flows through the collector shall collect the heat for some useful application.
- the transfer of heat shall take place mainly through conduction and convection process. Therefore, the tubes should be made out of high conductivity material like copper.

These are best suited to the applications where the temperature need is between 30-70 °C. Air based collectors are typically used for heating buildings and for crop drying too. Liquid based collectors may be glazed (i.e. a thin smooth shining coating) or unglazed. The glazed liquid collectors are the most common type of solar collectors for offering domestic and commercial water. The flat plate collectors can be put up in a number of ways. It mainly depends on the following:

- type of building
- type of application
- size of the collector

Left to its own, a solar water heater works quite silently rather going un-noticed. That is the beauty of this system, which does not seek your presence. It sits pretty on just a small space of 2 sq.m., while leaving untouched rest of the rooftop space for some other uses of course.

7.3.1 Evacuated Tube Collector

It is made of parallel rows of glass tubes connected to a header pipe. Each tube has air removed from it to remove the heat loss through convection and radiation. ETC's are of two main groups:

Special features of an ETC are:

- can achieve high temperatures in the range of 77-177°C
- well suited for commercial and industrial heating applications and also for cooling applications
- get much hotter than the flat-plate collectors.

Figure 7.2 shows a evacuated tube collector.

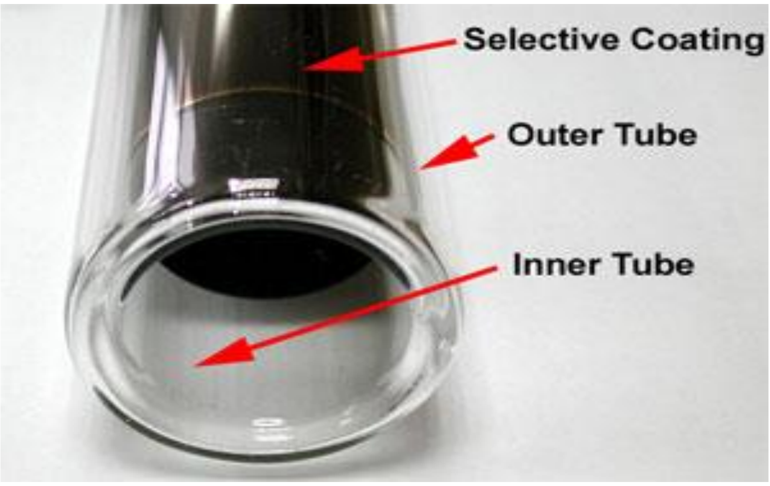


Figure 7.2: Evacuated tube collector

7.4 Working principle of a flat plate collector & evacuated tube collector– thermo siphon action

It is given below.

7.4.1 Flat plate collectors

A commonly used solar domestic water heater is made of a hot water storage tank and one or more flat plate collectors. The collectors are glazed on the sun facing side to allow solar radiation to come in. There is a black absorbing surface inside the flat plate collector. It absorbs the solar radiation and transfers the energy of the sun to water flowing through it. The water thus heated is collected in the tank. The tank has got insulation material on it to stop the heat loss. The water circulates from the tank via the collectors and back to the tank. It takes place due to another simple concept of temperature difference i.e. between the hot and cold water.

Advantages offered:

- it is simpler in design and cheaper too
- it is being produced much more widely
- it's operation and maintenance needs are simple

Disadvantages:

- heat loss takes place within the frame by convection
- it has a low efficiency
- it needs more panel area to collect the heat
- does not work efficiently in cold climates

Now there is one more solar collector technology at work. It is commonly known as the Evacuated Tube Collector (ETC) or simply vacuum tube technology. This new design overcomes the above mentioned disadvantages of a flat plate collector.

7.4.2 Evacuated tube collector

The evacuated tube collector or simply ETC is a new technology. It is based on the principle of an ordinary thermos flask. In a vacuum flask, loss of heat is stopped. In a ETC, each tube is made of an outer tube and an inner tube. Both of these tubes are sealed jointly. The water passes via the inner tube. Its outer wall is coated with a selective absorbing material. This absorbs the incoming solar radiation and thus stops the heat loss. The coated inner tube is closed at one end. It is sealed at the other end to an outer tube. The air from the space between the two tubes is evacuated. It thus leaves a vacuum which leads to no loss of heat. The coated inner tube absorbs the radiation thus heating the water present inside the tube. At this stage, the heated water moves up and goes into the tank. The relatively cooler water within the tank sinks into the tube. It gets heated and moves up again. In this way, convection current takes place. It heats all the water in the system very fast.

Key operational characteristics of an evacuated tube collector are as under:

- Glass tube is formed by fusing two co-axial glass tubes at both the ends. Air between the two glass tubes is evacuated to create vacuum which works as an insulation. Outer surface of inner tube in the evacuated tube collector forms the collector area
- Absorber coating shall be applied on the outer walls of inner tube selectively to absorb the solar radiation to collect energy and to convert light energy into heat energy.
- formation of scale is faster in FPC based system than in ETC based system

A rooftop of a urban residence houses an evacuated tube collector (Figure 7.3)

Figure7.3:Shows an evacuated tube collector based solar water heating system on a residential rooftop.

Table 7.2 below gives a quick comparison between a flat plate collector and an evacuated tube collector.

Table 7.2: Comparison between a flat plate collector and evacuated tube collector

Flat Plate Collector (FPC)	**Evacuated Tube Collector (ETC)**
Works very little on the cloudy and winter days	Works fine in cold conditions
More space needed for installation	Less area needed to install
Slow heat generation	Fast heat generation
Maximum absorption of heat takes place only at noon	Maximum absorption at any time of day
Difficult to clean the copper tubes due to small bore diameter (12.5 mm)	Easy cleaning of the tubes having inside diameter of around 37 mm
Heat loss more in the collectors during night	Less heat loss at night due to vacuum inside the collector tube

7.5 Major components of a solar water heater

Collector

Collector is the most important part of a water heater. It is made of an absorber which is basically a tube and sheet grid. It has a special type of coating to absorb the solar radiation. Such a coating is commonly known as a solar selective coating. Matt black paint may also work well for the low temperature uses. The absorber grid is generally made of copper. It is backed with insulation to stop the heat loss. These two elements are then put in a box made of aluminium, steel or fibreglass. The side of the box which is facing the sun is covered with a transparent (i.e a material through which sunlight can pass easily) glass sheet (i.e. glazing). It allows the solar radiation to fall on the absorber.

Hot water storage tank

It is made of copper, stainless steel or even steel materials. The tank is properly insulated (i.e. covered with some good heat retaining material) to stop the loss of heat. The storage capacity is normally kept equal to the daily heating capacity of the collectors.

Pumps

Key task of the pump is to push/circulate water through the absorbers in a collector. This type of function is not needed in the simplest design i.e. flat plate collector.

Controls

Some kind of control features are needed in such systems as use pumps or backup heaters. Thermostat with the help of switches controls the pump operation etc. Minimum and maximum water level cut-off functions are also used in some designs.

Heat Exchangers

The type of water that is to be heated may not always be clean. It could be dirty or contain some chemicals or may even lead to scale deposition. It being so, the collector water is contained in a close loop. This water on getting heated heats up the used water via heat exchanger. Such an exchanger could be made of ordinary steel, stainless steel or even copper.

Stands

The collectors are placed outside to face the sun all day long. These are mounted on the stands generally made of angle iron.

Backup heaters

Sunshine may not be available always. To take care of such days, an electric heater is used. It could well be kept inside the main hot water storage tank.

Sacrificial anode

It is a simple device which prevents the stainless steel tank from galvanic corrosion by being more reactive to hard water.

Other components

There are a few more components within a solar water heater such as:

- pressure and temperature gauges
- air vents
- cold water tank
- gate valves for adjusting flows
- water flow meter
- solenoid valve in cold water line

7.5.1 Types of commercially available solar water heating systems

There are two main types of water heating systems i.e. a) Thermosiphon system and
b) Forced circulation system.

Thermosiphon

In the thermosiphon system, the water circulates from the collector to storage tank by natural convection and gravity. The water gets heated in the collector so long as the absorber keeps collecting heat. It then moves to the storage tank which is placed slightly above. Figure 7.4 shows a basic design of a thermosiphon type solar water heating system. The cold water at the bottom of the storage tank runs into the collector to replace the hot water discharged into the tank. Brighter the sunshine, quicker will be the circulation.

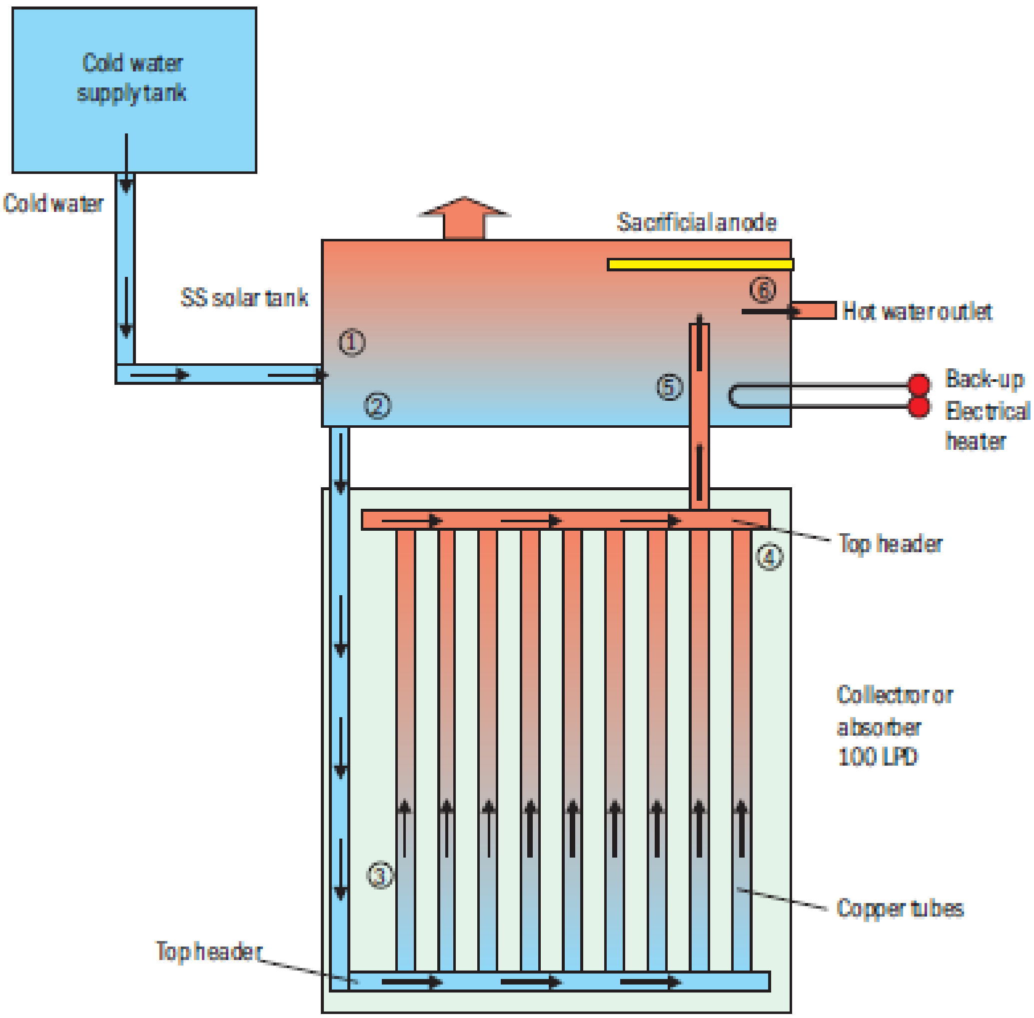


Figure 7.4: Thermosyphon in a Solar Water Heating System

Some of the most important advantages and disadvantages of a thermosyphon system are:

Advantages:

- simple to operate
- easy to maintain

- somewhat cheaper

Disadvantages:

- circulation of water is slow
- not suitable for systems with large requirement of hot water

A solar water heater deals both with the cold and hot water. Cold water is heavier and comes to the bottom of the unit i.e. copper tubes. It does not stay there when it gets hot. It quietly moves up to the well insulated hot water storage tank. Thus the cycle of cold water coming down and going up keeps on as long as the sun shines.

To sum it up, a solar water heater offers the following few important advantages:

- saves up to 1500 units of electricity per year
- easy to use
- near zero maintenance
- safe to use
- long life
- pollution free

These benefits are now increasing the use of solar water heaters in the below mentioned areas:

- homes, hostels, hotels, guesthouses & hospitals
- industrial process heating in food processing, textiles, dyeing, metal plating, pharmaceutical etc
- milk diaries & chilling plants

7.5.2 Forced circulation system

This type of system needs a pump. The function of a pump is to move water from the storage tank to the solar collector. A pumped system has got the following few advantages as compared to the thermosyphon system:

- collects more energy
- higher flow rates
- higher efficiency
- automatic pump shut off at sunset
- no limit on the size of the system

Limitations / Disadvantages:

- needs electricity supply on a regular basis
- needs maintenance of electronic controls

7.6 Hard water problem

- It is not always possible to circulate suitable quality water in a solar water heating system. In fact, its availability, quality and use varies from one geographical location to the other. A solar water heater needs soft grade water quality. The water hardness shows dissolved salts which get separated when water temperature goes above 40-45^{0}C. The generally acceptable hardness of water should be below 100 ppm.

Following few are the most important steps to handle the hot water problem:
Water softener for entire building water treatment

- Special designed heat exchanger system
- Inline water softeners like magnetic devices
- Use of vacuum tube collectors (Caution – generally for low pressure only)

7.7 Installation guidelines

If you fail to plan you plan to fail; with this underlying rationale in view, plan the solar water system in a design stage along the following few considerations mainly:

- Plan solar system during the design stage in terms of :
  - System size
  - Water quality
  - Cold water supply and availability with required pressure head
  - Backup arrangements
  - Utility points
  - Location
  - Water pressure and interconnection details
  - Optimize piping

Go for separate systems instead of a single large system for flexibility

- collectors to be installed facing south and on shadow free area
- gap between nearest tall building and collector surface should be at least twice the building height for buildings in south and east west side-North side buildings no problem
- plumbing to be insulated and if, possible inside the wall
- plan the piping and electrical back up connection up to terrace with control switch at convenient location
- take special care of getting system and piping pressure tested especially when pressurized water supply is used
- check water quality TDS /hardness should be less than 100 ppm, consult an expert if, some minerals are in an excess quantity (refer ISI standard for water quality)
- the source of the cold water must be placed at least 7 feet above the terrace level for size up to 500 liters.

- for larger tank sizes, the height requirement may go up to 10 feet or higher
- for systems of size larger than 3000 liters per day, customer may choose forced circulation system.
- these systems may also be used for smaller than 3000 litres/day capacity also where thermo-siphon system can not be used due to limitation of height of the cold water tank.

Chapter 8: Solar Cooker

8.1 What is a Solar Cooker?

Cooking is a day in and day out energy giving activity. Baking, boiling, frying and roasting are the allied activities. These take place at temperatures varying between 700-2500C. However, cooking is the most prominent activity out of these. A variety of cooking fuels are being used in the country. These mainly include firewood, charcoal, cow dung, kerosene oil and the LPG in varying proportions though. Solar cooking is a relatively new way of cooking. It makes use of a device now commonly known as a solar cooker. It

cooks food without any conventional cooking fuel/energy. This basically involves the conversion of incident solar radiation into useful heat energy.Thus solar energy becomes a freely available fuel for cooking food.

. In fact, solar cooking is the simplest, safest and an easy way to cook food. A box type cooker cooks at a moderate temperature. It has got several pots. These type of cookers are amongst the most widely used worldwide. A curved concentrator cooker commonly known as a parabolic cooker can cook faster at high temperatures. However, it needs a constant attention. These type of cookers find the maximum use in institutions.

8.1.1 Working principle of a solar cooker

Most solar cookers work on a basic principle i.e. convert sunlight into heat energy. This heat energy is then used for cooking. The cooker does not work at night. The dark surfaces get very hot in sunlight. Simply put, food cooks best in dark, shallow thin metal pots. These have tight fitting lids to hold in heat and moisture. It has an insulated box with a glass window. The curved concentrator cookers do not generally need a heat trap.

