Applications of Solar Energy

5.1. Introduction

The actual and proposed applications of solar energy may be considered in three general categories :

(a) *Direct Thermal Application* make direct use of heat, resulting from the absorption of solar radiation, for space heating (and cooling) of residences and other building, so provide hot water service for such buildings, and to supply heat for agricultural industrial, and other processes that require only moderate temperatures.

(b) *Solar Electric Applications** are those in which solar energy is converted directly or indirectly into electrical energy. Four general conversion methods are being investigated :

(i) Solar thermal methods involve production of high temperatures, such as are required to boil water or other working fluid for operating turbines which drive electric generators. These are considered under *solar thermal electric conversion*.

(ii) *Photovoltaic Methods* make use of devices (Solar Cells) to convert solar energy directly into electrical energy without machinery. This is discussed under solar *photovoltaic conversion*.

(iii) The conversion of solar energy into electrical energy without the use of machinery, by utilizing the *thermo electric effect*, is also considered in chapter *Thermo electric conversion*.

(iv) *Wind Energy* is the form of solar energy that can be converted into mechanical (rotational) energy and hence into electrical energy by means of a generator. This *indirect* use of solar energy to generate electricity is described under the chapter of *Wind energy*.

Ocean thermal energy conversion depends on the difference i temperature between solar heated surface water and cold deep ocea water to operate a vapour expansion turbine and electric generator This indirect use of solar energy is considered in chapter *Ocean Therma Energy Conversion*.

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*For detailed discussion on solar thermal and electric applications se author's book on "Solar Energy Utilization".

(c) Energy from Biomass and Bio-gas, refers to the conversion into clean fuels or other energy related product of organic matter derived directly or indirectly from plants which use solar energy to grow. Biomass materials include agricultural, forest, and animal residues, as well as terrestrial and aquatic plants grown especially for the purpose. For a detail discussion see chapter on *Biomass and Biogas*.

Other Forms of Solar Energy. Water power, other than tidal power, also represents the utilization of solar energy. Heat from the sun causes the evaporation of surface waters, the vapour rises is condensed in the upper atmosphere, and falls as rain. The resulting water that collects at higher elevations has substantial (potential) energy than can be converted into electrical energy by means of a turbine generator at a lower level. The discussion on Hydro-electric power*, is beyond the scope of this book, only some brief discussion is there on *Micro hydel energy*, which is a non-conventional method of generating electric-energy.

It may be noted, too, that since fossil fuels-coal, oil, and natural gas-originate from living matter, their energy is really solar energy that has been converted and stored for millions of years. In fact, only nuclear energy, geothermal energy, and to a large extent, tidal energy, do not originate in the sun. Based on the above classification, direct solar energy applications are discussed below in the following order :

(1) Solar water heating.
(2) Space heating.
(3) Space cooling.
(4) Solar energy : Thermal electric conversion.
(5) Solar energy : Photovoltaic electric conversion.
(6) Solar distillation.
(7) Solar pumping.
(8) Agriculture and industrial process heat.
(9) Solar furnace.
(10) Solar cooking.
(11) Solar production of hydrogen, and
(12) Solar green houses.

5.2. Solar Water Heating (or Hot Water Supply System).

The basic elements ~~of a solar water~~ heater are :

(*i*) Flat plate collector.
(*ii*) Storage tank.

(*iii*) Circulation system and auxiliary heating system.

(*iv*) Control of the system.

The use of solar energy for heating water in many respects quite similar to its use for heating buildings. There are however, several aspects of solar water heating, that make it potentially better investment of energy, money and effort than solar building heating. For one thing, the demand for hot water is relatively constant throughout the year. Thus the collector and the other parts of the solar water heater will be working harder and longer to produce the saving in fuel that eventually must pay for the higher initial cost of the system. The solar building heating system, on the other hand, fully operational only during the coldest months of the heating season.

The simplest type of solar water heater is the *thermosiphon* system. Some typical and commercial designs of solar water heaters are :

(*i*) Natural circulation solar water heater (pressurized).

(*ii*) Natural circulation solar water heater (non- pressurized).

(*iii*) Forced circulation solar water heater.

(*i*) **Natural circulation solar water heater** (pressurized). A natural circulation system is shown in Fig. 5.2.1. It consists of a titled collector (south facing), with transparent cover glasses, a separate highly insulated water storage tank, and well insulated pipes connecting the two. The bottom of the tank is at least 1 ft. (0.3 m) the top of the collector, and no auxiliary energy is required to circulate water through

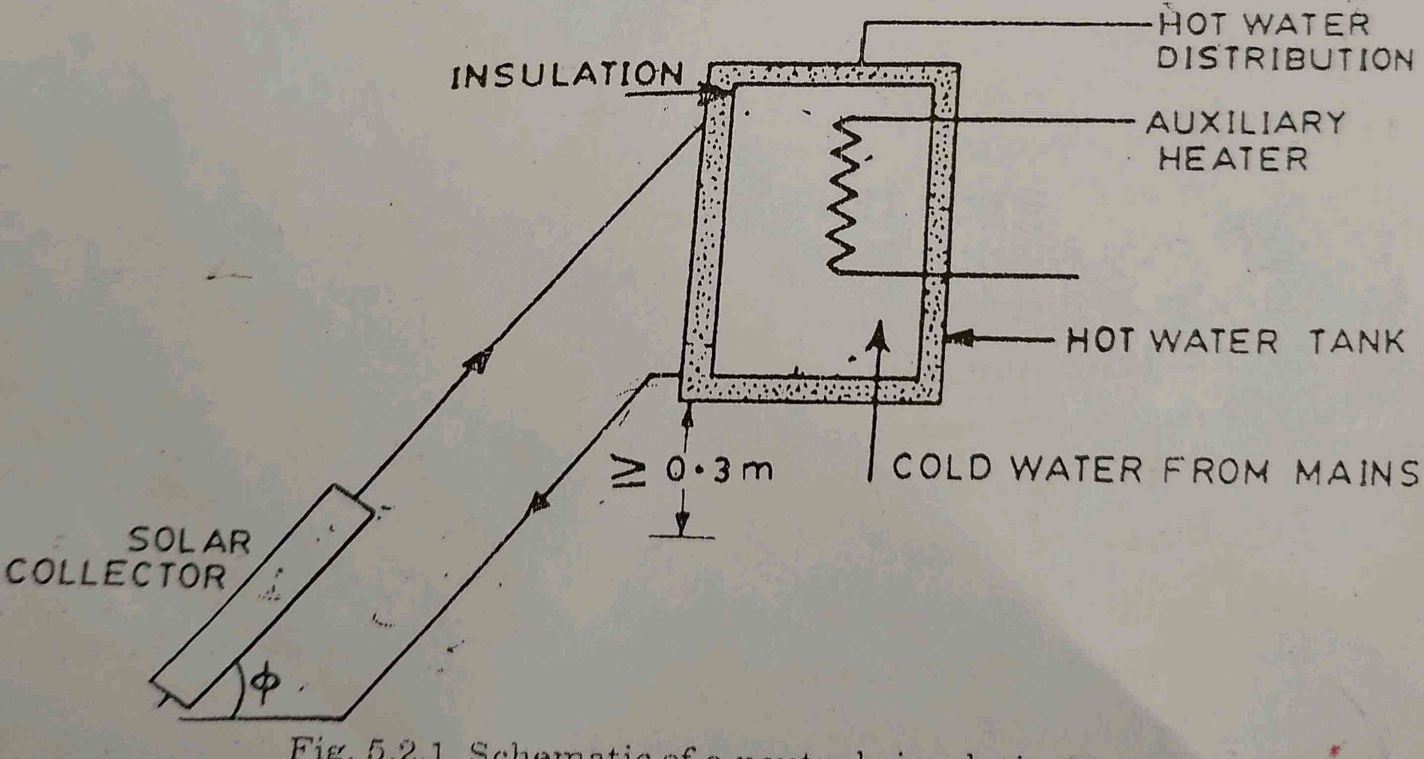
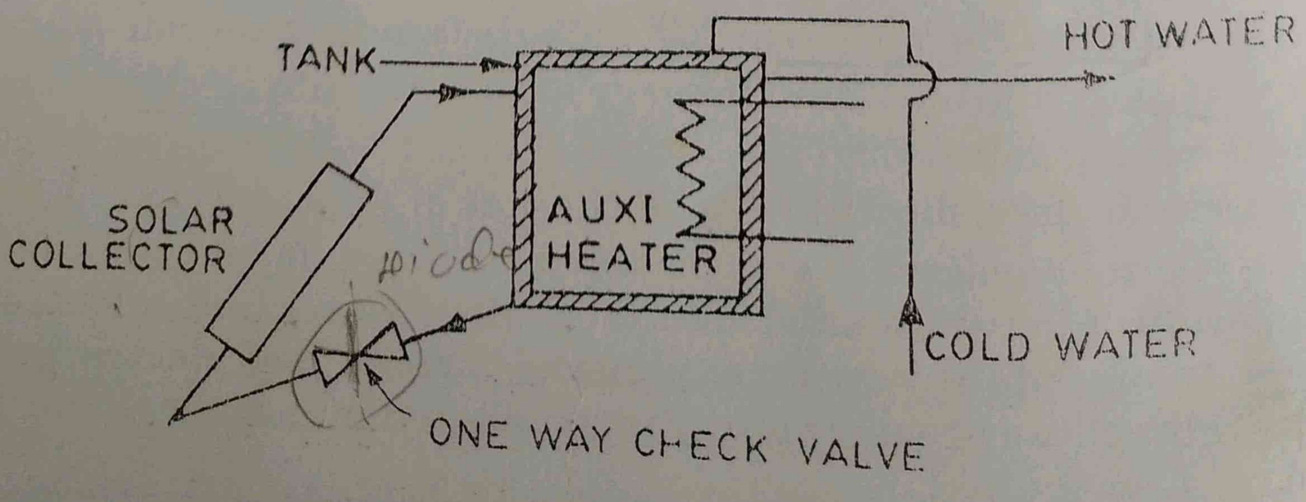


Fig. 5.2.1. Schematic of a neutral circulation solar water heater (pressurized).

it. Circulation occurs through natural convection, or thermosiphoning. As the water is heated in its passage through the collector, its density decreases and hence it rises and flows into the top of the storage tank, colder water from the bottom of the tank has a higher density and so tends to sink and enter the lower heater of the collector for further heating. The density difference between the hot and cold water thus provides the driving force (convection) for the circulation of water through the collector and the storage tank. Hot water is drawn off from the top of the tank as required and is replaced by cold water from the service system. As long as the sun shines the water will quietly circulate, getting warmer. After sunset, a thermosiphon system can reverse its flow direction and loss heat to the environment during the night. To avoid reverse flow, the top heater of the absorber is kept as stated abov 0.3 m below the cold leg fitting on the storage tank. To provide hea during long, cloudy periods, an electrical immersion heater can be use as a backup for the solar system. A non-freezing fluid may be used i the collector circuit. The thermosiphon system is one of the leas expensive solar hot-water systems and should be used wheneve possible.