Key operational characteristics of a solar cooker are as under:

- directing the maximum possible amount of Sun's light rays to the food (being cooked) by means of reflection
- converting these light waves into usable form of heat energy
- effectively retaining this heat energy by insulating the energy

8.2 Solar cooking technologies

Solar cookers come in different shapes, sizes and process features. The oven type solar cooker is suitable for baking and cooking, whileas box cooker is well suited for boiling and cooking. Likewise, the parabolic concentrator solar cooker meets the frying and cooking applications convincingly. One more class of cookers well adapted for these uses (i.e. frying and cooking) is the steam solar cooker. This type of cooker is better known as Shafler (after its inventor) dish.

8.2.1 Different types of Solar Cookers used in India

There are four different types of solar cookers as mentioned below:

- Box Solar Cooker
- Dish type solar cooker (SK-14) and (SK-10)
- Solar steam cooking system
- Community Solar Cooker (for indoor solar cooking)

Oven type solar cooker does not figure in this group as it is still not manufactured in India.

Box solar cooker

It is commonly made of a well insulated box. Hence the name box type solar cooker. The inside of the box is painted black. It is covered by one or two transparent covers of glass. These covers allow the solar radiation to come inside the box. At the same time, it does not allow the heat from the hot absorbing plate to leave. Hence the temperature of the blackened plate inside the box increases. It is thus able to heat up the inside space to temperatures up to 140^{0}C. This temperature is good enough to cook many different types of food. The outer box is generally made of fibre reinforced plastic or metal. Figure 8.1 shows a commonly used box type solar cooker available in the market today.

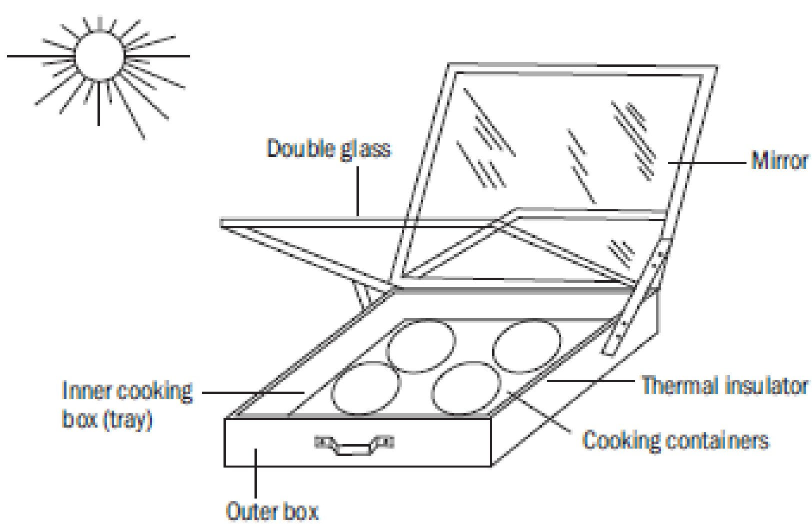


Figure 8.1: Box type of solar cooker

It is possible to make the inner box from galvanized iron, mild steel or aluminium sheet. Black paint is used both on the sides and bottom of the box. The space between the outer box and the inside box is packed with insulating materials like glass wool or thermoCole etc. A mirror is in place to increase the solar radiation input on the absorber surface. The cooking containers have tight covers. These are commonly made of aluminium or stainless steel material. Such containers are painted dull black on the outer surface. The simple idea is to make them absorb the solar radiation directly. Following few are the most important parts of a solar cooker:

- outer body
- inner cooking box/tray
- insulation
- double glass lid
- mirror
- cooking pots
- side window

Raw Materials Required for Fabrication

It is quite possible to fabricate a solar cooker using a proper mix of the following few materials and the associated range of equipment**:**

materials

- G.I. sheet, Aluminium sheet, M.S. Channels, Glass, Mirror ,Asbestos fibre Sheet, Glass wool, Caster wheel, Black board paint, Hinge, lock, Screws and other miscellaneous items.

machinery and equipment required for fabrication

- Hand saw, Hand shear, Portable drilling machine, Hammer, Screwdriver, Pliers, Measuring tape Painting brush etc

Simple maintenance of - box solar cookers

It is quite important to take a good care of the solar cooking system. This can be done in the following manner:

- The surface of the cooking box exposed to solar radiation and the outer surfaces of cooking pots should always be kept coated with black paint/selective coating material.

- There should be no leakage of hot air through the joints or any other portion of the cooker
- The lid with double glass system should be perfectly sealed so that water vapour, do not enter into the space between the glass surfaces and get condensed reducing the transmission of sunlight through the lid
- Gasket and mirror should be replaced as and when needed

The most important advantages of a box solar cooker are as under:

1. it uses no fuel other than the freely available solar energy
2. it is totally smoke free and thus good for health
3. it does not need any one to run it
4. it tastes better to use dishes cooked in it
5. it can be used for cooking 3-4 items at a time
6. its regular use can lead to savings of 3-4 LPG cylinders per year
7. it keeps cooked food hot for 4-5 hours
8. it works for around 10-12 years
9. it pays back for it self in 3-4 years
10. it is a cheap way of cooking
11. food will not be burnt

In all box type solar cooker offers a huge market potential estimated at around 97 million units. As against this, less than a million units have been deployed so far in India

Disadvantages

1. it is a slow way of cooking food
2. it can not be used during the cloudy days

Standards adopted for Box type solar cookers

There are many different types of solar cookers available in the marketplace. It thus becomes quite important to set up test standards against which the performance of cooker can be tested. This is mainly required to ensure a high degree of field performance reliability. It is also for the reason to discourage the manufacture cum use of poor quality devices. The Bureau of Indian Standards (BIS) is an accredited body for publishing the test standards. The Solar Energy Centre (SEC) of the Ministry of New and Renewable Energy (MNRE) is an apex testing cum certification facility for the solar thermal devices too. BIS

has so far published the following few standards in respect of the box type solar cookers.

- IS 13429 (Part 1):2000, Solar cooker-Box type - Specification, Part 1 -Requirements.
- IS 13429 (Part 2):2000, Solar cooker- Box type - Specification, Part 2 -Components.
- IS 13429 (Part 3):2000, Solar cooker- Box type - Specification, Part 3 -Test methods

Two tests associated with IS 13429 are known as the stagnation test and full load test. Accordingly, there are two performance parameters available for testing of this specific cooker. These are commonly known as Figures of merit FI and F2 and whose respective values should not lie below 0.12 and 0.40. Evaluation of FI and F2 involves the measurement of following few parameters:

- Solar irradiance
- temperature of cooking tray
- water temperature
- ambient air temperature

Dish Solar Cooker

It works on a simple principle of concentrating sunlight. The device which does this trick is known as a parabolic dish. The parabolic shape is needed for the proper reflection angles. Normally, a dish cooker has a dish diameter of around 1.4 m. It is made of a single reflector or by joining smaller pieces of reflectors. These are fixed to a rigid frame. This cooker when kept out in the sun forms a point focus. It is then used for cooking the food. Following few are the most important parts of a dish cooker:

- bright anodized aluminium sheets of 0.4 mm thick or 3 mm thick glass mirrors
- supporting frame for the bowl
- stand for the bowl
- tracking mechanism (manual)

Figure 8.2 shows commonly used dish type solar cooker

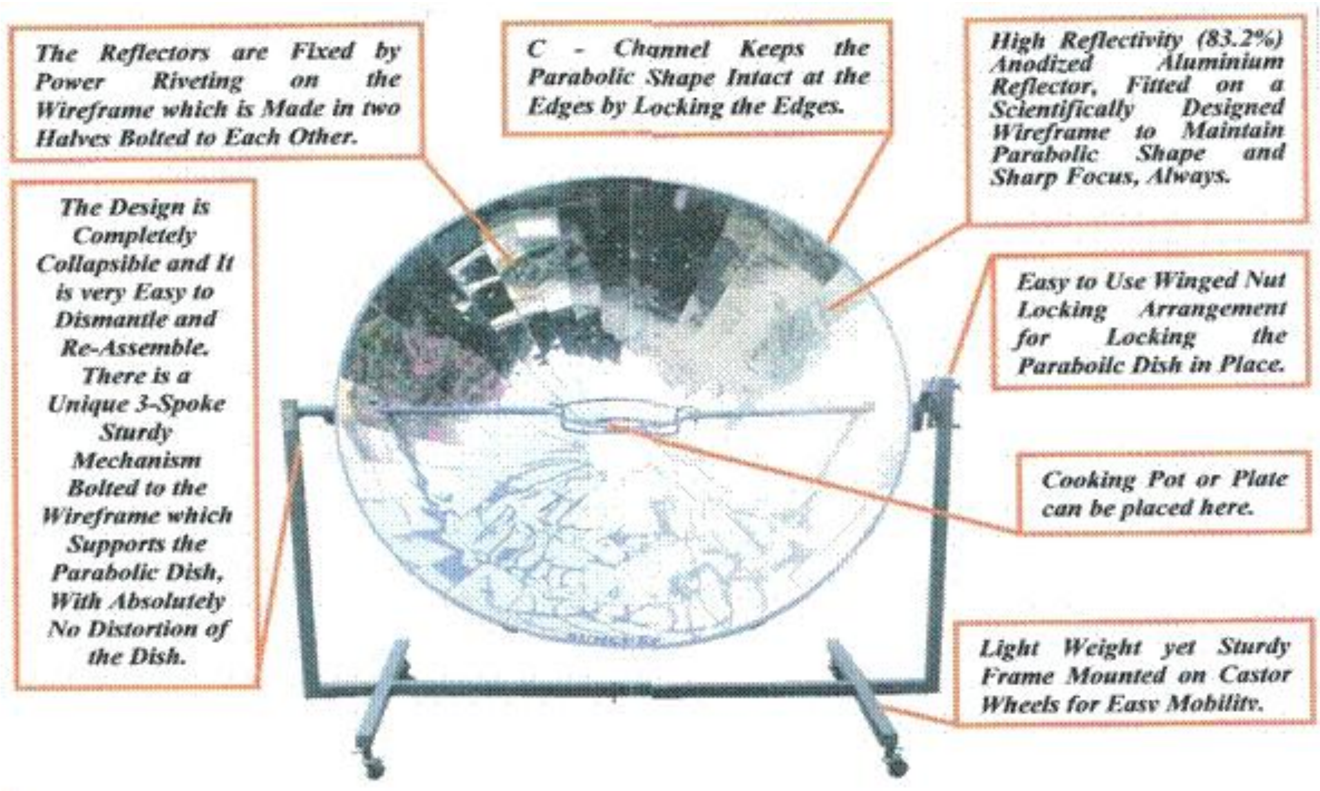


Figure 8.2: Dish type of solar cooker

The temperature at the bottom of the vessel may reach a few hundred degrees C. It is good enough to carry out roasting and frying of the food items. The same is not possible in a box type solar cooker. Remember the dish cooker can meet the cooking needs of 15-20 persons at one time.

How would it feel like one dish playing up the television programmes of your choice and the other dish cooking up the tasty food on your terrace? The common ground is that both these dishes are in an open public view for a better understanding.

Key advantages of dish solar cooker

Following few are the key advantages offered by a dish solar cooker:

- suitable for faster outdoor cooking requirements of 10-15 people

- large families and small institutions can readily benefit from its simple usage
- potential to save around 10 LPG cylinders per year based on an effective use
- proven technology in extreme climates actively promoted by MNRE

Testing of dish solar cooker

Two tests associated with the test standard are known as heating test and cooling test respectively. Currently, the test standard relevant to SK-14 is still available in a draft stage only. There are following four broad performance parameters available for testing of this special type of cooker:

- heat loss factor
- optical efficiency factor
- standard cooking power
- overall heat loss coefficient

Solar steam cooking system

As the name suggests, water is changed into steam for cooking. The solar steam cooking system is based on the principles of solar energy concentration technology. A number of solar concentrators are put to use for concentrating solar energy. These are basically automatic tracking dish concentrators, which convert water into high pressure steam. Few thousand kgs of steam are produced every day at a temperature of more than 180^{0}C and even more.. In actual practice, the solar rays incident on the dish are reflected and concentrated on the receivers placed in its focus. The temperature obtained is normally very high (of the order of 450^{0}C to 6500^{C}. Thereafter, water in the receivers reaches the boiling point so as to become steam.

Following few are the most important components of a solar steam cooking system:

- parabolic concentrators
- central sun tracking system
- steam header pipe
- solar energy receivers

- system piping for supply of water and steam
- MS and civil support structures
- valves and pressure gauges
- temperature gauges
- cooking vessels

Just think about the size of a solar steam cooker for cooking food for around 500 persons. Solar concentrators (5 pairs) each of 9.5 sq. mtr area would be needed.

Community Solar Cooker (for indoor cooking)

Any one would like to cook inside a kitchen only. Community based solar cooker is a good answer to meeting such a need. It is much like the dish solar cooker mentioned above. However, it is much bigger in size. This cooker is made of solar concentrator with a minimum of 7.0 and 9.5 sq. m. aperture area. It is simply known as a primary reflector and has an elliptical shape. Further, it is made of a large number of reflecting mirrors. These are supported with a rigid frame/structure to form a Scheffler (after the name of its inventor) reflector. The cooker is kept in the path of sun by a clock type tracking mechanism. It can be easily used to cook food for around 50-75 persons in the community kitchens especially at the religious places, ashrams, hostels and industrial canteens etc. The solar cooker of this type is put up on a properly designed civil structure. The secondary reflector is installed within the kitchen to cook food on a daily basis. It basically concentrates the rays on to the bottom of the pot/frying pan. Black paint is used to absorb the maximum possible heat much like in a solar box type cooker. A very high temperature of up to 400 is obtained which can be used to cook any type of food. Following few are some of the most important advantages of a community solar cooker:

- highly improved form of a box type solar cooker
- cooks much quicker

8.3 Basic knowledge about relevant glass and its use

The surface of the solar collector is covered by glass. It is made of tempered glass i.e. made of soda lime. Basically, glass of this type passes through the following few manufacturing steps:

- it is first cut to the size
- it is then heated to a very high temperature
- it is then very quickly brought back at the room temperature

Key properties of this type of glass also known as toughened glass are as under:

- low iron content (58 parts per million)
- anti-reflection coating treatment-i.e. decreases the reflection of sunlight
- high transmittance (>96%) i.e. allows maximum possible sunlight to pass through it

The main applications of the tempered glass are both for the solar photovoltaic and solar thermal device applications. Simply put, it is used as the front surface cover of a solar module besides that of a solar collector.

8.3.1 Painting of solar cooker and metal pot i.e. heat absorption, reflection

The colour of a material has a very great effect on the thermal properties of a material. It comes into play when the material is exposed to the solar radiation i.e. heat. The metal pots in a box type solar cooker for example are normally painted black. Remember the paint used should not be toxic (i.e.. a toxic paint may give off fumes even at the room temperature.

Just think of why you like the light coloured dresses in summer than the dark one's. Everything on which the sunlight falls absorbs heat from it. However, black surfaces absorb heat better than the light coloured and white surfaces. The same principle is at work in case of a solar cooker too.

That means it would give off even more fumes at cooking temperatures. It is also important that paints on pots are kept thin. The simple reason is that thick paints may lead to some insulation.

Short Answer Type Questions-Solar Thermal

Q. What is the basic difference between Solar Photovoltaic and Solar Thermal Technologies?
A. SPV systems produce electricity, while as thermal systems produce heat

Q. What are the different types of solar cookers available today in the market?
A. Box type cooking-(suitable for 1-5 persons)
Dish type cooking- (suitable for 10-15 persons)
Scheffler type model-(suitable for 1-50 persons)
Solar Steam model- (suitable for any number of persons)

Q. Does it take more time to cook food in a box type solar cooker?
A. Yes, it takes more time roughly of the order of 2-3 hours to cook in a box type cooker. While as, it takes just around 1-1/2 hours in case of dish and Scheffler type solar cookers

Q. Which one between a balcony and rooftop would be better space to mount a solar thermal system?
A. Roof as it is expected to receive open sunshine

Q. Name the three ways in which the heat normally moves
A. Conduction, Convection and Radiation

Q. Which is the most common application of solar thermal technology globally so far?
A. Solar water heating

Q.Why are the pots painted black in the case of solar cooking?
A. Black pots absorb the maximum amount of available solar radiation

Q. What is the material used to fabricate the metallic sheet of a dish solar cooker?
A. Aluminum

Q. What is the maximum temperature attained in the case of a box type solar cooker?
A. 150^0 C

Q. Do domestic solar water heaters and an electrical backup go together?
A. Yes, an electrical backup is generally provided with a solar water heater to take care of no sunshine days etc.

Q.Is an electric pump an important component of a thermosyphon based solar water heater?
A. No, it does not use any type of electric pump

Q. What is the maximum possible temperature with a thermosyphon type solar water heater?
A. Generally, it ranges between $60\text{-}80^0$C

Q. Where is the world's largest solar steam cooking system at work?
A. It is installed at Shirdi Sai Baba temple in Shirdi (Maharashtra) and is capable of cooking thousands of meals per day

Q. How long will the water heated by solar energy remain hot in the tank?

A. Hot water is generally stored in an insulated water tank. Thus water can remain hot without any major change in temperature for around 24 hours.

Simple Questions in Solar Thermal

Q 1. Calculate the minimum distance (s) between two rows of collectors by using the formula

D= LSin φ/Tan (66.5-latitude)

Here φ=Collector Tilt a)20 degrees and b) 24 degress

L=Collector length=2 m^2 (for a 100 LPD Solar water heating system)

Latitude=may be taken for two different locations i.e. Kanpur (26 degrees) and Kolkata (22 degrees)

Steps:

a) insert the respective values of tilt angle, collector length and latitude in the above equation as:

Case-I: D= 2 Sin 20/Tan (66.5-26)

Case-II: D=2 Sin 24/Tan (66.5-22)

Try to read the values of Sin and Tan values from a scientific calculator and then complete the calculation

Q 2. Calculate the roof area needed for installation of 2 solar water systems of 100 LPD capacity each

Steps:

a) A 100 lpd solar water heating system has a surface area of 2m x 1m=2m2

b) Nearly 75% (or 3/4th of the collector area is an additional area needed for a shadow free installation

Thus the total roof area needed = 2 m^2 + 0.75 x 2

=3.5 m^2

Q 3. Calculate the heat available in kcal/day by use of a solar hot water system of the following specifications:

Collector area available= 2 sq. m.

Capacity of the hot water system=100 LPD

Hot water temperature needed=60°C

Steps:

Use the following formulae

Heat available=Solar insolation x calorific value of the fuel x efficiency of electrical heater

Assume Solar insolation at the site=5.5 kWh/sq.m/day

Efficiency of solar water system=50% at 60°C

Heat available= 5.5 x 2x 860x 0.5= 4730 kcal/day

(here 1 kWh of electricity output is equal to around 860 kcalories)

Q 4. Calculate the savings in electricity consumption per day using the above data. Assume the ambient temperature to be 25°C

Steps:

Savings in electrical consumption per day=Capacity (LPD) x (temperature of hot water-ambient Temperature/(860 x efficiency of electrical heater)

=100 x (60-25)/(860 x 0.8)

=5.08 kWh/day

=5 kWh/day

Q 5. Calculate the heat available for a solar water system of 200 LPD capacity taking a collector area of 4 sq. m. Consider the hot water temperature requirement as 60^0C and ambient temperature as 25^0C

Steps:

Heat available= Capacity (LPD) x (temperature of hot water-ambient Temperature/(860 x efficiency of electrical heater)

=200 x (60-25)/(860 x 0.8)

=10.08 kWh/day

=10 kWh/day

Thus it is quite clear that as capacity of a solar water heater doubles, so does the heat available

Q.6 Calculate the cost of electricity saved at Rs. 5 per unit taking into account the electricity saving under Q.No. 4 above

Steps:

Take number of solar days in a year as 300 for a good sunny location like Delhi

Per unit cost of conventional power= Rs. 5 (for a location like Gurgaon)

Cost of electricity saved = Heat available x no.of days x cost per unit

= 10 x 300 x 5

= Rs. 15000/-

Q.7 Calculate the pay back period for a solar water heating system of 200 LPD capacity

A. Assume the cost of a 200 LPD system as Rs. 39000/- &

Per unit cost of electricity=Rs. 5

Pay back period= Cost of the system/Cost of electricity saved

= 39000/15000

= ~ 2.6 years

So a user can get back the cost of a 200 LPD solar water heater in less than 3 years.

Q.8 Calculate the maximum temperature of the water that can be obtained in case of a 500 LPD solar water heater. This is nearly equivalent to 10 m^2 of the collector area. Assume that it has to give hot water at 60^0C by supplementing/replacing the existing electric geysers

Steps
Average solar insolation available = 5.5 kWh/m^2
Temperature of hot water= 60^0C
Ambient temperature= 25^0C
Cost of electricity= Rs. 5
Efficiency of electrical heater=80%
Efficiency of solar hot water system=50%
Hot water requirement for a small hostel=500 LPD
Life of the system=15 years

Heat available = 5.5 x 10 x 860 x 0.5 kcal/day
=23650 kcal/day

Maximum temperature that can be
obtained= (23650/500) + 25^0C
= 72.3^0C

Q.9 Calculate the maximum quantity of water that can be obtained at 60^0C using the assumptive data presented in Q. 8 above

Steps
Maximum quantity of water that can be obtained at 60^0 C= Heat available /Temperature of hot water-ambient temperature)

= 23650/(60-25)
=675. 71 LPD

Q.10 Calculate the focal length of a parabolic dish solar cooker

Step
Use the following formulae

F= R^2/4D

Here F is the focal length
D is the depth of dish
R is the radius of its rim

a) Depth of the reflector measured along the axis of paraboloid from its vertex to the plane of rim=1.8478 times the focal length

b) Radius of the rim is equal to 2.7187 times the focal length

Q.11 Calculate the amount of energy that must be added to heat water from 50^0 F F (i. e. 10^0C) to 120^0F (i.e. 49 ^{0}C)

Steps

Use the following formulae to calculate the energy needed

$Q=C^* m^* (T_{out}-T_{in})$

Here

Q –amount of heat added in joules

C= specific heat of water i.e. 4.18 J/gm x^{0}C

m= mass of water

Tout= outlet water temperature (49^{0}C)

Tin=inlet water temperature

Use the density of water=1g/cm^3

(1gallon=3785 cm3=3785g

Thus Q=(4.18)*3785 x (49-10)

=632852 joules

Remember there are 1.055 x10^8 joules per therm=0.006 therms

Remember there are 3.600 x 10^6 joules per kWh

Thus 6, 30,000 J=0.18 kWh

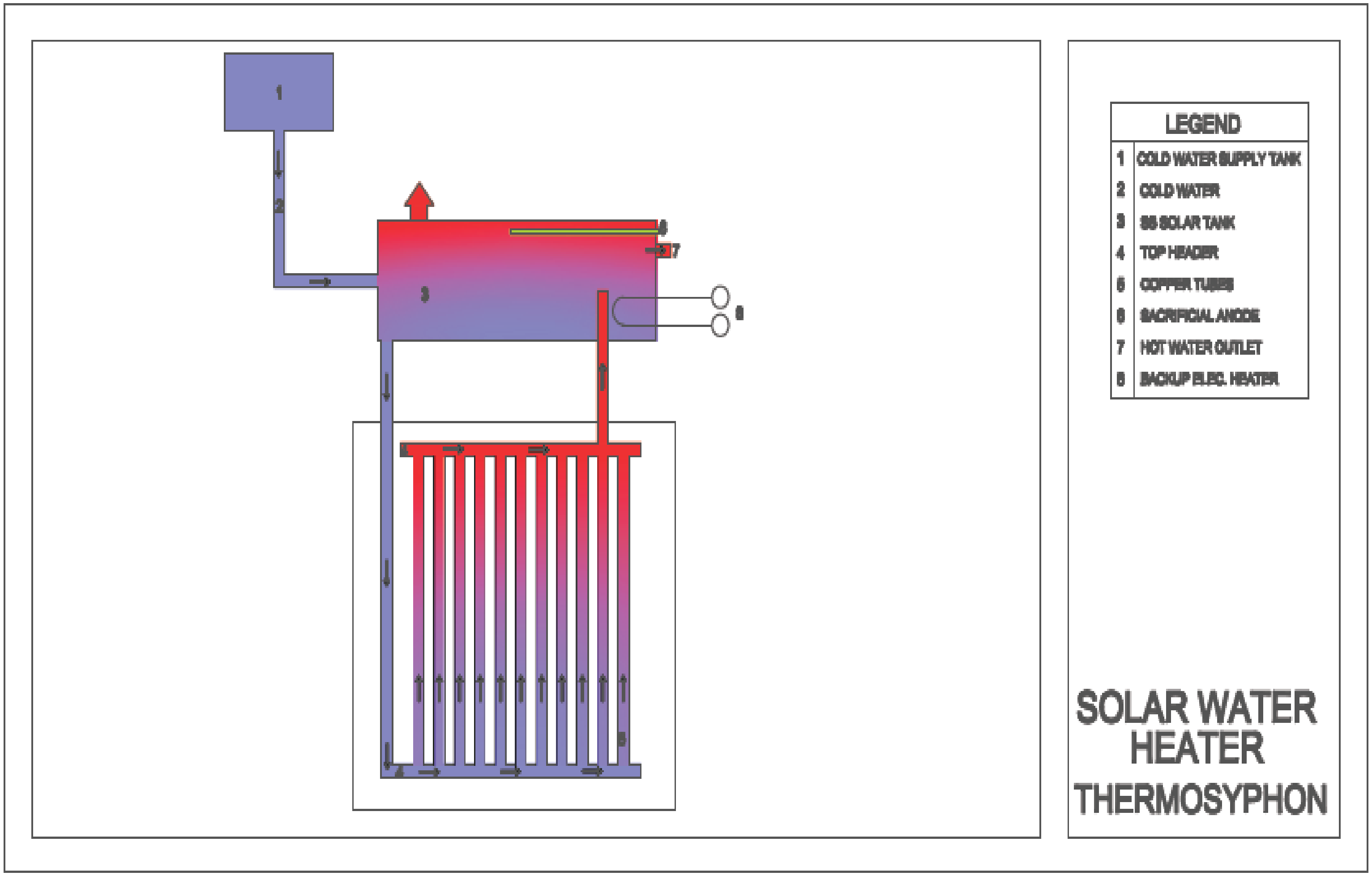
Tables: Symbols and sign convention for sun and related angles

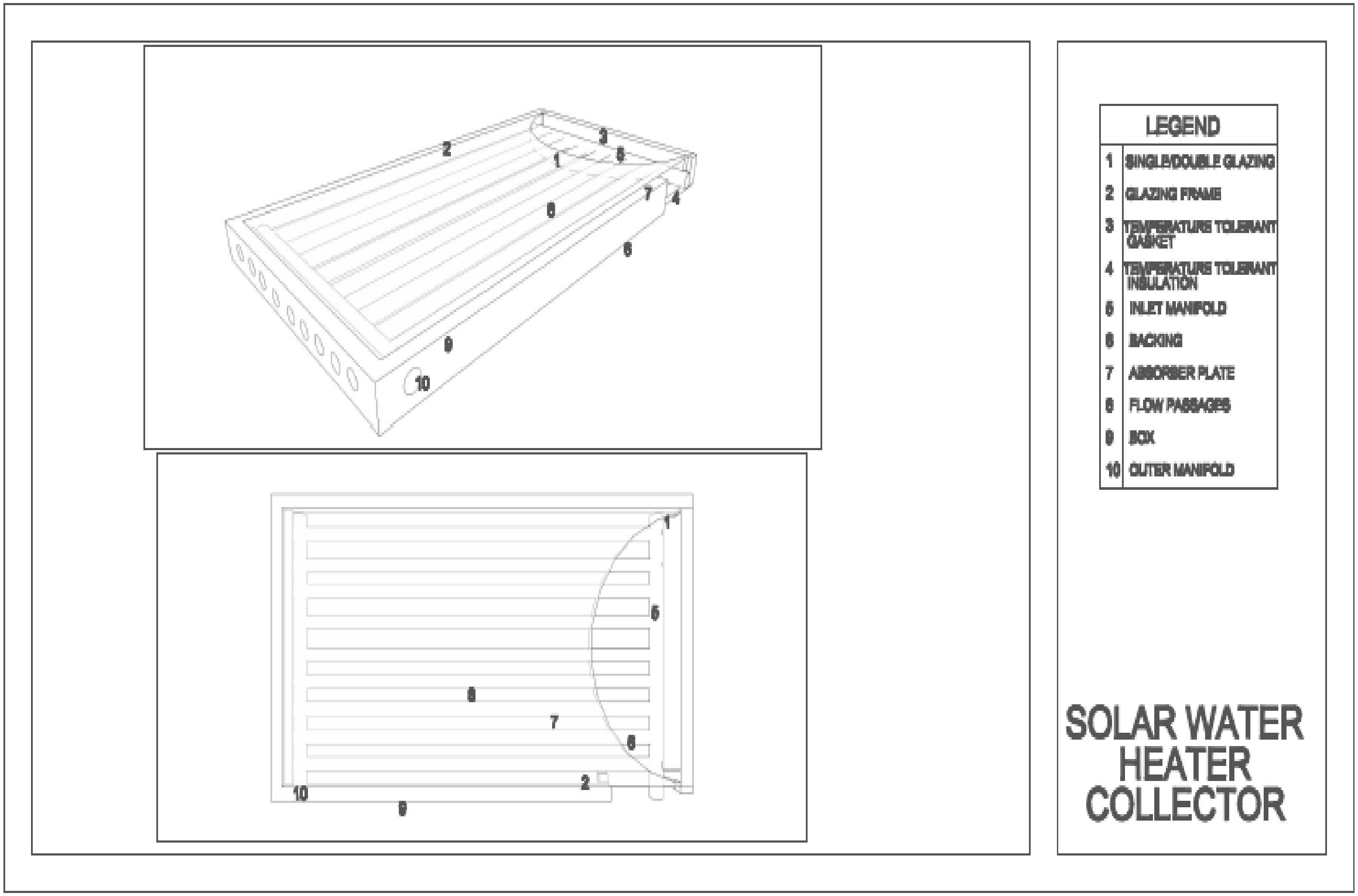
Quantity	Symbol	Range and sign convention
Altitude	α	0 to ± 90°
Surface tilt	β	0 to ± 90°; toward the equator is +ive
Azimuth (of surface)	γ	0 to 360°; clockwise from North is +ive
Declination	δ	0 to ± 23.45°
Incidence (on surface)	Θ,i	0 to + 90°
Zenith angle	Θz	0 to + 90°
Latitude	Φ	0 to ± 90°; North is +ive
Hour angle	ω	-180° to +180°; solar noon is 0°, afternoon is +ive
Reflection (from surface)	R	0 to + 90°
Solar radiation		
Global irradiance or solar flux density	G	W m-2
Beam irradiance	Gb	W m-2
Diffuse irradiance	Gd	W m-2
Global irradiation	H	J m-2
Beam irradiation	Hb	J m-2
Diffuse irradiation	Hd	J m-2
Atmospheric radiation		
Irradiation	Φ↓	W m-2