Thermosiphon solar water heaters are passive systems and d not require a mechanical pump to circulate the water. Such heaters ca be used extensively in rural areas, where electricity is expensive (or n available) and there is little danger of freezing.

(*ii*) **Natural circulation solar water heater** (non-pressurized). The pressurized system is able to supply hot water at locatio of the storage tank. This creates considerable stress on the wat channels in the collector which must be designed accordingly. T non-pressurized systems supply hot water by gravity flow only to use lower than tank. If pressurized hot water is required (for showers, appliances) the difference in height will have to be large enough to me the requirements. If the height of difference can not be accommodate the only solution is to install a separate pump and pressure tank. T stresses within non-pressurized system are lower which allows cheap



and easier construction. In this type also mechanical pump is not required as shown in Fig (5.2.2), however, a oneway check valve may be desirable to prevent reverse circulation and thus loss of heat at night. A typical system for domestic water heating is shown in Fig. (5.2.3).

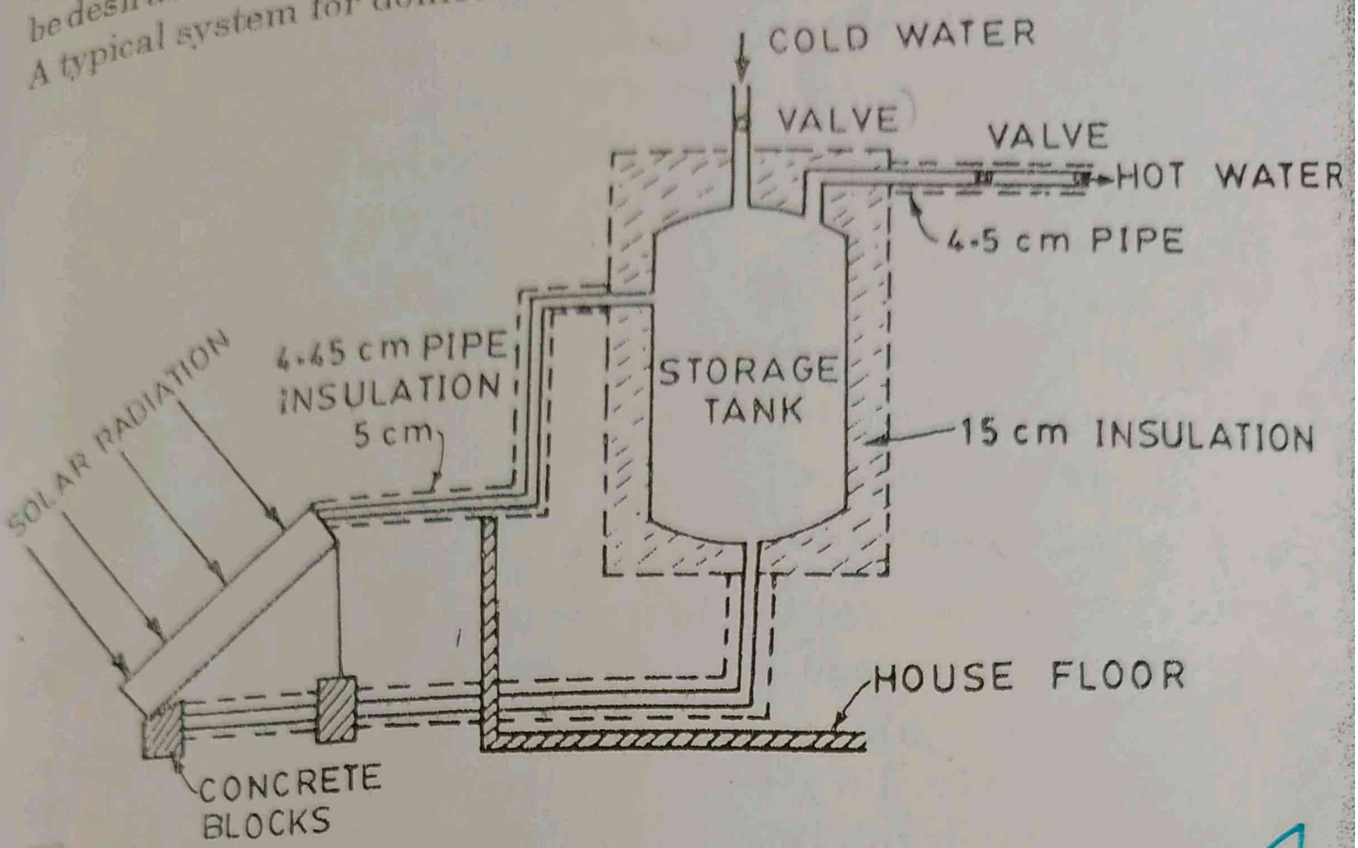


Fig. 5.2.3. A typical solar water heater.

(*iii*) **Forced circulation solar water heater.** Fig. 5.2.4 shows schematically an example of forced circulation system. By including an

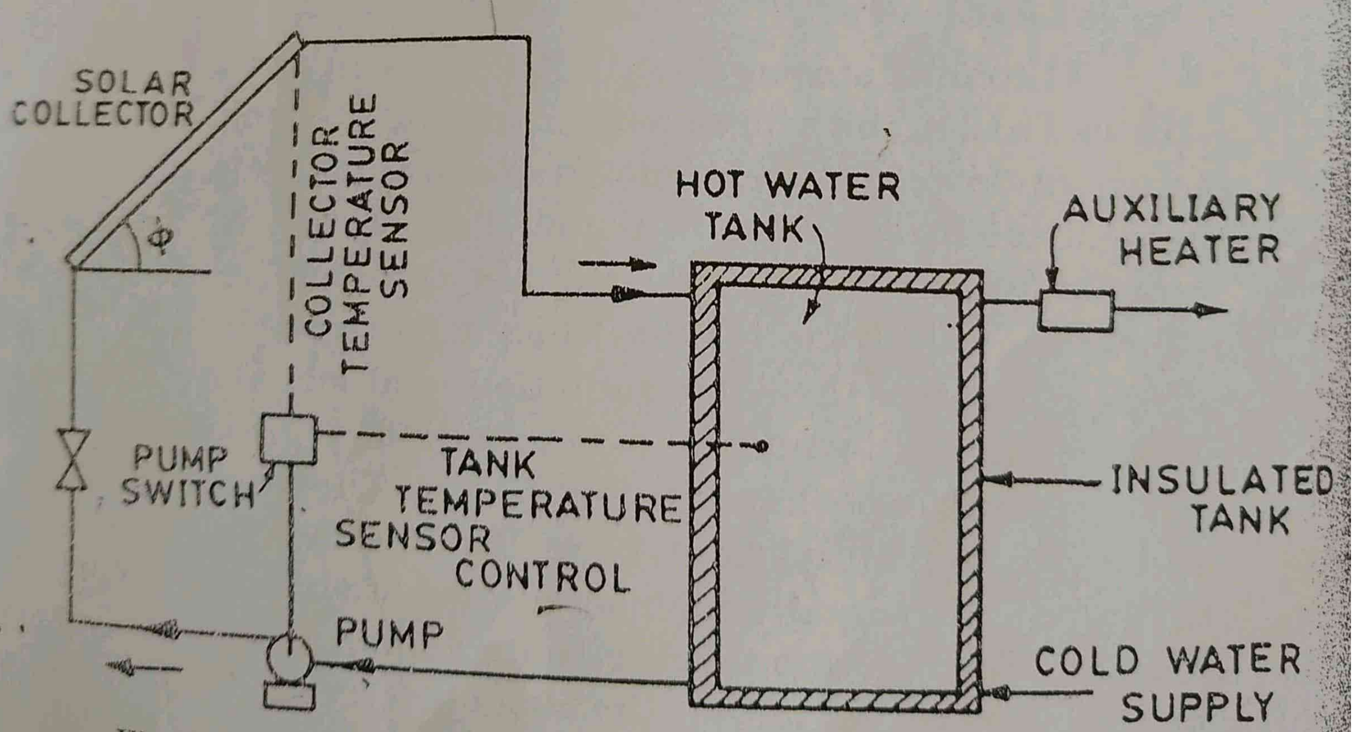


Fig. 5.2.4. Schematic of a forced circulation solar water heater.

electric pump in the return circuit between the bottom of the storage tank and the lower header of the collector, the tank can be placed at a more convenient level (*e.g.* in the house basement). This is now an *active system*. A control unit permits the pump to operate only when the temperature of the water at the bottom of the tank is below that of the water in the upper header.

A check valve is needed to prevent reverse circulation and resultant night time thermal losses from the collector. In this example, auxiliary heater is shown as provided to the water leaving the tank and going to the load.

When there is a danger of freezing, the water may be drained from the collector ; alternatively, a slow reverse flow of the warmer water may be permitted through the collector on cold nights. The freezing danger can be overcome, although at some increase in cost, by using an antifreeze solution as the heat-transport medium, as described earlier. The heat is then transferred to water in the storage tank by way of a heat exchanger coil. (See Fig. 5.2.5).

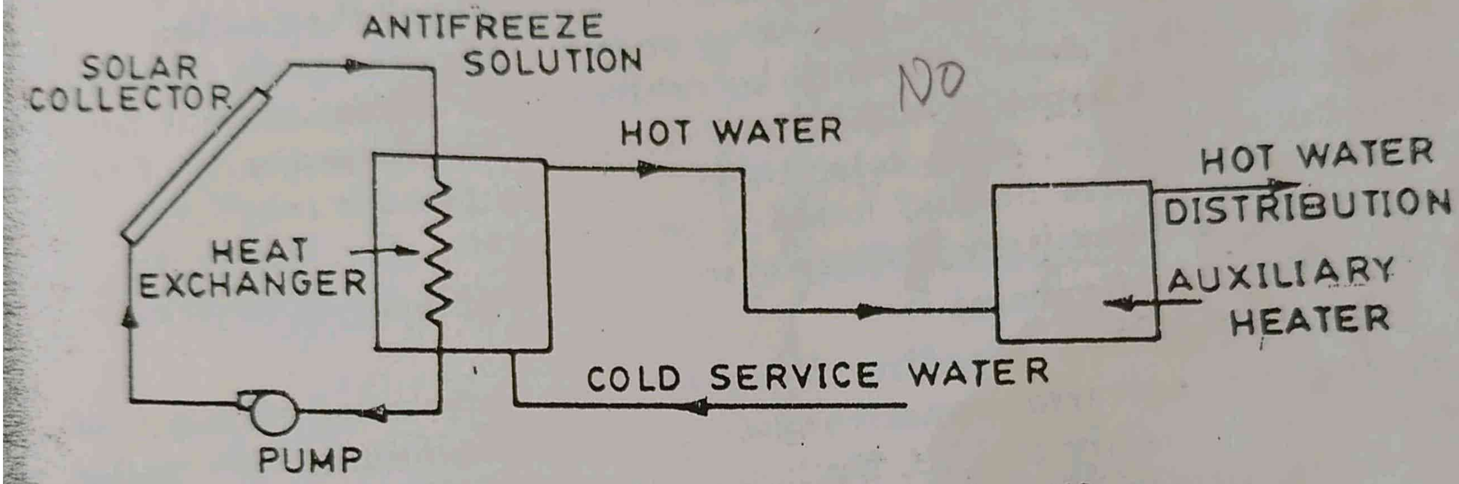


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Fig. 5.2.5. Solar water heating system with antifreeze.