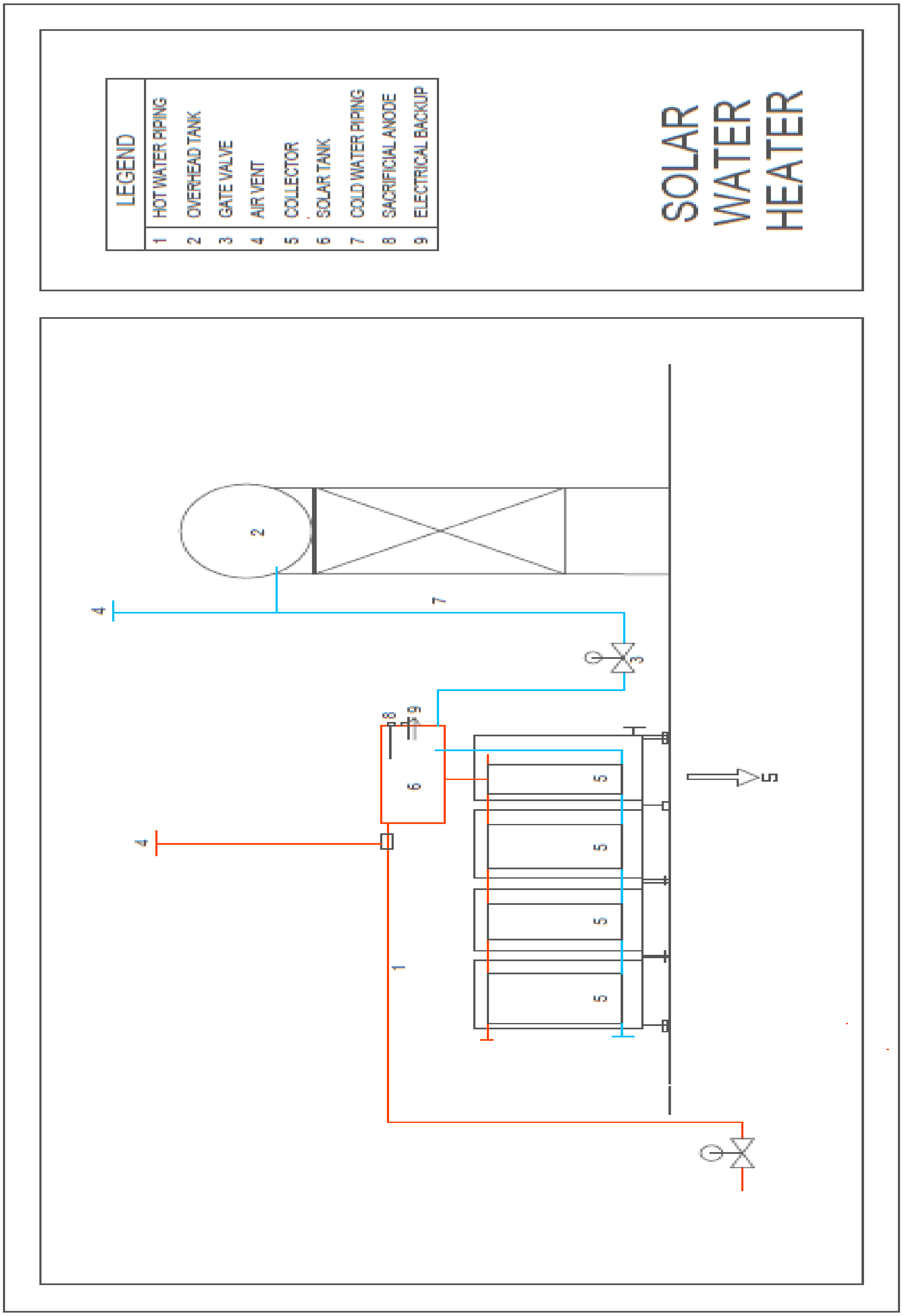
Table: Units and Conversion Factors

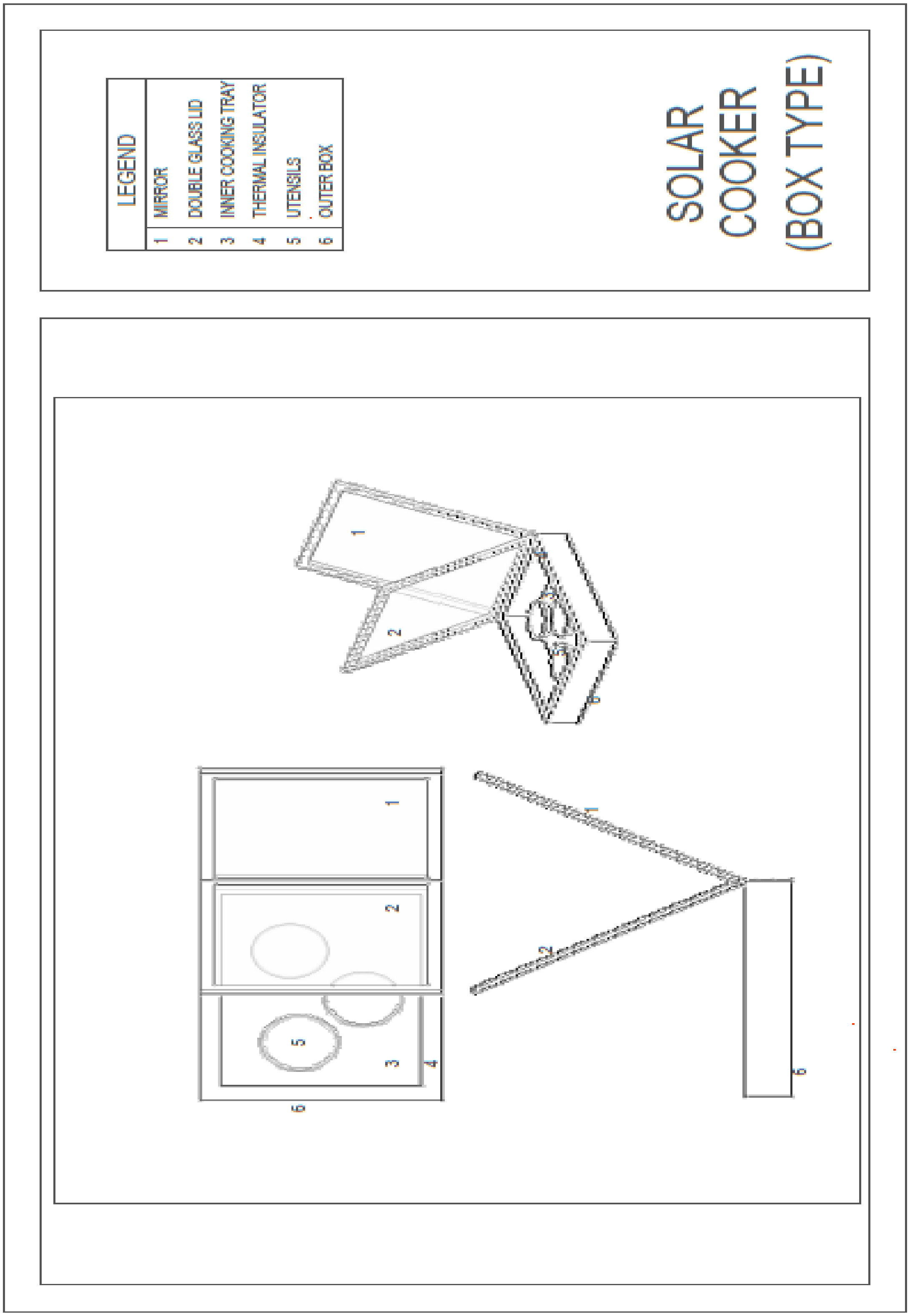
Multiply	by	To get
Calories	0.04	BTU (British Thermal Unit)
Watts	3.413	BTU/Hr
Watts/sq.m	0.317	BTU/(Hr)(sq.ft.)
Langleys	3.687	BTU/(sq.ft.)
Calories (cm) (sec)	13.272	BTU/(Hr.) (sq.ft.)
Langleys/minute	221.2	BTU/Hr.)/(sq.ft.)
Calories/Hr/sq.cm/Degree C	2.048	BTU/(Hr)/(sq.ft.)/Deg.F
kWh	3600	Kilojoules
kWh	860	Kilocalories (kcal)
kWh	3412	BTU
kWh	1.34	Horsepower-hours
Kilojoules (kj)	0.278	Watt-hours
Kilocalories	1.16	Watt-hours
BTU	0.293	Watt-hours
Horsepower-hours	0.746	kWh

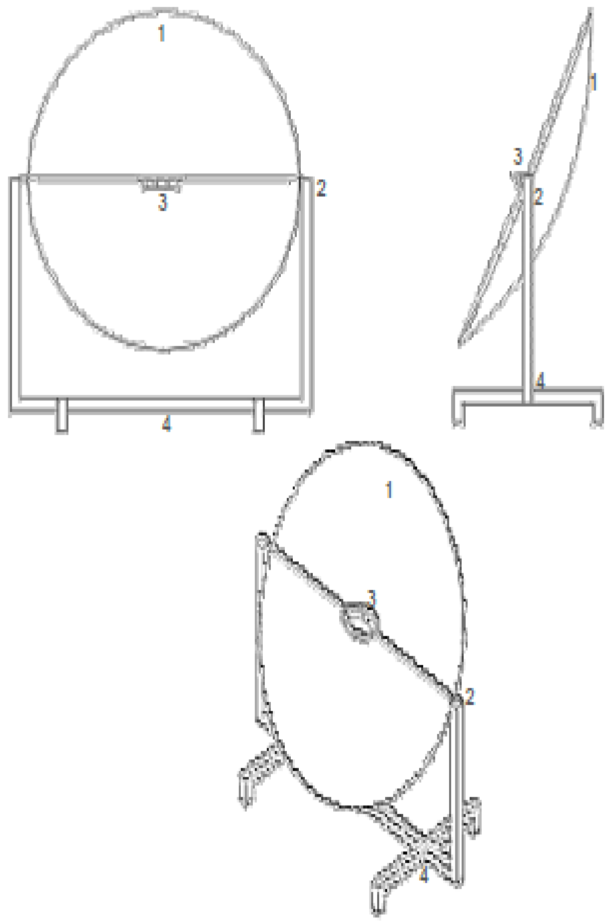
Drawing


1
2
3
4
5
6
7
8
LEGEND
1 COLD WATER SUPPLY TANK
2 COLD WATER
3 SS SOLAR TANK
4 TOP HEADER
5 COPPER TUBES
6 SACRIFICIAL ANODE
7 HOT WATER OUTLET
8 BACKUP ELEC. HEATER
SOLAR WATER HEATER
THERMOSYPHON


LEGEND
1 SINGLE/DOUBLE GLAZING
2 GLAZING FRAME
3 TEMPERATURE TOLERANT GASKET
4 TEMPERATURE TOLERANT INSULATION
5 INLET MANIFOLD
6 BACKING
7 ABSORBER PLATE
8 FLOW PASSAGES
9 BOX
10 OUTER MANIFOLD
SOLAR WATER HEATER COLLECTOR


LEGEND
1 HOT WATER PIPING
2 OVERHEAD TANK
3 GATE VALVE
4 AIR VENT
5 COLLECTOR
6 SOLAR TANK
7 COLD WATER PIPING
8 SACRIFICIAL ANODE
9 ELECTRICAL BACKUP
SOLAR WATER HEATER


LEGEND
1 MIRROR
2 DOUBLE GLASS LID
3 INNER COOKING TRAY
4 THERMAL INSULATOR
5 UTENSILS
6 OUTER BOX
SOLAR COOKER (BOX TYPE)



LEGEND

1	HIGH REFLECTIVITY (83.2%) ANODIZED ALUMINIUM REFLECTOR FITTED ON A SCIENTIFICALLY DESIGNED WIREFRAME TO MAINTAIN PARABOLIC SHAPE AND SHARP FOCUS.
2	LOCKING ARRANGEMENT FOR LOCKING THE DISK IN PLACE.
3	COOKING POT OR PLATE CAN BE PLACED HERE.
4	LIGHT WEIGHT/ STURDY FRAME.

SOLAR COOKER (PARABOLIC)

Part II- Practical Considerations
Solar Photovoltaic

Introduction

A solar Photovoltaic system works without making any noise or pollution.. This is because it has no moving parts at all. The power producing part i.e. the module is the most important part of this system. So, it makes sense to study this component in all possible ways. The practical units for this solar photovoltaic course curriculum mainly deal with the following:

- physical and Technical inspection of a solar module
- physical and Technical inspection of a battery
- technical inspection of CFL, Charge Controller, Inverter, LED driver etc.

Unit-I: Solar Module

Physical inspection of a Solar Module

A module consists of solar cells covered by a protective glass. It is just like the car windshield. The module remains outside for day and night. So, it gets dirty and needs to be cleaned regularly. It is very important to take a close look at the module. This is commonly known as the physical inspection of a module. The simple purpose is to know if any?

- dust is present on the module
- bird droppings are there
- cell is cracked or broken
- cell has turned brown
- any moisture is present inside
- shading is there (whether at any particular time of the day or always)
- shadowing is present (whether at any particular time of the day or always)
- frame is in its place
- junction box is properly screwed
- all the connections are tight

Key Conclusions:

Knowing the Physical & Technical Specifications

Design

A solar module is produced in a factory. It is generally made of single crystal and polycrystalline solar cells. These cells are encapsulated using stabilized polymer i.e. Ethylene Vinyl Acetate (EVA). The back cover of the module is made of Tedlar-polyster-tedlar. The glass through which the sunlight passes is made of toughened glass. The frame is made of anodized aluminum to mount the modules easily.

Specifications

A module manufacturer normally gives information both on the physical and technical specifications. These are generally called the module ratings. It is very important to know these specifications before doing some simple experiments on a solar module.

Table 1: Physical observations

Parameter	**Unit**	**Record these Values (as marked on the Module)**			
		5W	**10W**	**37W**	**50W**
Number of Cells	Nos.				
Dimensions (lengthxwidthxthickness)	mm				
Weight	kg				

Table 2: Electrical observations

Parameter	**Symbol**	**Unit of measurement**	**Record these values (as marked on the Modules of**			
			5W	**10W**	**37W**	**50W**
Open Circuit Voltage	Voc	V				
Short Circuit Current	Isc	A				
Maximum Power rating*	Pmax	Watt				
Minimum power rating *	Pmin	Watt				
Rated Current	IMpp	A				
Rated Voltage	VMPP	V				

* Under Standard Test Conditions (Irradiance 1000 W/m2, Cell temperature 25 degrees C, Air Mass 1.5)

Environmental rating

A module is placed outdoors. So, it gets exposed to all types of weather like for example Sun, rain, snow, dust storm etc. The module should be able to put up with these things. The module manufacturer gives the following type of ratings:

Table 3: Environmental tolerance

Parameter	Unit
Nominal operating cell temperature	45°C ± 2
Maximum allowed module temperature	-40°C to + 85°C
Relative humidity at 85	85%

Key Conclusions:

Connecting the modules in series and parallel arrangement

A solar module has two terminals. These are marked just like the positive and negative ends in an ordinary battery. The red colour wire is generally for the positive side and a black wire is for the negative side. Small systems like a home lighting system generally run on a 12 V battery. However, some other appliances may be working on 24 V. Simply put, two modules of 12 V are then to be joined in series. In a series connection, voltages add up keeping the current same as that for a single module. The opposite happens in a parallel connection of modules. Here the currents add up keeping the voltage same as that for a single module. It is interesting to note here that a standard battery is 12 V. That is why, if you use a solar module, 12 V would be the most common voltage. However, that does not mean that there can not be a different voltage. One can easily combine several modules to get a higher output voltage like 24V, 48 V etc., if, needed.

Try the following few steps

Items needed:

- Solar Modules (37 Wp-2 nos.)
- Multimeter
- Connecting wires
- Connecting pins

Step-by-step method

For series combination of modules:

1. Connect the positive terminal of one module to the negative of the second module or vice versa .
2. Now measure the current and voltage values at the remaining two terminals of solar module using a multimeter as shown below
3. Note down these values

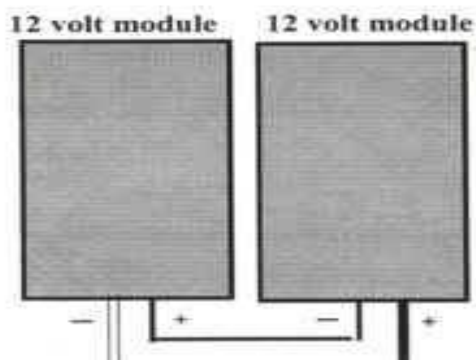


Figure 1 :

For parallel combination of modules:

4. Connect the positive of one module to the positive end of the second
5. Connect the negative of one module to the negative end of the second module
6. Repeat the measurement of current and voltage at the two ends with a multimeter
7. Note down these values
8. Mark up the difference in values of I and V under a) series and b) parallel modes

Data Table:

Module S. NO	Module Capacity (Wp)	Individual Voltage (V)	Individual Current (A)	Series Connected Voltage Current	Parallel connected Voltage	Current
1						
2						
3						
4						

Key Conclusions:

Measuring the Open Circuit Voltage and Short Circuit Current of a Module

A solar module is expected to run a load. Be it a lantern or a home lighting system. So, when the load is being run, voltage of the module will decrease. Now if, no load is being run, the voltage will not decrease. Instead, it will be the maximum voltage that a module can produce under a clear sun. This value of voltage (minus any load) is known as the Open circuit voltage or simply Voc. In the same way, Short circuit current (Isc) is the maximum current than a module can produce without any load present. Voc is measured when the resistance is set at infinity (open circuit current=zero). Isc is measured when the resistance is set at zero (Voltage=zero).

Items needed:

- Solar Module
- Multimeter
- Connecting pins

Step by Step method

1. Take the module out in the Sun
2. Do not connect the module to any load
3. Set the multimeter in the current mode
4. Touch the probes of the voltmeter directly to the modules positive and negative terminals
5. Record the voltage on the multimeter (that is set in 'voltage mode', thus behaving like a voltmeter)
6. Change the position of probes in the multimeter from voltage mode to current mode
7. Now touch the probes of ammeter (multimeter in 'current mode') directly to the modules positive and negative terminals
8. Record the current

   Note: Don't measure the voltage while multimeter is set in 'current mode' .