5.3. Space-Heating (or Solar heating of Building)

Many different concepts have been proposed (and tested) for using solar energy in space heating of buildings. There are two primary categories into which virtually all solar heating systems may be divided. The first is *passive systems*, in which solar radiation is collected by some element of the structure itself, or admitted directly into building through large, south facing windows. The second is the *active systems* which generally consists of (*a*) separate solar collectors, which may heat either water or air, (*b*) storage devices which can accumulate the collected energy for use at nights and during inclement days, and, (*c*) a back up system to provide heat for protected periods of bad weather. Heat is transferred from the collectors or from the storage means by conventional equipment, such as fan coil units, when hot or cold water is provided ; fan, ducts, and air outlets, when the heat transfer medium is air ; and radiant means when heating is the only task which must be accomplished.

Passive heating systems operate without pumps, blowers, or other mechanical devices ; the air is circulated past a solar heated surface (or surface) and through the building by convection (*i.e.*, less dense, cooler air tends to rise while more dense, cooler air moves downward). In *active heating systems*, fans and pumps are used to circulate the air and often a separate heat absorbing fluid.

Passive solar thermal systems are more practical in locations where there is ample winter sunshine and an unabstructed southern exposure is possible. The building to be heated is an essential part of the system design. Active systems, on the other hand, can be adopted to almost any location and type of building ; however they are more expensive than passive systems to construct and operate. An advantage of active solar systems is that the building air temperature can be controlled in the same way as with the conventional heating, but in most passive systems substantial temperature variations may occur in the course of the day.

In principle, it should be possible to provide all the heating (and cooling) needs of a building by solar energy. However, to do this, the heating system would have to be designed for minimum sunshine conditions and hence would be over-designed for the majority of the situations. In most cases, solar-energy systems provide roughly 50 to 75 per cent of the annual heating requirements. The remainder is supplied by an auxiliary-heating systems using gas, oil, or electricity.

Solar Heating Systems

(A) Passive Heating Systems. An increasing number of residences using various passive systems have been built and are under construction mainly in U.S. Building with large windows facing the equator (South in the northern hemisphere or north in the southern hemisphere) and arranged to admit solar radiation into the building when the sun is low in the winter sky, have been termed 'Solar houses'. The gains to be realized from properly oriented windows are significant, but in cold climates losses during the periods of low radiation, nights and cloudy weather, must be controlled so net gains can be realized.

If a building is designed properly :

(*i*) It will function as a solar collector, collecting heat when the sun is shining and storing it for later use.

(*ii*) The building will function as a solar store house. It must store the heat for cool times when the sun is not shining, and store the cool for warm or hot periods when the sun is shining. Buildings which are made of heavy materials such as stone or concrete do this most effectively.

(*iii*) Building will function as a good heat trap. It must make good use of the heat (or cool) and let it escape only very slowly. This is done primarily by reducing the heat loss of the building through the use of nsulation, reduction of infiltration and storm windows.

Wall and roof of the building must be oriented in such a way as to receive solar radiation heat in the winter and shed it in t summer. A building can benefit from its orientation ; for similar reaso it also benefit from different ratios of its length to its width to its heig The optimum shape losses, the minimum amount of outward mov heat and gains maximum amount of solar heat in the winter, a retains the minimum amount of solar heat in the summer.

The basic design principles of passive solar space-heating s tems, that is, without mechanical components, fall into the follow five general categories :

(*i*) Direct gain
(*ii*) Thermal storage wall
(*iii*) Attached sun space
(*iv*) Roof storage
(*v*) Convective loop.

There are modifications within each of these categories anc or more may be combined in a single building.

Direct gain. In this system, the building has a south wall a large number of windows ; two layers of glass minimise heat lo Solar radiation entering the windows falls on thick concrete, sla brick floors (and possibly walls) and is absorbed and stored as heat building air is then heated by radiation and convection from the and walls. Covering the windows with shutters or curtains at reduces heat losses.

Thermal storage wall. A large wall like mass which ab solar radiation and stores heat, is placed directly behind large s facing windows. The best known example of the storage wall des the vertical *Troumbe wall*, made of concrete brick, or other ma some 0.3 m or more thick. Dr. Felix Trombe, Director of solar e laboratory at Odeillo (France) has used this principle. The syst passive, because the solar radiation is absorbed by a heavy con south facing wall which is covered with double glazing. A Trombe arrangement is outlined in Fig. (5.3.1). The distance between gl and concrete wall is about 10 to 20 cm. Concrete, wall is about thick, painted black, which serves as both a radiation absorber heat storage medium. Heat radiated outward from the wall is tra by the glass cover, so that the air in between is heated. The heat rises and enters the adjacent room through vents at the top of the the air circulates by natural convection and is returned by way of at the bottom of the storage wall. Electric strip heaters are provid standby purposes during excessively cold weather and during day little sunshine.

Attached sunspace. A sunspace is any enclosed space, such as a green house or sun porch, with a glass wall on the south side. A sunspace may be attached (or built on) to a thick south wall of the building to be heated by the sun. Vents near the top and bottom of the wall, as in Fig. (5.3.1), permit circulation through the main building of the heated in the sunspace. Heat storage is provided by the thick wall, a concrete or masonry floor, water containers, and other materials in the sun space. Thus, an attached sunspace system combines features of direct gain and storage wall concepts.

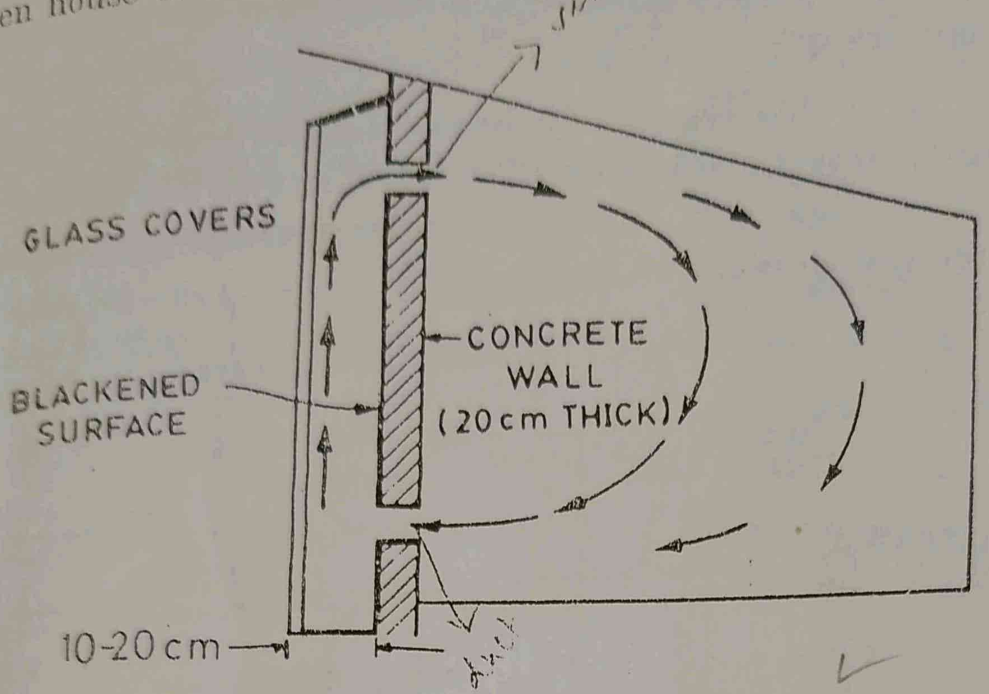


Fig. 5.3.1. A passive solar heating system.

Roof storage. A passive solar system, trade named Sky Therm, was designed for house having a flat roof located in a mild climate. The heat is absorbed and stored in water about 0.25 m deep contained in plastic bags held in blackened steel boxes on the house roof (Fig. 5.3.2). In a later design, a layer of clear plastic sealed to the top of the bag provides a stagnant airspace to reduce heat losses to the atmosphere.

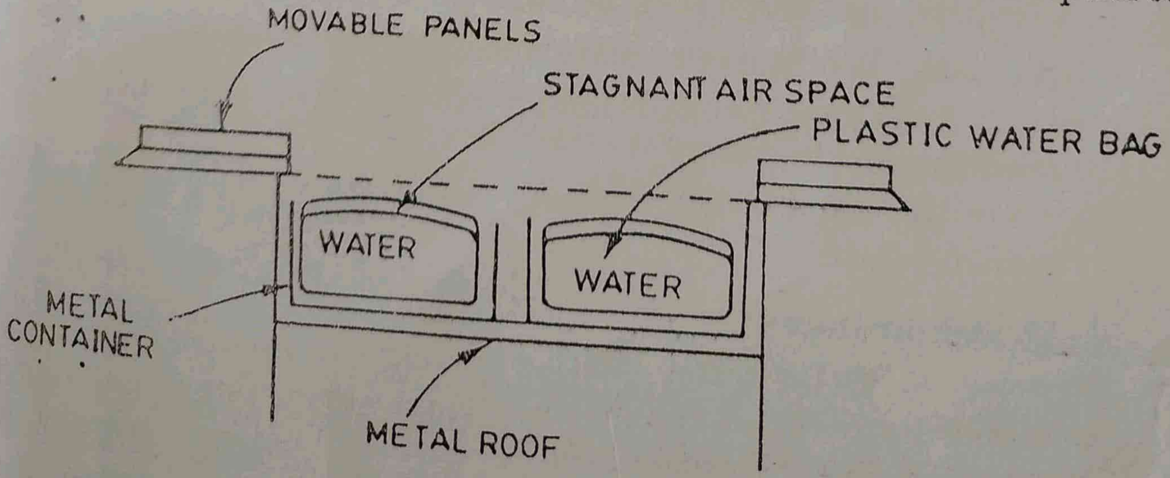


Fig. 5.3.2. Roof storage of Solar heat.

Heat is transferred from the heated water to the rooms below by conduction through a metal ceiling. Air circulation may be aided by means of electric fans, but this is not essential. To prevent loss of heat during the night, thermal insulator panels are moved, either manually or by a time controlled electric motor, to cover the water bags. In the day time, the panels, which are in sections, are removed and stacked one above the other.

Convective Loop. In most passive solar space heating systems, the heated air is circulated by convection, but the term convective loop is applied to systems that resemble the thermosiphon hot-water scheme described earlier. Such a convective loop heating system is outlined in Fig. (5.3.3). It includes a conventional flat-plate collector at a level below that of the main structure. A bed of rock, which may be located beneath a sun space, provides thermal storage. In normal operation, air passing upward through the collector is heated and enters the building through floor vents. The cool, denser air leaving the building returns to the bottom of the collector and is reheated. If more solar heat is available than is required for space heating, the floor vents may be partly (or wholly) closed. The heated air then flows through and deposits heat in the storage bed. Heat stored in this way may be used later, as needed, by transfer to the cooler air leaving the building.