Key Conclusions:

Knowing the values of minimum and maximum values for a resistor
The Current-Voltage (I-V) plot of a solar module gives knowledge of various important parameters. In general, variable resistance method is used for the purpose. As the resistance is increased from zero to infinity, current and voltage are measured. The minimum and maximum resistances required from the variable resistor are:

Step-by-step method

1. Make a note of the Voc and Isc measured in the last activity

2. Calculate the Rmin value by using the formulae- Rmin= Voc/4Isc

3. Calculate the Rmax value by using the formulae-Rmx=4 Voc/Isc

Key Conclusions:

Plotting the Current-Voltage characteristics of a Solar Module
The current-voltage (I-V) of a PV module is based under the Standard Test Conditions (STC). The STC condition on a clear day is taken as 1000 watts of solar energy per square metre (1000 W/m2 or 1 kW/m2). It is also known as one sun or peak sun. Current expressed in amperes is plotted on the Y-axis and Voltage in volts is shown on the X-axis. The power available from a module at any point on the curve is just a simple product of current and voltage at that point. It is expressed in terms of Watts (W= VxA). There is a point on the knee of the I-V curve, where the maximum power output is present.

Items needed:

- Solar Module
- Voltmeter (multimeter in 'voltage mode')
- Ammeter (multimeter in 'current mode')
- Variable resistor
- Connecting wires
- Pyranometer/Suryamapi
- Surface temperature thermometer

Measurement conditions

1. I-V curves should generally be measured under clear sky and within two hours of solar noon to obtain irradiance values near the standard test condition irradiance of 1000 W/m2

2. Cell temperature should be allowed to stablise before being measured

3. During the measurement, the I-V curve, data points should be taken as quickly as practical to minimize the effect of a change in the irradiance level or a change in the cell temperature during the test period

Step-by-step method

1. wire the circuit as shown in the figure
2. tilt the module towards the sun to maximize irradiance
3. record the Voc and Isc values
4. on the data sheet, record the irradiance reading and cell temperature
5. adjust Rvar to zero ohms or short-circuit (voltage becomes zero)
6. record the short circuit current IsC
7. increase the amount of resistance, Rvar, until the voltage reading is approximately ¼ th the estimated Voc. (for example, if, the estimated Voc is 24 volts, adjust Rvar until the voltmeter reads 6 V)
8. record the current and voltage readings
9. increase Rav until the voltage is increased by approximately 2 V
10. record the current and voltage readings
11. repeat steps 8&9 until the maximum Rvar is reached or the current becomes zero
12. Disconnect Rvar from the test circuit (current becomes zero)
13. Plot the current and voltage values thus recorded

I-V Data Sheet

Module Type:
Module Model :
Module Serial No.:

Voltage (V)	**Current (amperes)**	**Power (Watts)**
0	Isc=	
Voc=	0	

Pmax (Watts)	
Vmp (Volts)	
Imp (amperes)	

Key Conclusions:

Plotting Current-Voltage characteristics at different values of solar Irrdiance

The I-V characteristic of a solar module depends on the solar irradiance (sunlight) incident upon the module. It also depends on the operating temperature of the cells. That is why these parameters should also be measured. Sunlight changes throughout the day. It has the maximum value at noon time. Each PV module has a characteristic I-V output for a specific cell temperature and irradiance level.

Items needed:

- Solar Module
- Voltmeter
- Ammetre
- Variable resistor
- Connecting wires
- Pyranometer/Suryamapi
- Surface temperature thermometer

Step-by-step procedure

1. wire the circuit as shown in the figure
2. tilt the module towards the sun to maximize irradiance
3. record the irradiance reading and cell temperature, for the tilt of module
4. adjust Rvar to zero ohms or short-circuit (voltage becomes zero)
5. record the short circuit current IsC
6. increase the amount of resistance, Rvar, until the voltage reading is approximately ¼ th the estimated Voc. For example, if, the estimated Voc is 24 volts, adjust Rvar until the voltmeter reads 6 V
7. keep the pyranometer sensor on the module surface in the path of sun
8. note down the value of solar radiation (in W/m2) or Mw/cm2
9. record the current and voltage readings
10. increase Rav until the voltage is increased by approximately 2 V
11. record the current and voltage readings against different values of solar radiation
12. repeat steps 8&9 until the maximum Rvar is reached or the current becomes zero
13. disconnect Rvar from the test circuit (current becomes zero)
14. plot the current and voltage values thus recorded on a graph paper

I-V Data Sheet

Module Type:
Module Model:
Module Serial No.:

Solar Irradiance (W/m2)	**Voltage (V)**	**Current (amperes)**	**Power (Watts)**

Pmax (Watts)	
Vmp (Volts)	
Imp (amperes)	

Key Conclusions:

Measuring the effect of Cell temperature on the Current-Voltage characteristics
As cell temperature increases, current increases slightly. However, voltage decreases more . The net result is reduction in power. Cell temperature is measured by placing a surface temperature probe or sensor at the back surface of the module.

Items needed:

- Solar Module
- Voltmeter (multimeter in 'voltage mode')
- Ammetre (multimeter in 'current mode')
- Variable resistor
- Connecting wires
- Pyranometer/Suryamapi
- Surface temperature thermometer

Step-by-step method

1. Wire the circuit as shown in the figure
2. Tilt the module towards the sun to maximize irradiance
3. On the data sheet, record the irradiance reading and cell temperature, for the tilt of module
4. Adjust Rvar to zero ohms or short-circuit (voltage becomes zero)
5. Record the short circuit current IsC
6. Increase the amount of resistance, Rvar, until the voltage reading is approximately ¼ th the estimated Voc. For example, if, the estimated Voc is 24 volts, adjust Rvar until the voltmeter reads 6 V
7. Keep the temperature probe at the back surface of the module
8. Note down the temperature
9. Record the current and voltage readings
10. Increase Rav until the voltage is increased by approximately 2 V
11. Record the current and voltage readings against different values of temperature
12. Repeat steps 8&9 until the maximum Rvar is reached or the current becomes zero
13. Disconnect Rvar from the test circuit (current becomes zero)
14. Plot the current and voltage values thus recorded on a graph paper
15. Note the power output values corresponding to Voc and Isc

I-V Data Sheet

Module Type:
Module Model:
Module Serial No.:

Module back surface temperature (degrees C)	**Voltage (V)**	**Current (amperes)**	**Power (Watts)**

Pmax (Watts)	
Vmp (Volts)	
Imp (amperes)	

Key Conclusions:

Basic Introduction and Testing of Electronic components

Most of the solar photovoltaic systems use charge controllers. These circuits are fabricated on the Printed Circuit Boards or simply the PCB. The PCB itself has several components (like resistors, capacitors, transistors, diodes and integrated circuits etc.) joined together. The ratings or the values of these components change from one solar device application to the other. However, their working principle remains more or less the same. This section deals with the simple testing methods of these components as under

Resistors

Resistance is just like a hole in a bucket of water. More water will come out of the bucket if a hole is big. Less water will come out if, the hole is small. The simple reason is that a small hole will resist the flow of water more than a large one. Thus, a material with a high electrical resistance may be thought of as a small hole in a bucket. Metals generally have a low resistivity allowing the electricity to pass through them. Different metals have different resistivity. Take for example copper. It has a low resistivity in direct comparison to iron with a high resistivity. That is why copper wire is used in the wiring cables. The simple unit for measurement of resistivity is Ohm. The resistance of a given material depends upon its length (l) and the area of cross-section (a). Increase in the length of wire increases the resistance. While as, increase in thickness of wire decreases the resistance of the wire.

Resistors can be divided into the following two types mainly:

- Fixed resistors
- Variable resistors

The fixed resistor is further divided as:

- Wire wound resistor
- carbon resistor
- metal compostion
- oxide coated

Colour code in resistors

The resistor colour code is being used in both the electronics and electrical industries. It represents the value of a resistance. It is measured in Ohms as per the well known Ohms law (R=V/I) . The first two colour bands indicate a number. The third colour band indicates the multiplier or in other words the number of zeros. The fourth band indicates the tolerance of the resistor +/- 20%, 10% or 5%. In most of the cases, there are four colour bands only. Table 1 shows the values of the colour band resistors as under:

Band colour option	**Band 1 value**	**Band 2 value**	**Band 3 value**	**Multiplier value for Band 3**	**Band 4** **Value Tolerance**
Black		0	1	1	
Brown	1	1	1	10	
Red	2	2	2	100	
Orange	3	3	3	1000	
Yellow	4	4	4	10000	
Green	5	5	5	100000	
Blue	6	6	6	10,00,000	
Voilet	7	7		100, 00,000	
Gray	8	8		100,000,000	
White	9	9		1000,000,000	
None					20%
Silver					10%
Gold					5%

Activity: Calculate the R-value of various resistors on the basis of above Table

Testing of a Resistor

It is basically related to its being open. If a resistor becomes open, then its resistance increases very much. That also means it will pass no current. A simple multimeter can check a resistor. If, it is open, then it shows a resistance much higher than its rated value. Do not touch the lead of a multimeter while checking the resistance value

Activity: Measure the R value of various resistors using a multimeter

Capacitor

A capacitor is basically used to store electricity in the form of an electrical charge. The basic formula related to the capacitors is C=QV (Q is the amount of charge, V is the voltage). Capacitance is measured in Farads. The most common types of capacitors are:

- air
- mica
- paper
- ceramic
- electrolytic

Colour coding of capacitors

Colour	Digit A	Digit B	Multiplier D	Tolerance (T) >10 pf	Tolerance (T) <10 pf
Black	0	0	x1	±20%	±2.0
Brown	1	1	x10	±1%	±0.1%
Red	2	2	X100	±2%	±0.25
Orange	3	3	X1000	±3%	±3%
Yellow	4	4	X10000	±4%	±4%
Green	5	5	X100000	±5%	±0.5%
Blue	6	6	X1000000		
Voilet	7	7			
Gray	8	8	x0.01	+80%, -20%	
White	9	9	X0.1	±10%	±1.0
Gold			X 0.1	±5%	
Silver			0.01	±10%	

Testing of a capacitor

A simple ohm meter can test a capacitor easily. Choose megaohm range while testing a capacitor.

Put across the lead of ohm meter across the two leads of the capacitor. A good capacitor would show less resistance in the beginning and will go up by and by. If, ohmmeter reading shows a zero value, then it means it is short circuited. In case, the ohm meter needle shows the high resistance value very suddenly, it means capacitor is in an open circuit condition. This type of testing is done only for electrolytic capacitors. Rests of the capacitors are checked by a capacitor meter.

Diodes

These are normally made of semi conducting materials like Germanium and Silicon. n-type and p-type diodes are the most common one's. A diode is generally used to make the current flow in one direction only. It is often used between a battery and solar module. It allows a battery to get charged by a module during the day. However, it stops the current from flowing from battery to the module at night. The other important use of diode is to change AC into DC.

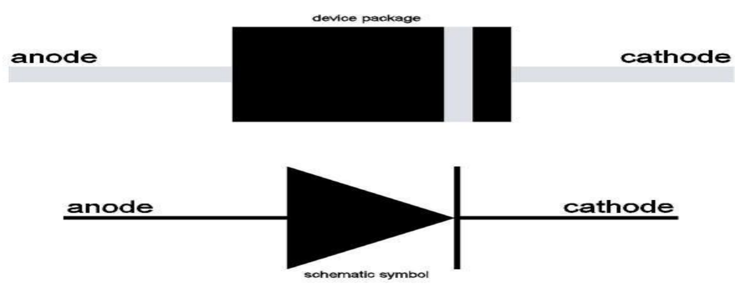


Figure 2 :

Diode symbol-

Brief idea about wire sizing

Electric current is carried through the wires. It is very important to choose a right size of the wire. Such a size is normally given in terms of mm2. This measurement is in fact the cross-sectional area of the wire. The larger that area the higher the current it can carry. Now think if, a wire size used is small for the amount of current passing through it, it can result in:
a) overheating
b) fire
c) risk to the human life

Table below gives a sample idea about the PVC insulated multistranded copper conductor as under:

S.No.	Nominal Area (sq.mm.)	Number and Size of Wire	Current Carrying Capacity (amps)	Remarks
1.	1.00	14/0.3 mm	11.0	It is quite clear that more the nominal area, higher is the current carrying capacity of the wire
2.	1.50	22/0.3mm	13.0	
3.	2.00	28/0.3 mm	15.0	
4.	2.50	36/0.3mm	18.0	
5.	4.00	56/0.3mm	24.0	

Remember household circuits are often wired with two different types of wires i.e. 12 gauge and 14-gauge. The 12 gauge wire has a diameter of 1/12 inch and the 14-gauge wire has a diameter of 1/14 inch. Thus a 12-gauge wire is wider than a 14-gauge wire. It simply means that a 1 2 gauge wire will allow a larger current to pass through it. It is just like water running out of a wide pipe. The 12-gauge wire is used in such circuits, as are protected by 20-amp fuses and circuit breakers. While as the 14-gauge wire finds use in such circuits, as are protected by 15 amp fuse and circuit breakers. The simple reason is that a 12-gauge wire offers lesser resistance to flow of an electric current than a 14-gauge wire.
Note, in an electrical system, the wire should not be sized with voltagr drops exceeding 3%. For a 12V system, the maximum voltage drop should be less than 12 (V)x 3%=0.36 V. There are standard tables available for the purpose of choosing a right wire size.

Testing of Diodes

A diode has a cathode (negative) and an anode (positive). The positive probe of the ohm meter is put on the cathode and negative probe of the ohm meter on the anode. The needle of the meter shows a deflection thus indicating resistance. Reverse these connections now. No such deflection is noticed.

Checking of Zener diode

A zener diode shows just the opposite reading in comparison to the other diode types. This simply means that when the positive probe of the ohm meter is put on the cathode and negative probe on the anode, there is no deflection as such. The reverse is also true. It simply happens because cathode is positive in a zener diode and anode is negative.