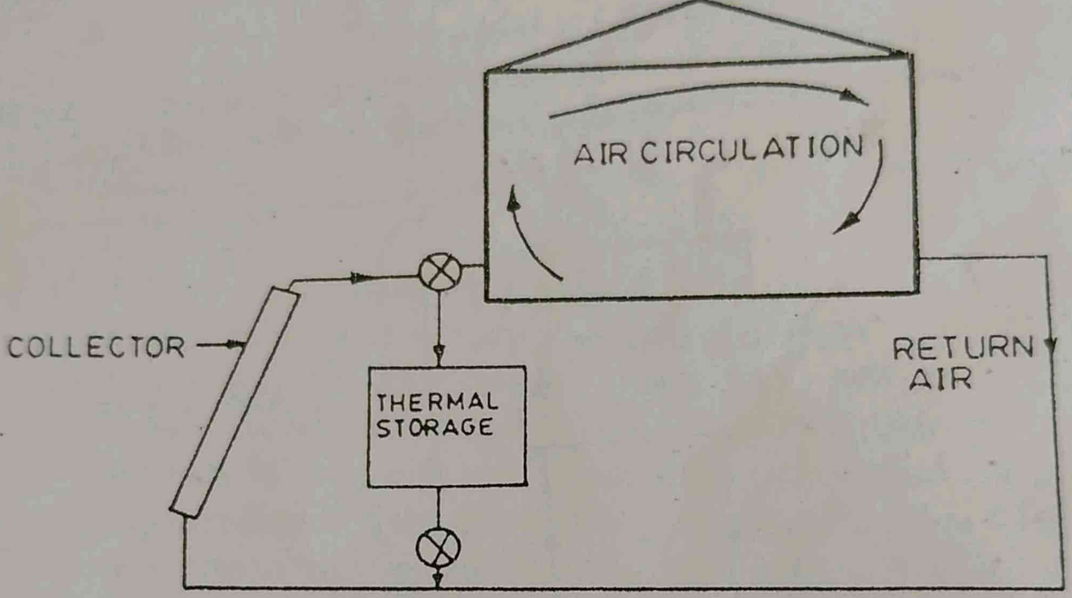


Fig. 5.3.3. Convective loop passive Solar heating.

(B) Active Space-Heating Systems. Most of the hundreds of solar-heated residences built throughout the world use the active system, in which separate collectors are used together the solar radiation, transfer it to water or air, and store it in tanks of water or rock piles or both. The water and air are circulated by pumps or fans and conventional means are used to distribute the heat to the interior of the residences.

General Principles. Nearly all existing or proposed active solar space-heating and/or hot-water supply systems utilize three main components in addition to pumps and blowers : (1) a solar radiation collector with its associated heat transport (or heat-transfer) fluid, (2) a heat-storage medium, and (3) a distribution systems. The same arrangement of components can also be used to provide hot water for domestic and related use and, with the addition of other components, space cooling (air conditioning). In the collector the solar radiation is collected and converted into heat. The heat-transport fluid removes the heat and carries it to the heat-storage system ; the heat can then be withdrawn from the storage and distributed throughout the building.

Schematics of basic hot water and hot air heating systems are given in the Fig. (5.3.4) and (5.3.6) respectively and their individual components are considered in the following sections.

(1) Basic Hot Water System

An outline of an active heating system with a sloping flat plate collected located on the roof of the building is given in Fig. (5.3.4). This

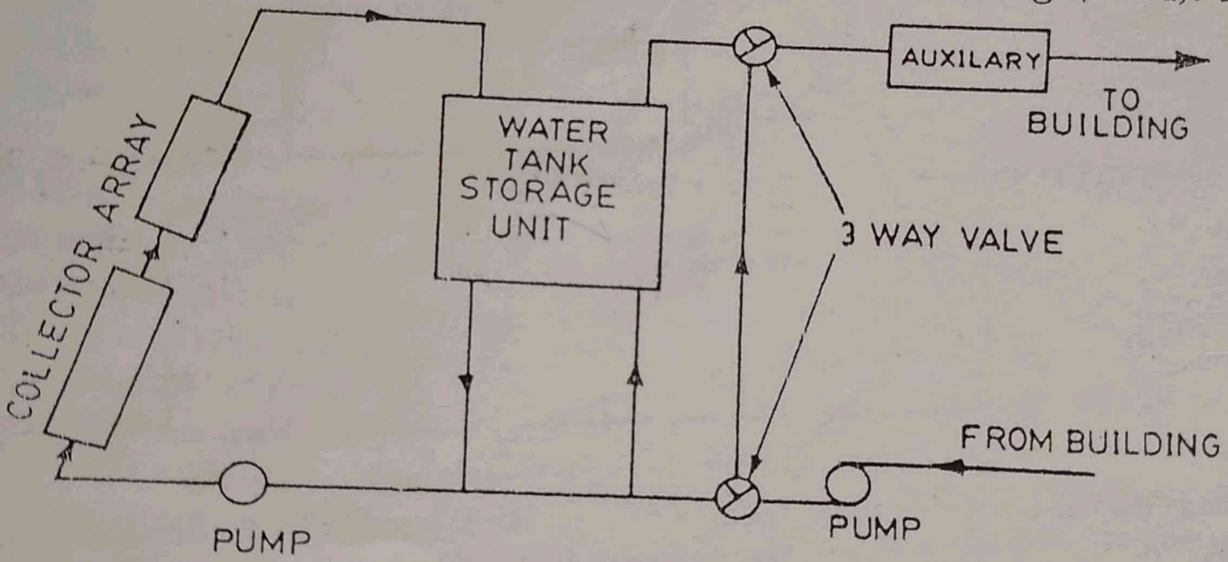


Fig. 5.3.4. Schematic of a basic hot water active system.

is a basic *hot water heating* system, with water tank storage and auxiliary energy source. Heat is transferred to the water in the storage tank, commonly located in the basement of the building. The solar heated water from the tank passes through an auxiliary heater, which comes on automatically when the water temperature falls below a prescribed level. For space heating, the water may be pumped through radiators or it may be used to heat air in a water to air heat exchanger.

During normal operation, the three way valves are set to permit solar heated water to flow from the storage tank and auxiliary heater to the distribution system and back to the tank. If after several cloudy days, the heat in storage is depleted, the valves will adjust automatically to bypass the storage tank. In this way, auxiliary heating of the large volume of water in the tank is prevented. If the temperat the heater at the top of the collector should fall below that at the b of the tank, the pump (at bottom left of figure) would be switch automatically.

If in this system, the heat transport medium is an ant solution, then there is a closed circuit of it, with the heat exchan in the storage tank. This type of solar space heating system w water system is shown in Fig. (5.3.5).

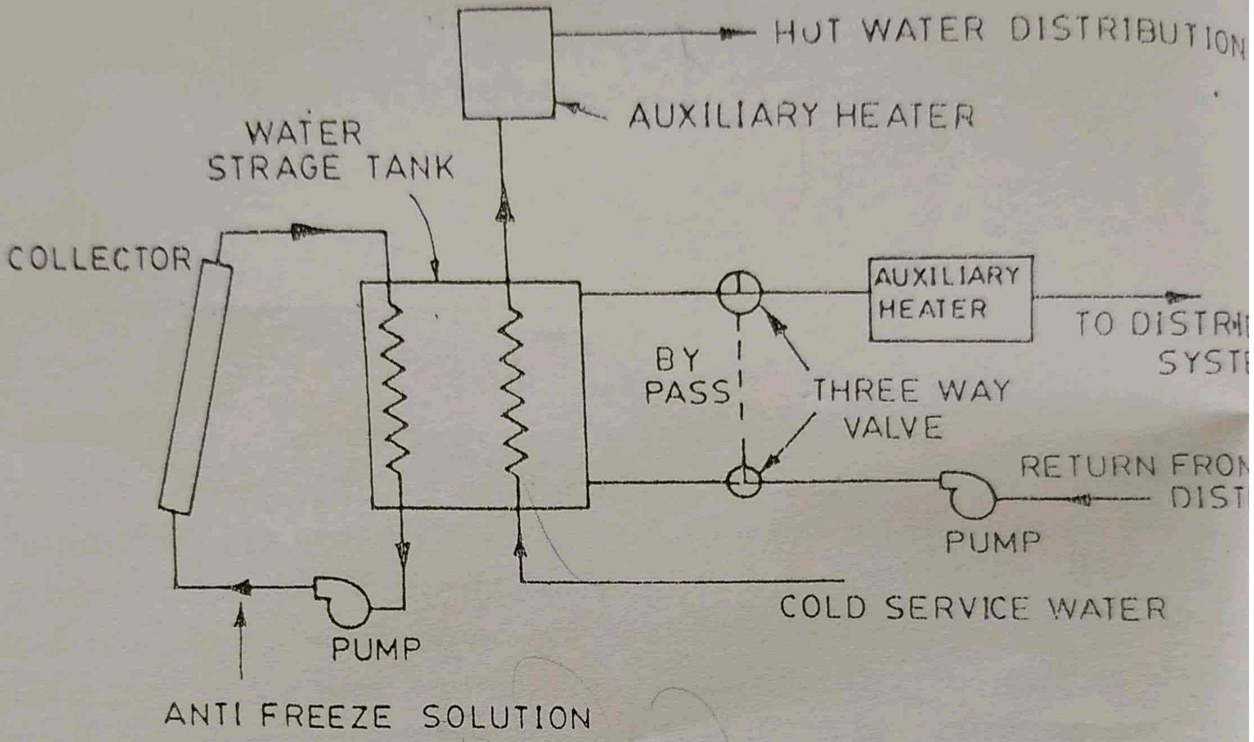


Fig. 5.3.5. Solar space heating and hot water system.

Advantages and disadvantages of basic hot water s listed below :

Advantages

(*i*) In case of water heating, a common heat transfer a medium, water is used, this avoids temperature drop durin of energy into and out of the storage.

(*ii*) It requires relatively smaller storage volume.

(*iii*) It can be easily adopted to supply of energy to abs conditioners, and

(*iv*) Relatively low energy requirements for pumping transfer fluid.

Disadvantages

(*i*) Solar water heating system will probably opera water temperature than conventional water systems and t additional heat transfer area or equivalent means to transf building.

(*ii*) Water heaters may also operate at excessively high temperatures (particularly in spring and fall) and means must be provided to remove energy and avoid boiling and pressure build up.

(*iii*) Collector storage has to be designed for overheating during the period of no energy level.

(*iv*) Care has to be taken to avoid corrosion problems.