Transistor

It is an electronic device which controls the flow of an electric current. It has got at least three electrodes. Transistor is made of p and n type materials. It has got a P-n-p junction. The first part i.e. the base acts as an emitter thus producing charge. The second part is known as collector. It collects the charge emitted. In between these two junctions is base. It can either be a p-type or a n-type. The base controls the amount of charge in the collector. A transistor is mainly equivalent to two diodes. The one on the left side is known as emitter base diode and the one on the right side is base collector diode. It is possible to combine P-N and N-P junctions in two ways. A transistor is basically of two different types namely:

a) N-P-N
b) P-N- P

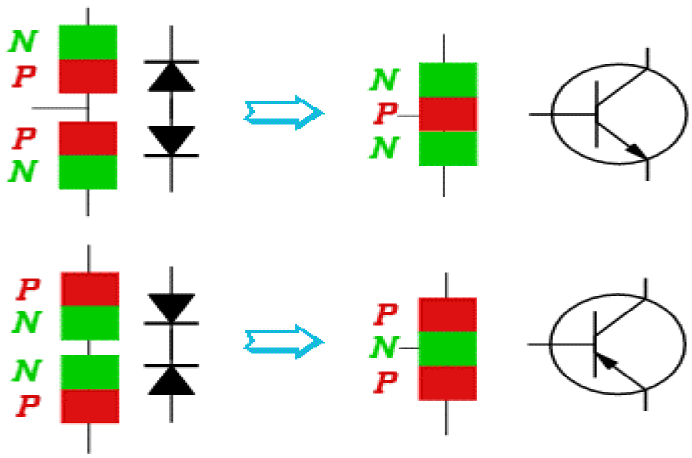


Figure 3 :

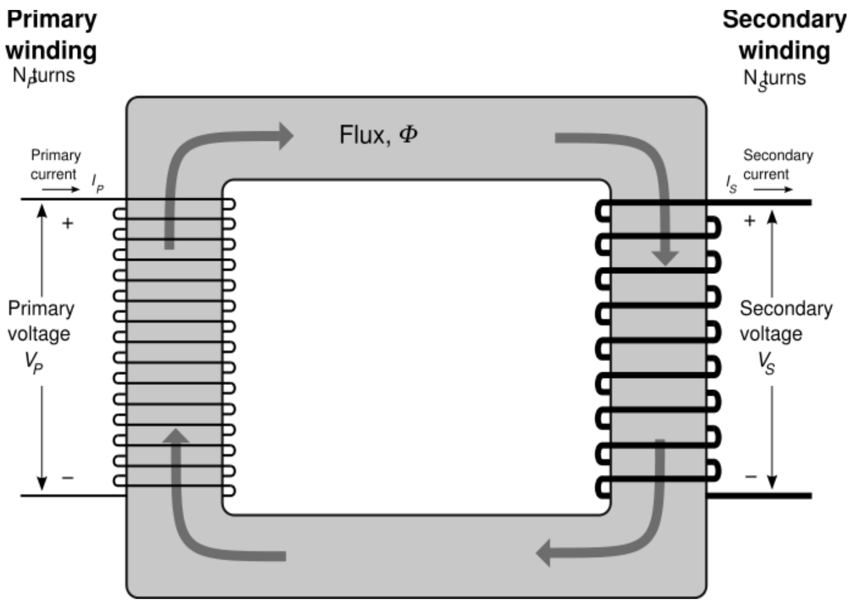
Transistor testing

NPN

- take an ohm metrer. Place the negative probe of the metre on the base and positive probe on the collector.
- the needle of metre will show some deflection thus indicating resistance
- remove the positive probe from the collector and place it on the emitter
- it will show the deflection thus indicating some resistance
- now place the positive probe on the base and negative probe on the collector
- there will be no deflection of the needle
- now keep the positive probe on collector, negative probe on emitter followed up by poisitive probe on the emitter and negative probe on the collector
- in both these cases, no deflection of the needle will take place

PNP

- keep the negative probe of an ohm metre on the base
- keep the positive probe of an ohm metre on the collector
- notice if, there is any delection- there is none
- now keep the positive probe on the base and negative probe on the collector and notice if, there is any electric current in the process



- the needle shows some deflection thus indicating some resistance
- now keep the negative probe on the emitter-the deflection is there

Transformer

A simple single phase transformer is made of two electrical conductors. These are commonly known as the primary coil and secondary coil. The primary is fed with a varying alternating electric current. It then creates a varying magnetic field around the coil. In practical transformers, the primary and secondary conductors are coils of wire usually copper. The high current-low voltage windings have fewer turns of wires. The high voltage-low current windings have more turns of wires. Step up- the secondary has more turns than the primary. Step down-the secondary has fewer than the primary. Core is of great importance in a transformer. Ferrite core is the best suited. Transformer is essentially used to increase voltage in an inverter circuit

Figure 4 :

Relay

It is simply a switch which is under the control of another circuit. Historically, electric relays were made with electromagnets. These continue to be in use today as well. However, in some cases, solid state relays are now being used. The key difference is that electromagnetic relays have moving parts. There are no such moving parts in the solid state relay. A relay can control an electric output, which is higher than the electrical input that it receives. Relays can turn on and off in response to things like, a current overload, irregular current etc.

Testing of a EM relay

- Apply 12 V input to the relay and see if, gets ON or not
- At times, a relay may get ON, but may fail to develop a contact due to a loose held spring

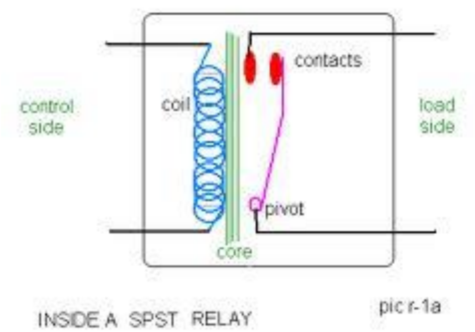


Figure 5

- Check the relay and change if, defective
- At times, low voltage from the battery may fail to switch on a relay and light does not glow
- The contact of relay may get dirty or a capacitor connected in parallel with it may get damaged-then a chattering sound may be heard
- Change the relay quickly

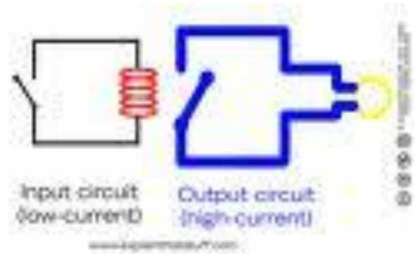


Figure 6

MOSFET

A MOSFET is a semiconductor device.It is a device used to amplify or switch electronic signals. It can be thought of as a transistor that is controlled by voltage rather than current

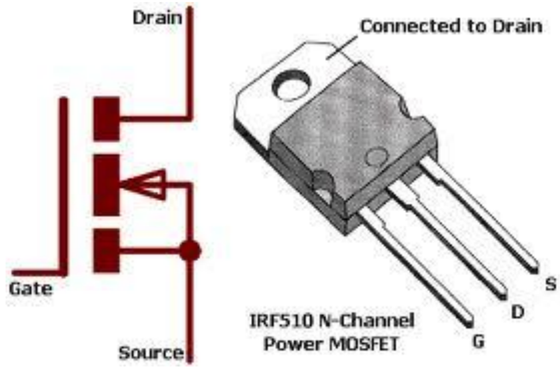


Figure 7:

Opto-Coupler

There are situations where signals and data need to be transferred from one sub system to another within a piece of electronic equipment. It can even be from one piece of equipment to the other without making a direct ohmic electrical connection. An auto coupler can do this task very well. It typically comes in a small 6-pin or 8-pin IC package. These are mainly a combination of two distinct devices i.e.an optical transmitter, typically a gallium arsenide based LED. The second part is an optical receiver such as a phototransistor. These two are separated by a transparent barrier. It stops any flow of current but does allow the passage of light

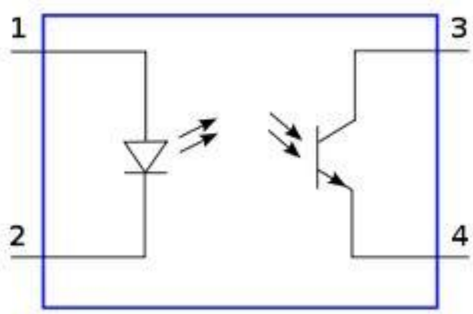


Figure 8:

Drum coil/Inductor coil

It is a coil for producing a high voltage from a low voltage source. It stores energy in the form of a magnetic field. The simplest form of an inductor is made of a wire loop or coil. The inductance depends directly on the number of turns in the coil, radius of the coil. It also depends on the type of material around which the coil is wound

Micro Controller IC

It is a small computer on a single integrated circuit. It can be thought of as a miniaturized electronic circuit that combines a number of electronic components. These mainly include the resistors, capacitors, transistors and diodes into one small piece

Driver circuit

It is an electrical circuit or other electronic component used to control another circuit or other component, such as a high power transistor.

Inverter Circuit

It is an electrical device which converts direct current (DC) into alternating current (AC)

Printed Circuit Board

Semiconductor components are normally mounted on the PCB's. This is because the electrical paths on a PCB are perfect for the needs of most of the semiconductors. It thus offers conductive pathways, tracks or traces etched from copper sheets laminated onto a non-conductive substrate

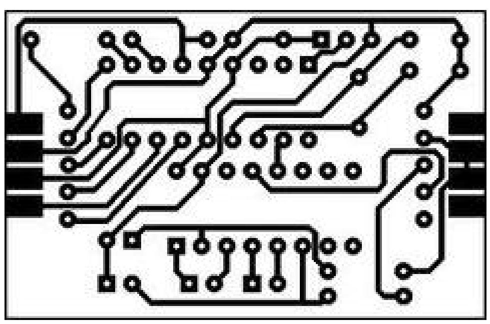


Figure 9:

Switches and Sockets

Switches and sockets are an important part of any electronic equipment. These are available in several types. Switching is a simple process of making or breaking an electric circuit. It is also a process of making a choice between the multiple circuits.

Light Emitting Diodes

It is simply a semiconductor diode that emits light when voltage is applied. It basically emits a narrow spectrum of light

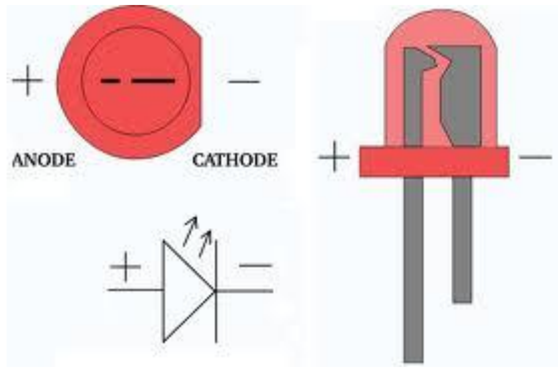


Figure 10:

Activity II- Demonstration of different models of the following few lighting systems:
a) Solar Lantern (individual charging)
b) Solar Lantern (Centralised charging)
c) Solar Home System

Physical appearance

Solar lantern is available in two different models. These use CFL and LED's as the lighting source. Both these models will be made available for the training purpose. Similarly, solar home system comes in several models. Crystalline silicon modules together with thin film amorphous silicon module are to be demonstrated alongwith:

- batteries of different types (sealed maintenance free-lead acid battery, NiMH Lithium ion battery batteryl)
- lamps of different types (Compact fluorescent lamp, Light Emitting Diodes)
- junction boxes of CFL and LED lanterns
- all electronic and electrical components

The solar modules of different capacities have already been dealt with in the beginning. So, it is intended to demonstrate the physical form of the following:

- sealed maintenance free batteries (4.5 Ah, 7 Ah)
- low maintenance free batteries (40 Ah)
- components on the PCB assemblies of solar lantern
- electronic components on the PCB assembly of charge controller for solar home system

Table below shows the upper and lower charging voltage limits for a standard 12 V battery:

Parameter	Value
Rated Voltage	12 V
Over charge protection	14.4 ±0.3 VDC
Over discharge Cutoff	11±0.3 VDC
Over discharge resume	12±0.3 VDC
Over Voltage cutoff	16.5 VDC
Over Voltage resume	15.0 VDC
Voltage drop (input to battery)	0.5 VDC
Voltage drop (battery to load)	0.2 VDC
No load current draw	Below 5 mA

Circuit assembly & testing

This activity is planned to be divided into the following few sub-activities:
a) circuit assembly of lamps and charge controllers, Lanterns
b) circuit testing of lamps and charge controllers (home lighting system)
c) installation of a solar lantern (both models included)
d) installation of home lighting system
Brief description of these activities for practical consideration is as under:

Circuit assembly

It would mainly deal with knowing the components and parts of solar circuits. These mainly include the following few:

- Resistances
- Capacitors
- Diodes
- Transistors
- Heat sinks
- Transformer
- Printed circuit boards
- Integrated circuits
- Jumper wire
- Choke coil
- Fuse
- Male and female connectors

The circuit assembly can take place properly if, one is aware with the use of each of these components, location and importantly, the assembly technique. To carry out this activity, it is useful to keep the following few tools at hand:

- Assembly jigs

Wire cutter

- Wire strippers
- Soldering iron and wire

Circuit Testing

- The above mentioned component circuits are commonly tested. Key objective of testing circuits is as under:
- ensures correct battery consumption
- ensures longer life of battery and CFL tubes
- ensures that the battery does not get overcharged/deep discharged
- Following three type of circuits are to be tested as a part of the practical training:
- Lantern circuit- related to testing of frequency, current and voltage settings, under/over charge settings
- Inverter circuit (lamp)-related to testing of frequency, current and voltage setting
- Charge controller Circuit-under/over charge setting
- Protection testing –(short circuit, reverse current flow)
- Remember to keep a multimeter at hand, power supply, tools and soldering iron for testing of the above mentioned circuits

Testing and Repair of an Inverter

Defect	**Solution**
Tube is not working	Take out the lamp from the charge controller and connect it directly to a battery Check the battery voltage, it should be 12 V Check the ON/OFF Switch to see if, it is damaged Check the fuse and replace a defective one by a 1.5 A fuse Check all the connections of tube light Check the battery polarity
Fuse is burnt and lamp is not glowing despite taking measures mentioned above	Either one or both the transistors of the circuit may be faulty Take these out from the circuit and replace by new one
Fuse burns every now and then	Capacitor may be leaking (2.8 kpf/2B), replace it Check the choke and transistor to see if, these have got too hot If so, replace these
Light is glowing with a medium intensity	Replace both the lamp holder and lamp
Tubelight is not working and circuit is drawing some current	Transformer may be defective, replace it along with a new circuit

Charge Controller Circuit description

A. Charging circuit

1. Charging circuit-green LED glows
2. Limits the current of resistance R1 (2K2)
3. Battery gets voltage from the solar panel via diodes D1 and D2
4. Battery starts getting charged after getting full voltage

B. Load circuit

1. The positive supply of the battery goes to common C contact via switch and fuse
2. If, battery is okay, then relay's C and N/C contact are connected
3. In this way, the battery supply is available at the load terminal
4. Simply means that the lamp will glow, if, it is connected

C. Control circuit

1. Control circuit gets the supply directly from diode D2
2. Reference voltage is set via R2, D3 and P1
3. R3, R4, R6, R7, R8 are voltage dividers, which means that battery voltage can be measured
4. On 16 pin nos. 6&7, both rising and falling voltages can cause yellowing (i.e burning) of pin no.1
5. LED burns at a voltage of 11.8 V
6. When the battery voltage reaches near 11.0 V, according to voltage on R3 and R4, then it switches on transistor Q2.
7. The coil of the relay gets a supply, then the relay current goes through contact C or N/O
8. The battery supply does not reach the load now and red LED strarts glowing

Broad Parameters of Charge Controller

1. Operating Voltage- 10-20 VDC
2. Nominal Voltage- 12 VDC
3. Current rating-Maximum of 3 amps in solar lantern and 5 amps in home lighting
4. Low battery cutoff-11 V

Testing and Repair of a Charge Controller

Defect	**Solution**
Charging indicator does not glow	Check the connections of Module, Charge Controller and Battery Check the polarity of the lead Check if, LED is okay
Charging indicator is ON, but battery is not charging	Check the blocking diode

Defect	Solution
	Clean the battery terminal and reconnect again
LED glows again and again on low voltage	Battery is not fully charged More load connected Pre-set adjustment not proper, Set it at 2.5 V, when battery voltage reaches 12 V
Tubelight terminal not getting the power supply, even when the battery is okay	Open the Controller to check fuse May be faulty due to overloading Check the relay contact and clean it Relay is getting hot, means transistor B-D 140 is shorted, replace it Check the toggle switch and replace Check the fuse and replace it

Installation and commissioning of solar modules and arrays could be included.
It has been largely included in the theoretical portion i.e. Part-I of the course content e.g. points like type of roof, direction of installation, selection of site and other related dos and donts. ?

Installation of the Solar lighting system

This practical activity involves installation of the following:

- Solar Lantern (in an individual mode)
- Solar Lantern Charging Station
- Solar Home System

a) Lantern-connecting together a solar module and lantern
b) Solar Lantern Charging station- connecting together of modules, junction boxes & lanterns
c) Solar Home System-connecting together a module, tubular battery, charge controller and lamps

Method for replacing the Luminiare PCB

a. Remove the acrylic cover carefully

b. Remove the CFL lamp and keep it in a safe place

c. Remove 4 screws on the 4 corners mounted on the plate on the backside of the lamp

d. Now the PCB is accessible

e. Disconnect the plug-in-cable

f. Now replace with spare PCB

g. Put back the plate and tighten the screws

h. Replace the lamp system

i. Reconnect the plug-in cable

j. System will turn ON now

Method for replacing the Charge controller PCB

a. Remove PCB from the top end of the charge controller by pushing the PCB towards outside using the screwdriver which is supplied along with the system

b. Now the PCB is accessible

c. Disconnect the cables connected to terminal block carefully without shorting any wires

d. Now replace the spare PCB by inserting at the terminal side first and the top side. It should be pushed slightly by hand and PCB gets fixed

e. Reconnect the cables to the terminal block

f. System will turn ON now

Method for replacing the battery

a. Slide the lantern in a horizontal position to access the four screws in the base plate

b. Unscrew all the four screws

c. Lift up the upper portion of the lantern and let it rest on the side of the base plate

d. Remove the PCB circuit board from the plastic holder by pressing one of the side supports inside

e. Use a small screw to unlock it

f. Remove the red and black connectors from the battery terminals along with the plastic insultors

g. Replace the battery and connect back the connectors

h. Connect red wire to the red marked positive terminal and black wire to the other battery terminal

Tools needed for assembly and maintenance

1. Digital multimeter
2. Spanner set
3. Screw driver set
4. Cloth
5. Hydrometer

Testing of a battery

The electrolyte in a wet lead-acid battery is a mixture of sulfuric acid and water. A battery can be tested in a number of ways. The simple idea is to know if, it stores the charge properly. This calls for a measurement of battery voltage. Remember, there is a definite relationship between the specific gravity of a battery and its state of charge. The most reliable method is the measurement of specific gravity and battery voltage. Following few tools are needed for this purpose:

- Hydrometer
- Digital Voltmeter

Remember, it is not possible to test a sealed battery in this way.

Testing procedure

About the hydrometer

It is a low cost float-type hand held device used to measure the concentration of sulfuric acid (specific gravity) of battery electrolyte (battery acid). A hydrometer is a glass barrel or plastic container with a rubber nozzle or hose on one end. It has a soft rubber bulb on the other end. Within the container is a float and calibrated graduations used for the specific gravity measurement.

Step-by-step procedure:

- remember if, a battery has been charged or discharged within the last four hours
- if so, remove the surface charge of the deep cycle battery to be tested.
- Use a load that is around 33% of the ampere-hour capacity of the battery for about 5 minutes
- wait for around ten minutes before taking any measurements

- wear protective glasses in case of any spillage of electrolyte
- squeeze the rubber bulb while holding a clean hydrometer upright or vertically
- put the nozzle into the electrolyte in the cell and release the bulb
- this way the electrolyte will be sucked up into the barrel or container thus allowing the float to ride freely
- start with the cell that is just near the positive terminal
- tap the hydrometer to remove any bubles on the float
- squeeze the rubber bulb to release the electrolyte back into the battery's cell
- watch if the float is now steady i.e. at one place
- read the specific gravity at the point the surface of electrolyte crosses the float markings
- release the electrolyte back into the cell from which it was taken
- note down the reading

Measuring the voltage of the battery

Remember ordinary analog voltmeters are not accurate enough to measure the millivolt differences of a battery's state of charge. Instead, a digital voltmeter or a multimeter is good enough to measure the battery terminal voltage. Simply put the probes of multimeter on the battery terminals and read the voltage display.
State of charge

The specific gravity measurement (s) is a good way to know about the battery state of charge. Table below gives different values of SOC for a 12 V/6V battery:

State of Charge	**Specific Gravity**	**Voltage**	
		12 V	**6V**
100%	1.265	12.7	6.3
75%	1.225	12.4	6.2
50%	1.190	12.2	6.1
25%	1.155	12.0	6.0
Discharged	1.120	11.9	6.0

Battery capacity

The most common battery rating is the ampere-hour rating or simply Ah. It is a unit of measurement for the battery capacity. This is obtained by multiplying a current flow in amperes by the time in hours of discharge. Take for example a battery which gives 5 amperes for 20 hours. It can deliver 5 amperes times 20 hours or 100 ampere-hours. Table 1 shows the Watt-hours in case of a solar system as under:

Load (Watt)	Use= hours/day	Watt-hours
4	12	48
8	12	96
16	12	192
32	12	384

Battery size

It can be worked out as under:
a) divide the Watt-hours per day by the DC System Voltage
b) the value obtained is that of Average Ah/day
c)divide the Ah per day thus obtained by the Discharge limit
d) the value obtained is that of battery capacity in Ah

Watt-hours Per day	DC System Voltage	Average Ah Per day	Autonomy Days	Discharge Limit	Battery Ah	Battery Available Ah
32	12	2.67	1	0.5	5.33	7
48	12	4.00	1	0.5	8.00	14
64	12	5.33	1	0.5	10.67	14
96	12	8.00	1	0.5	16.00	18
128	12	10.67	1	0.5	21.33	26
192	12	16.00	1	0.5	32.00	40
256	12	21.33	1	0.5	42.67	48
384	12	32.00	1	0.5	64.00	64

Battery maintenance

It is important to keep a battery in good health. The same can be done by a) its regular cleaning, b) checking of specific gravity of electrolyte at regular intervals and c) regular charging

Cleaning method for batteries:

1. to begin, turn off the solar charge
2. disconnect the battery from its leads
3. remove the terminals from the posts
4. clean the terminals and the posts till these become shiny

5. check if, the battery terminals are corroded. It simply means if, any white powder is present on them?

6. clean them with a solution of baking powder and water

7. put back the cleaned terminals and tighten the bolts

8. use petroleum jelly or grease on the connected terminals

9. keep a wet cloth on the tight bolts for some time to get loose

Topping up the battery

1. take out the caps of each of the cells though one at a time
2. check the electrolyte level
3. remember to keep the acid level within two cms of the battery top
4. add ionized distilled water till it is around 2 cms below the top of the battery
5. do not ever add the rainwater/tapwater/acid to the battery

Other components

Checking the module junction box

1. the junction box is at the back of a solar module
2. check it to ensure that the wiring is tight
3. see if, it is free of any insects and rats etc.

Wiring and control

1. different components of a PV system are joined with wires
2. check the wiring to look for any loose connections/inset bites/animals
3. check the tightness of all connector strips
4. see if, any naked wire is present
5. check system wire runs for any breaks, cracks in the insulation
6. check the switch. It must not cause sparking during ON/OFF
7. check the indicator lamps on the control
8. check the ground wires to ensure their intactness

Lamps and other loads

1. turn off the lights and appliances when not in use
2. clean lamps, reflectors and fixtures once every few months
3. light output comes down by as much as 20% in the presence of dust/dirt on the lamps
4. see if, any blackening is there on the tubes
5. If so, replace them fast

Important don’ts regarding a battery

- batteries store a large amount of charge-never short circuit a battery
- batteries can produce flammable gases-avoid making sparks, using fire or any naked flame
- make sure the battery room is ventilated
- use insulated tools, stand on dry ground and keep your hands dry
- do not expose a battery to high temperatures (>60 degrees C)
- do not ever try to break a battery
- 5mm to 10 mm of free air space should be provided when connecting batteries
- never store a battery in a discharged state as it may damage the battery
- clean any dust with a dry or water dampened cloth
- transport the battery in an upright position
- check the batteries regularly
- top up the electrolyte in the battery as and when needed

Maintenance procedure of solar lighting systems

It is very important to properly maintain all the three systems (solar lantern, charging station and home lighting system). This can best be understood in terms of the following:

Component	Risk involved	Due to what
Solar Module	Produce less power	If, not cleaned regularly If, not connected properly
Battery	Lose precious electricity Reduced life span	If, electrolyte level not checked regularly Electrolyte level not maintained
Charge Controller	Drain out the battery	If, it fails to work properly
Lamp	Not glow properly Drain out the battery	If, it does not have the right frequency or ampere

Remember: defect in any one part may stop the system from working normally

Troubleshooting-Solar lantern

A solar lantern is a very useful source of lighting. It works on a simple principle of electricity production, storage and its use. However, some thing or the other may go wrong with it at times. So, it is important to take a note of the problem solving steps as under. This whole procedure is generally known as the troubleshooting.

Problem	**Possible cause**	**Solution**
Lantern not working	ON/OFF switch may be at the OFF position	Keep the power switch at ON position
	Fuse failure	Replace the fuse
		See if, earthing strip/wire is fixed properly in the lamp
	Battery low- See if red LED indicator is on	Charge the battery with PV module
		Keep on charging the lantern till the green LED stops glowing
		Check PV module input connection
	Blackening may be present on the lamp	Replace the lamp
Not getting sufficient Backup	Battery charging problem	Check the PV module connection
		Ensure there is no shading on the module and enough sunlight is falling on the module
		Battery may be damaged, please contact the dealer
Charging indicator not glowing		See if, sunlight is falling directly on the module
		See if, the surface of module is clean
		See if, the charging lead is connected properly to the lantern and module
Lantern still not working		Please contact the lantern supplier

Dos

- always keep the solar module in the sun at a suitable angle
- if, the angle is not known, then keep the module in the sun on a horizontal surface
- charge the lantern for a full day before its first use
- in case the red LED glows, charge the battery of the lantern till green LED switches off
- try to use the lantern daily for 2-3 hours
- charge the battery on a regular basis, even if, the lantern may not be in use
- charge the battery, even if, lantern is out of order for some time
- store the lantern in a clean dry state

Don’ts

- do not keep the module in shade at any time
- do not try to open the solar panel in any case
- do not allow dust to settle on the glass surface of a panel
- do not allow any bird droppings to settle permanently
- do not scratch the glass surface to remove bird droppings with any sharp object
- do not ever use any chemicals/detergents for cleaning (it may damage the plastic parts)
- do not expose the lantern to direct Sunlight
- do not clean the lantern/solar module with acid, detergent or any other chemical
- do not allow the lantern to get wet (solar module may get wet)
- do not pull out the panel from the lantern by pulling hard the wire
- do not try to remove the fixed diffuser for changing the lamp
- do not keep the lantern in a fully discharged condition for more than a month (otherwise, the battery may get damaged permanently)
- do not connect the lantern to the AC mains supply

Maintenance and troubleshooting for Solar Charging Stations

A solar charging station can very useful for a lantern user. He need not worry much as to how the lantern battery gets charged. The operator of a charging station takes due care of such needs and many more too. He locates the problems that may come up both in the junction boxes as well as the individual lanterns. However, a user too must use a battery regularly. He should use it just to run the CFL/LED's and nothing more. Following few are the important measures that are needed:

If the green LED is not glowing:

- check if the green LED of the lantern is glowing, when put on charge
- if, not then see if, enough sunlight is present for charging
- see if, the charging wire/cord is properly connected to the junction box port

Check now, if, green LED is glowing. If, still not, it could be due to the below given reasons:

a) Lantern LED is blown

- plug another charged lantern in ON condition on this very port
- see, if, lantern goes off and the green LED of the lantern begins to glow clearly, the port is working and LED of the previous lantern is blown
- replace the green LED of the previous lantern

b) Lantern is not charging

- check the fuse and replace it, if found faulty

c) Green LED is still not glowing

- plug the same lantern on a different port
- check now if, the green LED is glowing with this new port
  If, yes, there is some defect in the previous port of the junction box

d) Green LED is still the same i.e. it is not glowing

- there may be some problem in the lantern itself
- contact the lantern supplier

Dos and Don'ts

Dos- Solar lantern and junction box

- always charge the lantern completely through the junction box
- the battery of the lantern should be charged regularly even if, lantern is not in use or out of order
- always clean the lantern with a cotton cloth

- always charge the LED lanterns through LED junction box only
- always charge the CFL lanterns through CFL junction box only

Solar Modules

- always clean the solar module with a moist cotton cloth
- check and ensure proper connection of wires from the module to the junction box.
- this is ensured by observing that the green LED of the junction box is glowing when there is sunlight

Don't's

Do not connect the lantern to AC mains supply
Troubleshooting-Solar Home System
Solar systems are mostly installed in the remote areas of our country. These systems must work without any problems. However, some minor problems may come up at times. A solar technician should be able to fix up most of these problems on his own. Table below shows the possible reasons and their solutions in a typical SHS:

Symptom	**Part involved**	**Possible defect (s)**	**Check cause**	**Check/remedy**
Lamp does not glow	Luminiare	Fuse failure	Remove the fuse and check whether it is blown	If, blown, replace the fuse
	Luminiare	Loose terminals	Check for loose connections at input terminals and CFL holder	If, found loose, tighten the terminals
	Luminiare	Lamp failure	Check for blackening of the lamp	If, blackening is found, replace the lamp
	Luminiare	Inverter PCB failure	Check for any burns on the PCB, transformer, capacitor etc.	If, burns found, replace the PCB
	Charge controller		Check the fuse	Replace the fuse blown
		Battery low LED (red) ON a. Electrolyte level of the battery is low b. Loose	a. Check for the level of electrolyte b. Check for the loose	a. If, found low, top up the battery with distilled water b. Tighten the

Symptom	Part involved	Possible defect (s)	Check cause	Check/remedy
		connection at the battery	connection of the terminals and lugs	connections and replace the lug if, found loose
		c. Battery not charged	.Check for charging indication during the day time	c1. If, no indication, tighten the loose connections at the module end c2. If, no rated current found at module end, replace the module c3. If, point nos 1&2 are okay, then replace the PCB
		d. Battery wrong polarity		Remove the reverse polarity

Safety considerations in case of a SHS

Module, battery, CFL and Charge controller form the most important components of a solar home system. It is very important to feel safe while dealing with these parts and system as a whole. Following few safety steps are being put up:

Module

- modules should be covered or shaded from the sun by an unclear sheeting, before any electrical connections are made to the modules
- modules should be mounted firmly onto the structure as per the foundation details and the installation plan mentioned in the drawing
- construction of the structure must not be attempted in high winds

CFL's

- protect all the lamps from rain, snow, condensation of droplets or water
- do not stare at the lamp directly
- ensure safe throwing away of the lamps after use

Charge Controller

Charge controller is necessary to monitor and to allow sequence of operation so that solar energy is utilized efficiently

- protect it from the direct sunlight
- place it in a dry environment
- never install it in humid rooms (like the bathrooms)

Battery

- batteries must be placed in a well ventilated area
- lift the batteries only by the handles
- keep these upright at one place
- try to use a protective gear while filling the electrolye in the batteries
- do not overfill the batteries above the maximum level indicator
- do not smoke in the battery room
- check for any traces of acid on the battery housing, racks and connectors
- check for any traces of corrosion on racks and compartments
- importantly, care well for the battery

LED Driver

Use of high brightness LED's is a new trend in the area of lighting. These LED's offer the following few advantages:

- longer life
- higher efficiency
- lower maintenance cost

As such, a LED driver is needed to maintain constant current in the LED's. Generally, it is a DC-DC Step up/down converter.

Safety instructions for SHS (as a whole)

- do not expose a home lighting system to rain, liquids of any type.
- a SHS is designed for indoor use only
- to reduce risk of electric shock and spark, disconnect all the wiring before cleaning
- do not cover your SHS with any cover or cloth
- do not install the SHS on or near flammable materias like plywood, chemicals or gasoline
- ensure correct and proper polarity wire connections at input terminals of SHS from PV and load
- Remove all metallic ornaments (wrist watches, jewellery) and use insulated tools, wear googles, protective clothing and soled rubber shoes for relevant installations
- follow the connection and disconnection sequence of cables, interconnecting the charge controller, solar array, battery bank, load, voltage regulator etc. as per the suppliers drawings
- do not short the positive and negative terminals of array, battery bank etc.
- do not mess about with the electronic components while it is in a working condition
- do not remove the PCB assemblies until module and battery are disconnected

Best use practices of Solar home systems

Dos

1. keep the solar panel clean from dust and bird droppings
2. top up the battery with distilled water only once in 3-4 months, if, needed
3. disconnect the SPV cable before removing the battery connection when you are replacing the new battery
4. apply petroleum jelly to the battery terminals regularly

Don’ts

1. do not short the battery terminals
2. do not reverse the polarity of the battery cables

3. do not top up the battery with electrolyte. It is to be used only for the initial preparation

4. do not short the charge controller terminals

5. do not use excess load other than what is supplied with the system

List of tools needed for assembly

S. No	Item	No
1	Digital Multimeter	1
2	10 W / 230 V Soldering Iron for SMD	1
3	30 W / 230 V Soldering Iron	1
4	12V /15W DC Soldering Iron	1
5	Screw Driver (±911,±923,±922)	1
6	Box Spanner (M3, M4, M6)	1
7	Mulititec Cutter - (06, 07)	1
8	De-Soldering Pump	1
9	Nose Plier	1
10	Solder Wire	1
11	Dust cleaner brush for PCB	1
12	Tweezer	1
13	Flat File	1
14	Camal Cutter	1
15	Adjustable wrench	1
16	PVC Tape	1
17	Compass	1
18	Bag for toolkit	1
19	Hydrometer	1

Part II- Practical Considerations
Solar Thermal

Activity: Study of SWH designs/components (restricting to 100 LPD systems)

A solar water heating system of 100 LPD capacity suits a family of 4 members. The capacity of the water heater will increase proportionately as the number of persons increase. The acceptable standard of hot water use is as under:

- Domestic users-25 liters/per person/day
- Commercial users-50 liters per person/day
- Industrial users varies from one unit to the other

A solar water heater is amongst the most widely installed systems in India. Under this activity, a 100 LPD system is to be taken up for a practical study as per the following:

I. understanding a physical layout of the system

II. component-wise marking

III. step-by-step demonstration of different components

IV. observing their physical shapes

V. observing their material formation (s)

VI. recording the individual ratings of these component

Sub-activity: Grading of the Solar flat plate collector systems on the basis of following information