(2) Basic Hot Air System

Schematic diagram of a basic hot air heating system is shown in Fig. (5.3.6). In this system the storage medium (pebbles or rock) is held

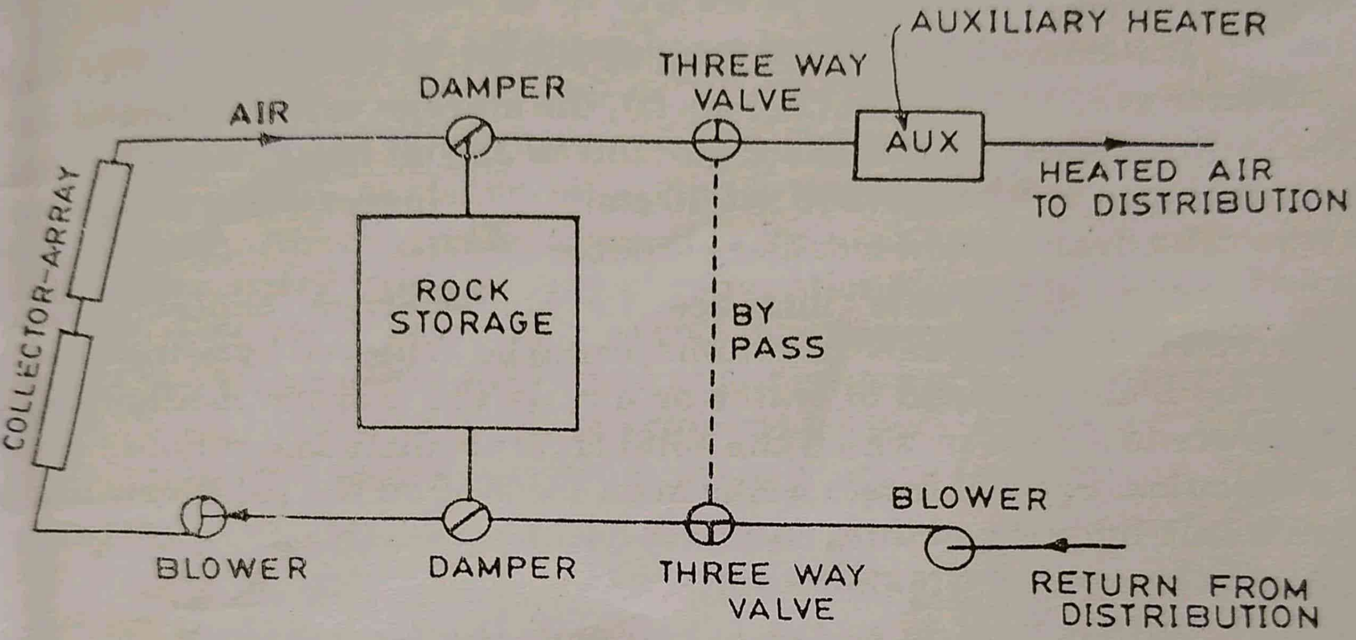


Fig. 5.3.6. Schematic diagram of a basic hot air heating system.

the storage unit, while air is the fluid used to transport energy from llector to the storage and to the building. By adjusting the dampers, e heated air from the collector can be divided between rock storage nd the distribution system, as might be required by the conditions. For ample, when the sun shines after several cloudy days it would be sirable to utilize the available heat directly in the distribution system ther than placing it in storage. Two three way valves can be used to pass the storage tank, as explained above. An auxiliary source of ating is also provided. Auxiliary heating can be used to augment the ergy supply to the building from the collector or storage if the supply heat from it is inadequate.

The position of the blower in figure is shown at the upstream of e collector and the storage, and it forces the air through these for ating. In this case slight leakage of heated air will take place. Blower also be placed on the down stream side of the collector and storage, that the pressure in the collector is not above ambient pressure, ich might be advantageous in controlling leakage.

System based on this concept have number of *advantages*, compared with those based on use of water as a heat transfer medium.

(*i*) There is no problem with freezing in the collectors.

(*ii*) Corrosion problems are minimised.

(*iii*) Conventional control equipment for air heating is already available and can be readily used.

(*iv*) Problems of designing for over heating during periods of no energy removal are minimized, and,

(*v*) The working fluid is air and the warm air heating systems are in common use.

Disadvantages of air heating system are :

(*i*) Relatively higher power costs for pumping air through the storage medium.

(*ii*) Relatively large volumes of storage units.

(*iii*) Difficulty of adding absorption air conditioners to the system.

Collectors and Heat Transport. Because of their simplicity, fixed position, flat-plate collectors are almost invariable used in space heating applications of solar energy. Since they can collect diffuse as well as direct solar radiation, flat-plate collectors are partially effective even when the sun is not shining. Either air or water can be used as the heat-transport fluid. The plumbing system is less likely to have problems in a system using air, but larger ducts and a larger heat-storage volume are required.

Many types of flat-plate collectors are available. As a general rule, these collectors are fabricated in panels, commonly about 6 to 8 ft (1.8 to 2.4 m) long and 3 to 4 ft (0.9 to 1.2 m) wide. The number of panels (or the total collector area) depends on the space to be heated (or cooled) and the local climate, as well as on economic factors. In new home construction, the panels are mounted on a roof facing south (or south-southwest) with the optimum slope (*e.g.*, latitude + 15° for heating). Otherwise, the panels with the required slope may be placed on the ground or on a flat roof, if one is available. The panels must then be spaced in such a manner that they do not shade one another significantly when the sun is low in the sky.

An essential piece of information for the design of a collector for space heating is the daily insolation, that is, the total amount of direct and diffuse solar radiation energy received per day on a horizontal surface of unit area on the ground. For a surface inclined at an angle to the horizontal equal to the latitude + 15°, the solar radiation received is higher in winter and lower in summer.

From a knowledge of the daily temperatures throughout the year, it is possible to determine the amount of thermal energy (heat) required for space heating in the winter and cooling in the summer. By using the daily insolation at the given location, an estimate can then be made of the area of a flat-plate collector, sloping at a prescribed angle, that will supply a certain proportion of the heat required.

The degree (or percentage) of dependence on solar energy for which a collector system is designed is determined by balancing the cost of the collectors against the estimated future costs of alternative energy sources. It is the future rather than the present costs that are important in this respect. The higher the expected cost of an alternative energy supply, the larger the economically acceptable collector area. Thus in deciding on this area, the local climatic and economic factors must be considered. Further more, the collector area should be proportional to the area of the building to be heated (or heated and cooled). A very rough rule for moderately cool climates is a collector area about 50 percent of the floor area.

Heat Storage. A means for storing heat is necessary in active solar energy systems to supply heating requirements during the evening and on cloudy days. The larger the heat-storage volume, the greater is the heat-storage capacity for a given material and the longer the sunless period for which heat could be available. But increasing the volume means increasing the cost and space requirements. As a compromise, heat storage tanks are generally designed to have a heat capacity equivalent to three days normal demand. The common heat storage materials are water and small pieces of rock. When water (or an antifreeze solution) is used as the heat transport fluid in the collector, a large, well-insulated tank of water provides the heat storage. The water may be pumped directly from the collector through the storage tank. It may pass through a heat exchanger coil in the tank when the heat-transport liquid contains an antifreeze compound (*e.g.*, ethylene glycol).

If air is the heat-transport medium, the heat is usually stored in pieces of rock or pebbles, roughly 2 in. (5 cm) across, contained in an insulated tank through which the air circulates. The efficiency of transfer of heat from the hot air to the rock pieces is greater for smaller sizes of the pieces. With decreasing size, however, the resistance to air flow increases and more pumping power is required to circulate the air. The selected size thus represents a compromise between two opposing factors.

A given volume of water can store substantially more heat than an equal volume of rock, assuming the same temperature increase in each case. Thus, water can store 4100 kilo joules per cubic metre per

°C increase in the temperature on the other hand, the rock can st roughly 1460 KJ per cu m per °C, where the volume includes allowa for the spaces between the rock pieces. Hence, for the same heat stora rock would occupy about three times the volume of water.

The following data provide an approximate guide to the relati ship between the storage volume and the area of the flat plate s collector for water and rock storage :

Water : 0.05 to 0.075 m^3 per m^2
Rock : 0.17 to 0.02 m^3 per m^2.

These numbers are average values for different climatic co tions ; both smaller and larger volumes have been used in sp circumstances.

If a home with a floor area of 150 sq. m (1600 sq. ft) has a collector area of 85 sq. m (915 sq. ft), the storage volume of water w be in the range of 4.2 to 6.3 cum (150 to 225 cu ft), whereas for ro would be 14 to 21 cum (500 to 750 cu ft). The larger volume in each would be desirable in a colder climate.

A considerable increase in heat-storage capacity, w corresponding decrease in volume, could be achieved by using a su salt-hydrate, instead of water or air, as the storage medium. A hydrate is a salt in which the solid crystals include a number of molecules. Special interest has been focused on the relatively ine sive salt-hydrate sodium sulphate decahydrate (Na_2SO_4, $10H_2O$) monly known as Glauber's salt.

When heat is added to the salt, the temperature increa 32°C, called the transition point. At this point, the temperature re constant while the salt changes to an aqueous solution plus Na_2SO_4 (*i.e.* without the water molecules) ; during this stage h stored, although the temperature does not rise. When all the N 10 H_2O has been changed to Na_2SO_4, the temperature can inc again as more heat is added. If heat is withdrawn from the syste temperature falls to 32°C, where it remains while the stored h released and the Na_2SO_4 10 H_2O is completely regenerated ; thu

$$NO_2SO_4\ 10\ H_2O \underset{\text{Heat withdrawn at } 32°C}{\overset{\text{Heat supplied}}{\rightleftharpoons}} Na_2SO_4\ (\text{solid}) + H_2O\ (\text{sol}$$

In this way, the system offers the potential for storing he 32°C in about one-third the volume of a water tank (or one-tent volume of rock) for the same heat capacity.

Salt-hydrate heat storage has been tested in solar heating sys with air as the transport medium. The salt was contained number of stacked 5-gallon (19 litre) cans around which the ai circulated. The systems operated well for a time but gradually deterior

The reason was that as the solid Na_2SO_4 formed (from the Na_2SO_4 10 H_2O), it tends to deposit on the walls of the storage cans. As a result, the reverse process, in which the Na_2SO_4 10 H_2O is regenerated from the Na_2SO_4, did not occur completely. Hence, the storage capacity decreased as the system was operated. Further more, the solid deposited on the walls decreased the heat transfer efficiency. A possible means of overcoming both of these difficulties is by slow rotation of a drum containing the salt hydrate, the solid Na_2SO_4 formed would then remain in suspension in the solution.

Heat distribution. The distribution system for solar space heating is much the same as for any other heat source ; in fact, existing systems for the gas or oil heat have been readily adopted, to solar heating.

When water is the heat-transport fluid, it may be circulated through radiators in the building to be heated, and then back to the storage tank. Alternatively, a water to air heat exchanger can serve to heat air for distribution by way of conventional heating ducts. The air is blown (or drawn) across a pipe coil (heat exchanger) through which the hot water flows (Fig 5.3.7). In a modification of this system, transfer of heat from hot water to air is achieved by passing the air through a container of rock pieces surrounding the storage tank.

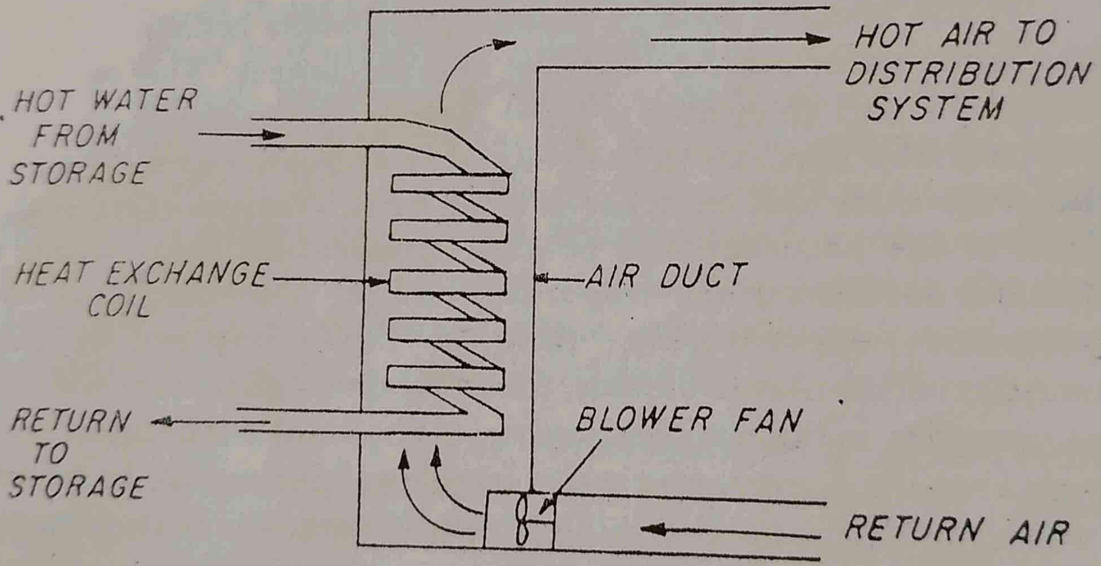


Fig. 5.3.7. Water-to-air heating system.

If air is the heat-transport fluid (with rock or salt-hydrate storage), the heated air can be circulated through the building and back to the storage system. The building space is then part of a closed circuit.

5.4. Space Cooling (or Solar Cooling of Buildings)

Introduction. The major current interest is in mechanical cooling (or air-conditioning) systems that depend on solar heat for their operation and are unaffected by atmospheric humidity. The two most common *refrigeration* techniques are vapor compression and absorption and, in principle, both could be adopted for use with solar energy, although the temperatures required are higher than those adequate for space heating. In the former procedure, solar heated water could vaporize propane or ammonia at a moderate pressure. The vapour could then drive a *turbine* which would in turn, operate a vapor-compression cooling unit. Such a low pressure vapor turbine, however, would inevitably have a very low efficiency. Further-more, propane is highly flammable whereas ammonia forms a noxious gas.

Absorption cooling with solar energy, which is regarded as more practical, is possible with current technology although improvements in design would be desirable.

(1) Absorption air conditioning

Two approaches have been to solar operation of absorption coolers. The first is a *continuous cooler* which is in construction and operation, is similar to conventional vapour absorption refrigeration system. The solar collector storage supplies the energy to the generator, where solar energy is available, otherwise it is supplied with the auxiliary energy source. The second approach is to use *intermittent coolers,* which are intermittent in operation and operate during the periods when solar energy is available. Intermittent coolers have not been used for air conditioning nor have been studied sufficiently for their application in solar air conditioning.

The two types of *absorption air conditioners* available in the market, the lithium-bromide water ($LiBr—H_2O$) system and the ammonia-water ($NH_3—H_2O$) system. Of the two common absorption air conditioning systems, the $LiBr—H_2O$ is simpler since a rectifying column assures that no water vapour, mixed with NH_3 enters the evaporator where it could freeze. In the $LiBr—H_2O$ system water vapour is a refrigerant. In addition, the aqua-ammonia system requires generator temperature of the order of 120°C to 150°C, such a temperature is higher than a flat-plate collector can provide, without special techniques. But this system could be possible with concentrating type collectors. The $LiBr—H_2O$ system requires lower generator temperature of the order of 85° to 95°C which are achievable by a flat plate collector. Also the $LiBr—H_2O$ system posses higher C.O.P. than the aqua-ammonia ($NH_3—H_2O$) system. The disadvantage of $LiBr—H_2O$ systems is that the water can not exit in liquid form below triple point temperature, (*i.e.*, 0°C, practically, this system can not operate much below 4°C) since the refrigerant is water vapour. This is not a major disadvantage in air conditioning applications.

The effective performance of an absorption cycle depends on the two materials that comprise the refrigerant-absorber pair. These two working fluids must have the following characteristics :

1. The absence of a solid phase absorbent.

2. A refrigerant more volatile than the absorbent, in order to be separated from the absorbent easily in the generator.

3. An absorbent that has small affinity for the refrigerant.

4. A high degree of stability for long-term operations.

5. It refrigerant that has a large latent heat so that the circulation rate can be kept at the minimum.

6. A low corrosion rate and nontoxicity for safety reasons.

The only disadvantage of the LiBr—H_2O pair is the possible problem with crystallization in the generator.

(A) LiBr—H_2O System. The absorption air conditioning system is shown schematically in Fig. (5.4.1). The system consists of two parts *viz.*

(*i*) the solar collector and storage, and

(*ii*) the absorption air conditioner and the auxiliary heating.

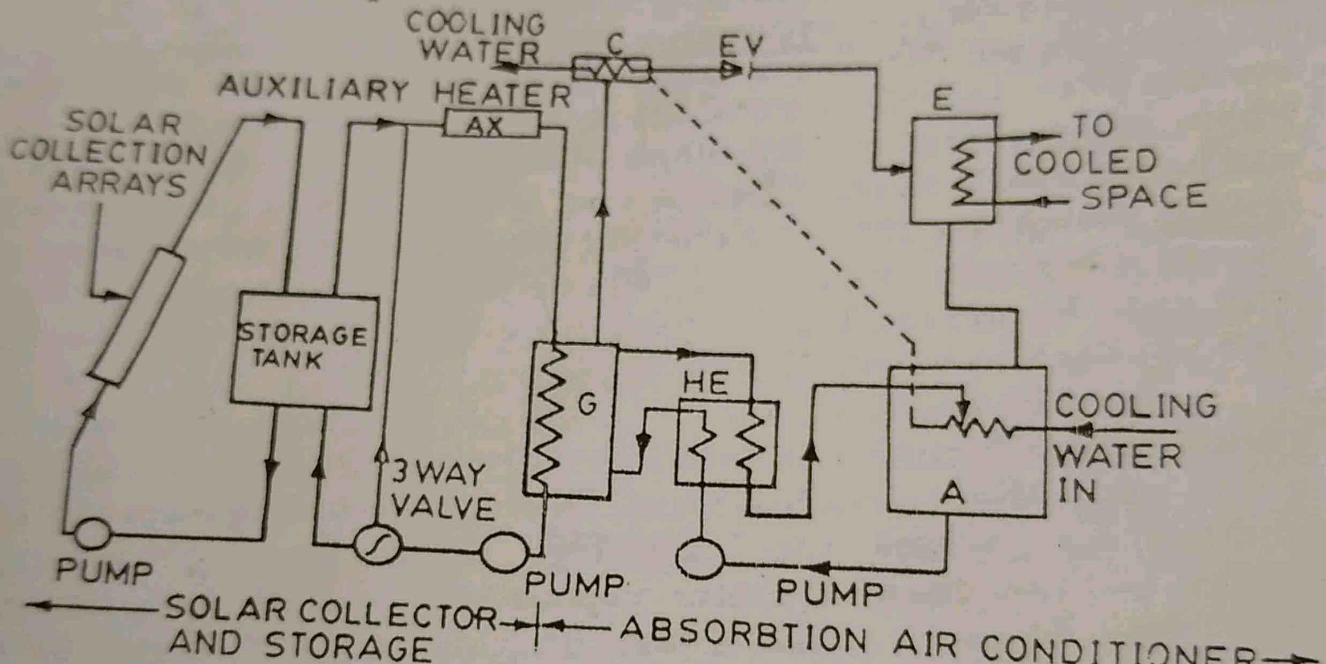


Fig. 5.4.1. Schamatic of Solar Operated Absorption Air Conditioner.

The essential components of the cooler are, (*i*) generator (G), (*ii*) condenser (C), (*iii*) evaporator (E) (*iv*) absorber (A) (*v*) heat-exchanger (HE).

The operation of air conditioners with energy from flat-plate collector and storage systems is the most common approach to the solar cooling today. In essence cooling is accomplished as the generator of the absorption cooler is supplied with heat by a fluid pumped from the collector storage system or from auxiliary. Heat is supplied to a solution of refrigerant in absorbent in the generator, where refrigerant is distilled out of the absorbent fluid..The refrigerant (now liquid) is condensed and goes through a pressure reducing valve to the evapor where it operates and cools air or water for the cooling space. refrigerant vapour goes to the absorber where it comes in contact the solution which is weak in refrigerant and which flows from generator. The vapour is absorbed in the solution, which is returned to the generator. A heat exchanger is used for sensible recovery and greatly improves cooler C.O.P.

From the point of view of use of a conventional energy sou there is a single index of performance for rating cooling processes, is the COP (Coefficient of performance), the ratio of the amou cooling to the energy required. For solar operation there are additional factors, the temperature required in the solar collect drive the process and the ratio of cooling produced to solar en incident on the collector. As solar processes are inevitably transie their operation, the energy ratios and temperatures will vary with and COP based on long term integrated performance provide appropriate index of performance. Pumping to more absorbent sol may be by mechanical means or by vapour-lift pumping in the gene for low pressure systems like LiBr—H_2O system require water co of absorber and condenser. Systems of this type shown in the f have been the basis of most of the experience to date with sola conditioning.

The coolers used in most experiments todate are LiBr- machines water-cooled absorber and condenser. The pressure i condenser and generator is fixed largely by temperature drops a heat transfer surfaces in the generator and condenser. The press the evaporator and absorber is fixed by the temperature of the c fluid to the absorber and by the temperature drop across the transfer surfaces in the evaporator and the absorber. Thus, to kee generator temperatures within the limits imposed by the ch teristics of flat-plate collector, the critical design factors and opera parameters include effectiveness of the heat exchangers and co temperature. Common practice in solar experiments has been t water cooled absorbers and condensers,which in turn requ cooling tower.

Many of the machines used to date have nearly constant (ratio of the cooling produced to energy supplied to the generat the generator temperature varies over the operating range as lo it is above a minimum value. The COP of LiBr-H_2O coolers is of the range of 0.6 to 0.8. The effect of variation in the solar energy s temperature to the generator is to vary the capacity of the cooler. is used as a coolant, and the generator temperatures may be in the of 75 to 95°C.

Major problem areas of system using solar operated LiBr-H_2O coolers include the following :

Supply temperatures of the fluid to the generator must be higher than the generator temperatures. There is a 'squeeze' between the supply temperatures required and the upper temperature limits of 100°C for unpressurized water storage tanks. Operation at 100°C is difficult with many collector types, particularly flat plate collectors. Cooling towers are needed in these systems.