S.No.	Item	Class-I (15 years and more)	Class-II (10 years and more)	Class-III 5 years and more
1.	Collector Box	Anodised Aluminum	Alumnium	Mild steel
2.	Absorber Panel Fin Risers and Headers	Copper Copper Copper	Copper Copper Copper	Mild Steel, Galvanised Steel or Copper Steel or Copper
3.	Coating	Selective black chrome coating	Selective black Chrome coating	Black paint
4.	Gasketing	Silicone rubber	EPDM	Neoprene or Rubber
5.	Cover glass	Tempered/low iron	Toughened	Window glass

S.No.	Item	Class-I (15 years and more)	Class-II (10 years and more)	Class-III 5 years and more
		float glass	Window/float glass	
6.	Insulation	Polyurethene (PUF)	High density fibre glass/Polyurethene	Low density mineral wool
7.	Sealants	Silicone	Silicone	
8.	Piping	All Copper	Galvanised Iron B class	Galvanised Iron A class
9.	Screw, bolts and nuts	Stainless steel or non-corrosive material	Stainless steel/non-corrosive material	Zinc coated/Nickel plated/mild steel

Activity: Assembly and dismantling of a SWH (component selection, assembly, testing)

I. Arranging the components in a manner (as per the physical layout)

II. Study of the drawing provided by the system manufacturer

III. Joining of components (as per the manufacturers drawing)

IV. Complete Assembly of the system

V. Testing of the full system

VI. Dismantling of the key components

Activity: Installation of a 100 LPD Solar Water Heating System

It is important to follow the below mentioned steps before taking up the actual installation:
a) Space

- identify a suitable space to put up the system
- measure the open terrace area to keep the system
- check for closeness of the space to the point of actual use in each case (i.e. with respect to the bathroom, kitchen etc.)

b)Site Selection

- check if, the collector can be put up due south
- tilt should be equal to latitude of that place

- use minimum of hot water piping length (to reduce heat and friction losses)

- hot water storage tank is to be placed at a minimum height of 50 cm above the outlet of collector

c) Quality of water

- check the water quality-it should be soft/treated

Remember water soluble salts in hard water are responsible for corrosion, formation of scales or deposits in the collectors, pipes and storage tank

d) water supply tank location

- direct connection of water supply to the solar water heating system is ruled out in most of the cases

- cold water supply tank should be at least a foot above the top of a solar hot water tank to make easy gravity flow to the system

Remember: in a pumped system, the cold water supply can be anywhere, above or below the collectors-however, it should be near to the installation

e) Shading

- Check, if, the site is free of shade all the year round

Remember: Shading takes place due to parts of the house itself such as chimeys, domes and overhangs and also the surrounding buildings and trees located around the collectors

f) Minimum distance between rows of collectors
Check if, shadow does not come on the collector
It is important to keep a minimum distance between the rows of collectors for an easy erection and maintenance too. Sufficient care is also needed to ensure that one row does not cast any shadow on another at any time during the day. The minimum distance is given by
$D=L \sin \varphi / \tan (66.5\text{-latitude})$
Where φ=collector tilt, L= collector length

Installation related:

- use only the suitable size of piping-otherwise the output temperature will drop

- take care that hot water piping is fully insulated from the solar tank up to the usage points

- ensure that the hot water piping is not more than 10 mtrs or 30 feet. If, it is more than this, the output temperature will come down because of excess heat loss

Guidelines-Civil Foundation

- foundation may be plain cement concrete (PCC) or reinforced cement concrete (RCC) depending on the installation site
- The PCC foundation of the structure legs shall be done with M20 grade (M indicates mixing) of mix ratio of cement/sand /jelly in the ratio 1:1.5:3)

Component	Diameter D (mm)	Height H (mm)
Collector legs	150	75
Domestic tank stand legs (100-500 LPD)	150	150

Follow step-by-step procedure as provided by the system manufacturer

Activity: General maintenance schedule for SWH components (Dos and Don'ts)

To get the maximum possible benefit from the system, follow these easy steps:

Dos

1. ensure that the tank is always full and never runs dry
2. ensure that the stored hot water is used once a day either during morning or evening
3. ensure that the full quantity of stored hot water is used within a period of 1 hour
4. ensure that the cold water piping gate is open always
5. ensure that the vent pipe is kept open always
6. ensure that only recommended pipes and pipe sizes are put to use
7. ensure that the collector glass is cleaned at least once every week or depending on the local dust conditions
8. ensure that no shadow falls on the collectors during any time of the day throughout the year

Don'ts

1. do not cover the collectors when the system is in use

2. do not put up any objects which can cast shadow on the collectors

3. do not draw the hot water when the temperature booster is on

4. do not draw the stored hot water more than once per day

5. do not run the collectors dry

Specific Maintenance instructions:

- check Solar tank, collector and piping insulation for any leakages
- ensure water does not seep into it by using proper sealants
- remember to drain and clean the system in the evenings only
- close the cold water inlet gate valve before draining
- system needs to be drained once in a year by opening the top end of cold water outlet hose. It is then connected to the bottom of the solar tank
- once it is drained, cleaning can be done and hose needs to be fixed back into the position
- open the cold water inlet gate valve after fixing the hose

Time to time maintenance is very essential to keep solar water heating system working. Table mentions the steps that one needs to follow:

Maintenance requirements of Solar Water Heating System:

Component	**Maintenance needed/ Issues**	**Expected result Observations**	**Improvement in System performance**
Collectors glazing	Glass is broken	No heat transfer from collector	System fails to work/system performance is low
	Clean with water off and on	Removes dirt, dust	More heat is collected
	Clean them when these are cold	Glass will not break in any case	No damage to glass results
	Clean bird droppings	Cleans the glass	Performance gets better
Absorber coating	See if, the coating is coming off	Heat collection reduces	Performance is poor
Absorber panel risers	Use treated water to flow	Scaling does not take place	Smooth flow, Efficiency of the system increases
Absorber panel	Corrosions and leakages	Poor water riser sealing	Collector does not work
Absorber-riser sealing	Poor thermal contact	Low transfer of heat	Poor solar heat collection
Collector Box	a. Dust present inside b. Corrosion c. Wetting of insulation	Leakages from glass beeding and corners of the box	Life of the collector becomes less
Circulating water pumps	Apply lubrication, see if, water is leaking	Pump works better	Does not result in any system failure
Pressure gauges	See if, these are working fine at regular intervals	Good monitoring	Does not lead to any system failure
Air vents	See if working well	Air locks	Smooth flow does not exist
Storage tanks	Drain and flush paint with anti-corrosive paint Paint off and on	Tank be cleaned at regular intervals to stop corrosion, dust collection	Active life of the storage tank increases

Activity: Fault finding and troubleshooting

It is very important to know the possible defects that may occur in a solar water heating system. Table below lists such situations alongwith their possible solutions. This process is more commonly known as the troubleshooting.

Indication	Part involved	Likely Cause	Check	Check/Solution
Not enough hot water	Collector (s)	1. Shading 2. Dirty glazing/glass	Check for any objects that are causing shadow Check for dust/dirt collection on the glass	Remove the objects to avoid the shadow Clean the dust/dust using mild soap and water in evening only
	Piping	1. high heat losses	Check for presence of insulation	If, the insulation is missing, insulate it
		2. Gate valves partially closed	Check that the gate valves are fully opened	If, not opened, open it fully
		3. Flow blockage	Check for slow flow of hot water at usage point	If, the flow is slow, flush the system
	Solar tank	1 high storage losses	Check the insulation/opening of the outer cladding due to tampering	
		2. loss of hot water due to leakage	Check whether the tank is leaking at any point	
		3 Improper cold water inlet	Check cold water inlet connection	If, not connected, connect it properly
No water at usage point	Piping	1. Gate valve completely closed	Check if, gate valve is closed	If, found closed, open it
		2. No cold water supply to the system	Check whether the gate valve is clsoed	If, found closed, open it
		Flow blockage	Check for slow flow of the hot water at usage point	If, the flow is slow, flush the system
		Over head tank empty	Check whether the overhead tank is empty	If, found empty, fill it fully

Indication	Part involved	Likely Cause	Check	Check/Solution
Cold water at usage point	Piping	Loss of hotness/hot water drawn is more than once a day	Check whether the hot water is drawn more than 1 time a day	Draw/use complete amount of hot water in a span of 1 hour in a day
	Make up tank	No Polypropylene glycol/antifreeze solution in the makeup tank	Check whether the makeup tank is empty	If, found empty, fill it up with polypropylene/glycol antifreeze solution
	Weather	Bad weather	Check for rain hit/cloudy day	Switch on the temperature booster

Water leakage	**Piping**	**End fitting/pipe fittings are loose**	**Check for tightness of fittings**	**If, anything found loose, tighten it**
	Collector	Damage to the collector	Check for damages in the collector	Contact the system supplier
	Tank	Damage to the tank	Check for damages in the tank	Contact the system supplier

Activity: Study of Solar Cooker models/components (parabolic type)

A parabolic dish cooker is turning out to be useful in many ways. So, it is important to study this model of cooker both from the physical and technical considerations. To begin with, following few sub-activities are planned:

I. understanding a physical layout of the system

II. component-wise marking

III. observing their physical shapes

IV. observing their material formation (s)

V. recording the individual ratings of the components

Activity: Demonstration on Solar Cooker and its various components

A solar dish cooker is mainly made of a single reflector. Or, it may have many small pieces of reflectors combined together. The dish is fixed firmly to an unbending frame. The size and shape of the dish is such that a point focus is formed on being exposed to the sun. Under this activity, it is planned to carry out the following few sub-activities:

- understand the specifications of each major component
- understand the role of each major component
- demonstrate a fully working model of a parabolic type dish cooker
- understand the point focus nature of the dish

S.No.	Element/Parameter	Specifications
1.	Dish diameter	Minimum of 1.4 mtr.
2.	Aperture shape	Circular/square/rectangular
3.	Aperture area	1.5 sq. mtr. Minimum
4.	Aperture shape	Circular/Square/Rectangle
5.	Reflector material	• Anodised aluminum with a minimum thickness of 0.4 mm • Glass mirror of thickness 0.3 mm with a suitable protective layer on the back (this is meant to reduce the degradation of the reflective coating due to weathering
6.	Supporting frame of the dish	• Made either of MS rings supported by MS strips, FRP material, or thick MS wire mesh structure • Should bear any bending of the dish shape due to wind pressure or physical handling • MS structure will have epoxy/anti-rust coating
7.	Stand for the dish	• Made of MS with epoxy/powder coating • Has an arrangement to hold cooking pot of different sizes • Has a suitable grip to secure the cooker to the ground
8.	Tracking mechanism	• Manual or automatic allowing unrestricted rotation of the dish along its horizontal and vertical axis enabling its adjustment in the normal direction to the sun rays • Option of a locking arrangement to hold/fix the dish at a desired position • Has an arrangement to enable the users to position the dish in a direction normal to the sun rays

Activity: Assembly of a solar cooker (component selection, assembly, testing)

It is planned to undertake the following few sub-activities under this broad activity:

I. Arrange small pieces of the reflector material

II. Combine these in a proper way to form a single reflector

III. Design a proper supporting frame for the dish

IV. Once ready, put together the stand to mount the dish

V. Complete the installation of the dish

VI. Attach a tracker assembly to the dish as per the drawings provided by the dish manufacturer

VII. Complete the dish assembly as per the drawing

VIII. Test the working of the assembled unit as per the standard procedures

IX. Dismantle the cooker assembly component-wise

Activity: General maintenance schedule for solar dish cooker components

A dish solar cooker produces very high temperatures. So, it is very important to know as how to feel safe while working on it:

Do's

- always use a large pot for cooking
- only use such pots as fit well in the support provided
- use only the black painted pots
- turn the reflector in such a way that you will be standing in its shade while putting on or checking the pots
- put the lid tightly on the cooking pots
- use cloth or oven gloves for touching the pots
- use sunglasses for precautionary measures while working

Don’ts

- do not stand right in front of the cooker
- do not allow small children to go close to it
- do not leave a reflector without any cover (after dismanting the cooker)
- do not ever look into the reflector
- do not put small pots on the cooker
- do not try to cook such food as need constant stirring

Maintenance schedule

- wash the reflector with a wet cloth or a sponge soaked in water
- rinse the reflector with water after that
- use a dry piece of cloth to remove any stains after washing
- do not use metallic things as these may cause scratches on the surface of the reflector sheets
- only use dark cooking vessels

Troubleshooting of the cooker

At times, cooking may simply take too long. That is the reason enough to locate a fault and take steps to set it right:

- there may be no clear sunshine on the reflector
- the cooker may be facing sharp wind, remember wind can take away a lot of heat
- reflector is not quite properly adjusted in the path of sun
- the lid of the part is missing or the pot may not be black
- a shadow is falling on the reflector
- the pot is too small so that part of the concentrated radiation misses the spot
- the reflector sheets are dirty enough

Corrective measures to make the cooker functional are recommended as under:

Symptom	Problem	Action
Food not cooked even on clear sunny day	Black coating from the cooking box and from pots has faded or peeled off	Paint the cooking box and pots with jet black paint or the recommended paint.
	Glass lid is broken	Replace the broken glass lid
	Mirror is broken or spoilt	Replace the mirror or silver the same mirror
	Heat is leaking from the joints	Find out the heat leakage points and seal them
	Dust has collected on the glass lid and mirror	Clean the glass lid and mirror
	The absorber box has become dirty	Clean the absorber properly
	Lid is being opened frequently	Minimise opening the lid
	Direction of the box is not proper	Keeps the cooker always facing the sun such that the reflected rays from the mirror fall on to the cooking box and cover its whole area.

- Maintenance and servicing of dish type solar cookers
- Maintenance required is an occasional coat of black paint on the outer surface of the pressure cooker
- Replacement of reflecting sheets once in 5 years
- Cleaning of the reflective panels on parabolic solar cookers should be done after every use. All that is needed is a soft cloth and clean water to remove dust and spilled food
- The reflectors should never be scrubbed or cleaned with soap or an abrasive material because that will dull the shine and reduce the temperature at which it cooks
- Covers for parabolic solar cookers that are left outside at night will dramatically extend their life span.

Supplementary Reading Material

1. **Title: From Sunlight to Electricity: a practical hand book on solar photovoltaic applications**
   Editor: Suneel Deambi
   Pages: 121 pp (soft bound)
   Year: 2008 (revised edition)
   Price: Rupees 200
   Publisher: The Energy and Resources Institute (TERI)

2. **Title: Solar Photovoltaics: Fundamentals, Technologies and Applications**
   Author: Solanki, Chetan Singh
   Pages: 504 (hard cover)
   Price: Rupees 475
   Publisher: Prentice Hall of India

3. **Title: Course Material in Solar Photovoltaics for ITI Students**
   Prepared by: New Concept Information Systems Pvt. Ltd. (on behalf of MNRE)
   Released by: Ministry of New and Renewable Energy
   Year: 2010

4. **Title: A Solar Future for India**
   Editor: G.M.Pillai
   Pages: 650 pp
   Year: 2010
   Price: Rupees 1200
   Publisher: World Institute of Sustainable Energy

5. **Title: Photovoltaics Design and Installation Manual**
   Editor: Solar Energy International
   Price: $35.43
   Publisher: Solar Energy International

6. **Title: RENEWABLE ENERGY TECHNOLOGIES : A PRACTICAL GUIDE FOR BEGINNERS (In Hindi)**
   Editor: Chetan Singh Solanki
   Pages: 168
   Price: Rs 225.00
   Year-2009

Publisher: Prentice Hall of India

7. **Title: RENEWABLE ENERGY TECHNOLOGIES : A PRACTICAL GUIDE FOR BEGINNERS (In English)** Editor: Chetan Singh Solanki
   Pages: 168
   Price: Rs 225.00
   Year-2008
   Publisher: Prentice Hall of India

8. **Title: SOLAR ENERGY : PRINCIPLES OF SOLAR THERMAL COLLECTION AND STORAGE**
   Editor: Suhas P Sukhatme
   Pages: 460
   Price: Rs 350.00
   Year-2008
   Publisher: Tata McGraw Hill

9. **Title: RENEWABLE ENERGY ENGINEERING AND TECHNOLOGY**
   Editor: V.V.N Kishore
   Pages: 925
   Price: Rs 2250.00
   Year-2008
   Publisher: TERI Press