Absorption coolers for present solar power projects are being designed to use temperatures at low as 80°C. In order to maintain reasonable efficiencies are high temperatures, collectors must (*i*) be built to withstand potentially high pressures within the system, (*ii*) have special transparent cover plates that admit the highest possible amount of incident radiation, yet be specially coated to reduce radiation of the energy as heat ; and (*iii*) have absorber plates that are of high grade metal, such as copper, with special selective coatings to increase absorptance and decrease emittance (reradiation of heat). In many cases, too, the collector must be made larger for the summer cooling mode than for the winter heating mode.

(B) **NH_3—H_2O coolers.** The schematic diagram of an ammonia water cooler is similar to that of Fig. (5.4.1) above, except that a rectifying section must be added to the top of the generator to reduce the water vapour content of the vapour stream going to the condenser. The basic solution processes are similar to those of the LiBr—H_2O system, except that the pressures and pressure differences are much higher. Mechanical pumps are required to return solutions from the absorber to the generator. In many applications the condenser and the absorber are air cooled, with generator temperatures in the range of 125 to 175°C. In applications where water cooling is used, generator temperature may be in the range of 95 to 120°C.

There has been relatively little work done on experimental operation of NH_3—H_2O systems with solar energy. The generator temperatures required in today's commercial coolers using air cooled condensers and absorbers are too high for present flat-plate collectors. Two approaches can be taken to this problem : Increase the temperature range of operation of collectors or reduce the generator temperature of the cooler. Work on NH_3—H_2O system has been directed at development of cycles using higher concentration of NH_3 and high effectiveness components to reduce generator temperature requirements. Collector developments such as evacuated tubular collectors, CPC (compound parabolic concentrator) or other focusing collectors, or well designed flat plate collectors with selective absorbers and low-reflectance covers may provide means of supplying energy at higher temperatures. In this case, new means of energy storage in the range of 100 to 170°C would have to be available.

(2) Intermittent absorption cooling

A modified method for absorption cooling which operates intermittently rather than continuously, is based on the following principle. In it, the system consists of two vessels which function in two alternative modes. In one (regeneration) mode, one of the vessels is the generator

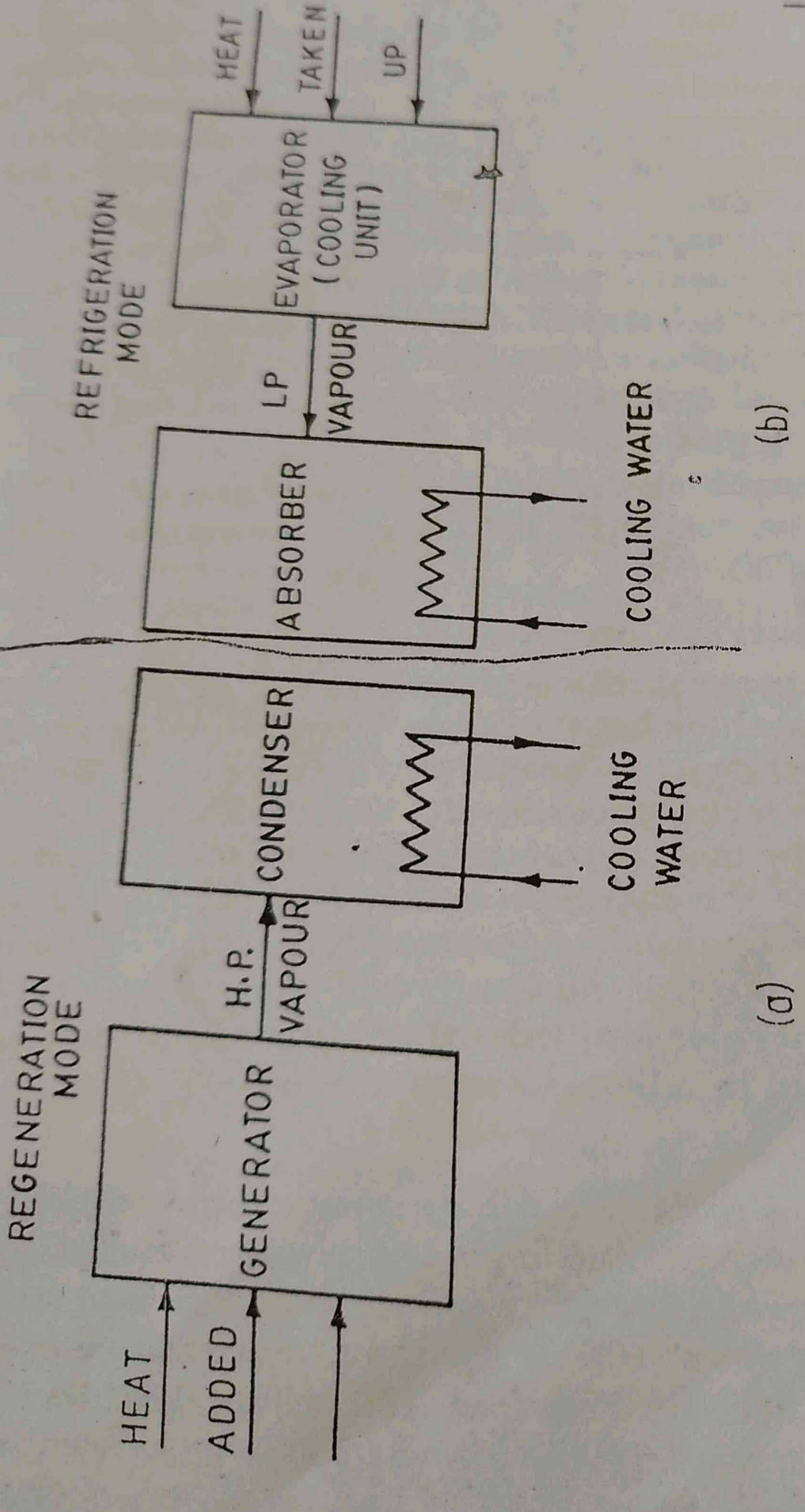


Fig. 5.4.2. Intermittent absorption refrigeration.

central pipe surrounded by an evacuated quartz envelo collected by a fluid flowing through the pipes could be stored at a temperature above 500°C in a molten eutectic salt and used as required to produce steam for electric power generation.

As noted earlier, distributed solar energy collectors may be preferred for thermal power plants of moderately small capacity (about 2 MW or less). Among the potential applications of such small plants, two under study are :

(1) total energy systems, and

(2) pumping water for irrigated farms.

Total Energy (or Cogeneration) systems. The total energy concept is based on the sequential use (or cascading) or solar energy at two different temperature levels. First, a working fluid at a higher temperature can be used to drive a turbine and generate electricity in the usual manner. Then the heat discharged in the condenser cooling water at a lower temperature can be utilized for space heating and cooling. Alternatively, in a cogeneration system, the turbine discharge may be used to provide process steam for industry. For the discharged heat to be useful, the temperature should be higher than in a conventional steam electric power plant. As a result, the efficiency for electricity generation is decreased, but this can be more than offset by the economic value of the discharged heat.

Irrigation water pumping. Irrigation pumps of relatively low power can be driven directly by a vapour turbine using solar energy as described earlier. For deep wells, pumps of higher power are required, and these are preferably operated by electric motors. In a deep-well irrigation project, solar energy is used to heat a hydrocarbon oil to about 290°C by passage through an array of parabolic trough type concentrating collectors. The heat fluid passes by way of a thermal storage tank, to a heat exchanger where toluene is boiled to provide vapour for operating a turbine generator combination. Pumped water is used as a coolant in the turbine condenser, and the temperature is more like a conventional power plant. The electric power which can be generated is of the order of 150 kW drives electric motors to operate a deep-well pumps.

5.6. Solar Electric Power Generation : Solar Photo-Voltaics

Introduction. The direct conversion of solar energy into electrical energy by means of the photovoltaic effect, that is, the conversion of light (or other electromagnetic radiation) into electricity. The photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. Energy conversion devices which are used to convert sunlight to electricity by the use of the photovoltaic effect are called *solar cells*. A single converter cell is called a solar cell or, more generally, a *photovoltaic cell*, and combination of such cells ; designed to increase the electric power output is called a *solar module* or *solar array*.

Photovoltaic cells are made of semiconductors that generate electricity when they absorb light. As photons are received, free electrical charges are generated that can be collected on contacts applied to the surfaces of the semiconductors. Because solar cells are not heat engines, and therefore do not need to operate at high temperatures, they are adopted to the weak energy flux of solar radiation, operating at room temperature. These devices have theoretical efficiencies of the order of 25 per cent. Actual operating efficiencies are less than half this value, and decrease fairly rapidly with increasing temperature.

The best known application of photovoltaic cells for electrical power generation has been in space craft, for which the silicon solar cell is the most highly developed type. The silicon cell consists of a single crystal of silicon into which a doping material is diffused to form a semiconductor. Since the early days of solar cell development, many improvements have been made in crystal growing and doping, electrical contact and cell assembly and production methods. Large number of cells have been manufactured with areas 2 × 2 cm, efficiencies approaching 10 per cent, and operating at 28°C. The *efficiency* is the power developed per unit area of array divided by the solar energy flux in the free space (1.353 kW/m^2).

For terrestrial applications, silicon solar cells have shown operating efficiencies of about 12 to 15 per cent. Though silicon is one of the earth's most abundant materials, it is expensive to extract (from sand, where it occurs mostly in the form SiO_2) and refine to the purity required for solar cells. The greater barrier to solar cell application lies in the costs of the cells themselves. Reducing the cost of silicon cells is difficult because of the cost of making single crystal. One very promising method is being developed to produce continuous thin ribbons of single-crystal silicon to reduce fabrication costs. Cells made from the ribbon have so far shown efficiencies of around 8 per cent. Several other kinds of photocells are in the laboratory stage of development. Cadmium sulfide and CdS/Cu_2S cells are other possibilities. So far, efficiencies have been in the range of 3 to 8 per cent, and these cells have been less durable than silicon cells owing to degradation with exposure to oxygen, water vapour and sunlight, especially at elevated temperatures. The active part of the CdS cell is a thin polycrystalline layer of CdS, about 0 μm thick, on which a layer of Cu_2S compound perhaps 0.1 μm thick is grown. These cells can be made by deposition on long sheets of substrates, a process that might be adaptable to expensive mass production.

Photovoltaic cells could be applicable to either small or large power plants, since they function well on a small scale, and may be adaptable to local energy generation on building roof tops. The cost of energy storage and power conditioning equipment might, however, make generation in large stations the most economical method. Solar cells have also been used to operate irrigation pumps, navigational signals, highway emergency call systems, rail road crossing warnings, automatic meterological stations, etc., in location where access to utility power lines is difficult.

A PV (photo-voltaic) system consists of :

(*i*) Solar cell array

(*ii*) Load leveller

(*iii*) Storage system

(*iv*) Tracking system (where necessary).

In actual usage, the solar cells are interconnected in certain series/parallel combinations to form modules. These modules are hermetically sealed for protection against corrosion, moisture, pollution and weathering. A combination of suitable modules constitutes an array. One square metre of fixed array kept facing south yields nearly 0.5 kWH of electrical energy on a normal sunny day if the orientation of the array is adjusted to face the sun's rays at any time, the output can increase by 30 per cent. Solar PV system can produce an output only if sunlight is present. If it is required to be used during non-sunshine hours, a suitable system of storage batteries will be required.

Solar Cell Principles. The photo-voltaic effect can be observed in nature in a variety of materials, but the materials that have shown the best performance in sunlight are the semi-conductors as stated above. When photons from the sun are absorbed in a semiconductor, they create free electrons with higher energies than the electrons which provide the bonding in the base crystal. Once these electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semi-conductor to do useful work. The electric field in most solar cells is provided by a junction of materials which have different electrical properties.

To obtain a useful power output from photon interaction in a semi-conductor three processes are required.

1. The photons have to be absorbed in the active part of the material and result in electrons being excited to a higher energy potential.
2. The electron-hole charge carrier created by the absorption must be physically separated and moved to the edge of the cell.

3. The charge carriers must be removed from the cell and delivered to a useful load before they loose their extra potential.

For completing the above processes, a solar cell consists of :

(*a*) Semi-conductor in which electron hole pairs are created by absorption of incident solar radiation.

(*b*) Region containing a drift field for charge separation, and

(*c*) Charge collecting front and back electrodes.

The photo-voltaic effect can be described easily for *p-n* junctio in a semi-conductor. In an intrinsic semi-conductor such as silicon, eac one of the four valence electrons of the material atom is tied in chemical bond, and there are no free electrons at absolute zero. If a piec of such a material is doped on one side by a five valence electro material, such as arsenic or phosphorus, there will be an exces electrons in that side, becomes an *n-type* semiconductor. The exces electrons will be practically free to move in the semiconductor lattic When the other side of the same piece is dopped by a three valenc electron material, such as boron, there will be deficiency of electron leading to a *p-type* semiconductor. This deficiency is expressed in term of excess of holes free to move in the lattice. Such a piece of semi-conductor with one side of the *p-type* and the other of the *n*-type is called *p-n* junction. In this junction after the photons are absorbed, the fre electrons of the *n*-side will tend to flow to the *p*-side, and the holes the *p*-side will tend to flow to the *n* region to compensate for thei respective deficiencies. This diffusion will create an electric field E from the *n* region to the *p*-region. This field will increase until it reache equilibrium for V_e, the sum of the diffusion potentials for holes an electrons. If electrical contacts are made with the two semiconducto materials and the contacts are connected through an external electrica conductor, the free electrons will flow from the *n*-type material throug the conductor to the *p*-type material (Fig. 5.6.1). Here the free electron will enter the holes and become bound electrons ; thus, both fre electrons and holes will be removed. The flow of electrons through th external conductor constitutes an electric current which will continu as long as more free electrons and holes are being formed by the sola radiation. This is the basis of photovoltaic conversion, that is, the conversion of solar energy into electrical energy. The combination o *n*-type and *p*-type semiconductors thus constitutes a photovoltaic (PV) cell or solar cell. All such cells generate direct current which can be converted into alternating current if desired.

The most normal configuration for a solar cell to make a *p-n* junction semiconductor is as shown schematically in Fig. (5.6.1). The junction of the '*p* type' and '*n* type' materials provides an inherent electric field which separates the charge created by the absorption of sunlight. This p-n junction is usually obtained by putting a p-type base material into a diffusion furnace containing a gaseous n-type dopant

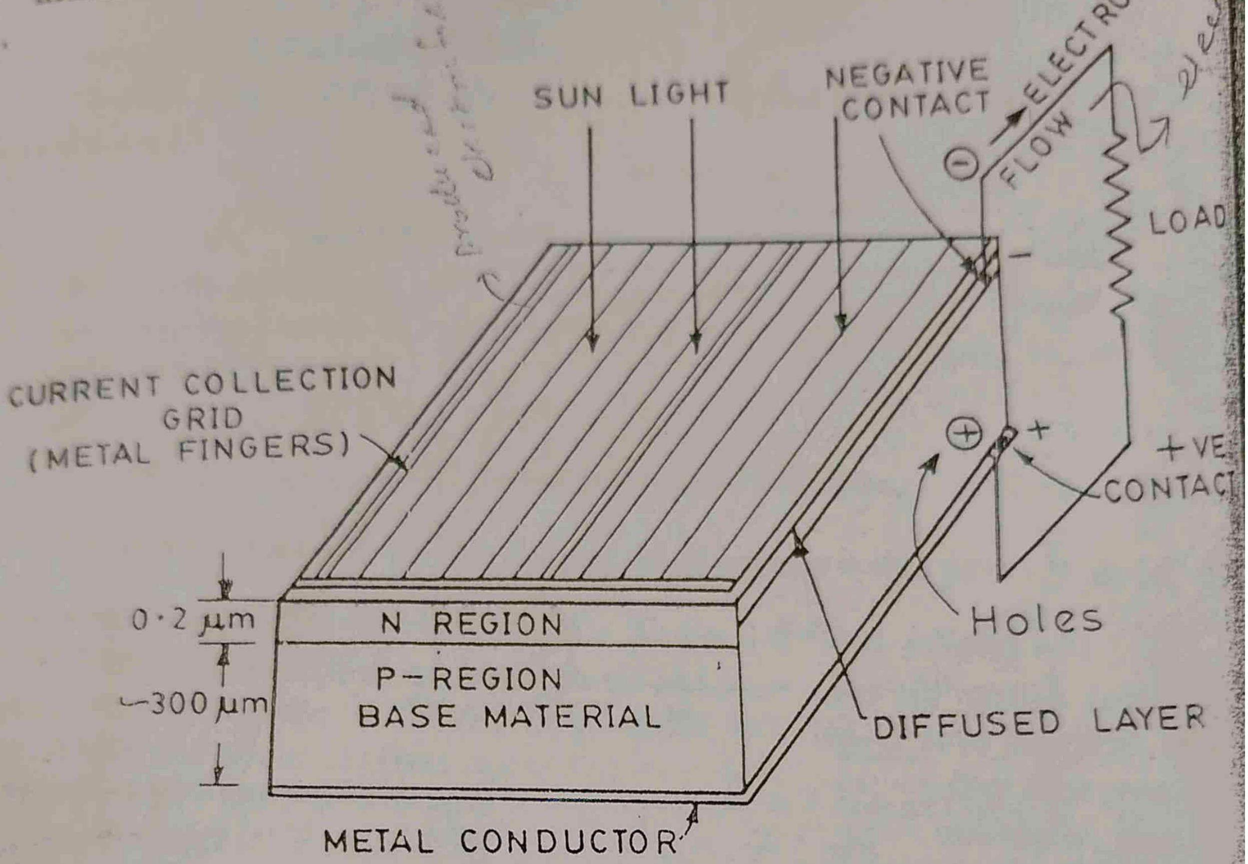


Fig. 5.6.1. Schematic view of a typical solar cell.

such as phosphorus and allowing the n-dopant to diffuse into the surfa about 0.2 μm. The junction is thus formed slightly below the plan surface of the cell and the light impinges perpendicular to the juncti The positive and negative charges created by the absorption of phot are thus encouraged to drift to the front and back of the solar cell. T back is completely covered by a metallic contact to remove the char to the electric load. The collection of charges from the front of the is aided by a fine grid of narrow metallic fingers. The surface cover of the conducting collectors is typically about 5 per cent in order to al as much light as possible to reach active junction area. An antireflec coating is applied on the top of the cell. Fig. 5.6.2 demonstrates how p-n junction provides an electrical field that sweeps the electrons in direction and the positive holes in the other. If the junction i thermodynamic equilibrium, then the *Fermi energy*, must be uni throughout. Since the Fermi level is near the top of the gap of an n-d material and near the bottom of the p-doped side, an electric field exist at the junction providing the charge separation function of the Important characteristic of the Fermi level is that, in thermodyn equilibrium, it is always continuous across the contact between th materials.

aluminium and gallium arsenide.

solar.

A Basic Photovoltaic System for Power Generation

A basic photovoltaic system integrated with the utility grid is shown in Fig. 5.6.5. It permits solarly generated electrical power to be delivered to a local load. It consists of :

(*i*) *Solar Array*, large or small, which converts the insolation to useful DC electrical power.

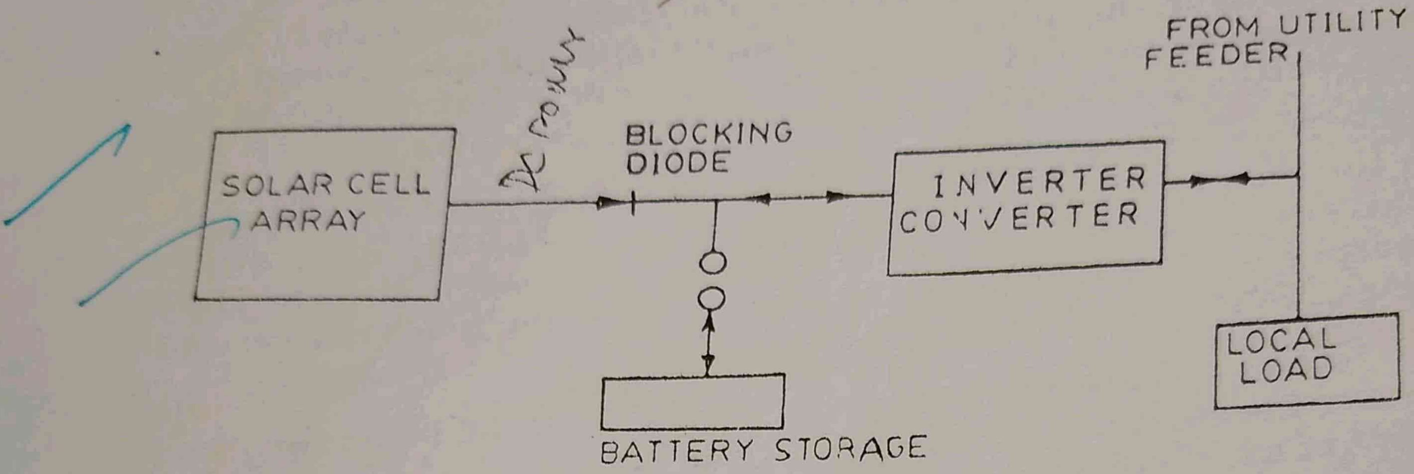


Fig. 5.6.5. Basic photovoltaic system integrated with power grid.

(*ii*) *A Blocking Diode* which lets the array-generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insolation (recall from Fig. 5.6.3 that the cell equivalent circuit has a forward biased diode in it).

(*iii*) *Battery Storage*, in which the solarly generated electric energy may be stored.

(*iv*) *Inverter/converter*, usually solid state which converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a DC, AC inverter. It may also contain a suitable output step up transformer, perhaps some filtering and power factor correction circuits and perhaps some power conditioning, *i.e.* circuitry to initiate battery charging and to prevent over charging. Power conditioning may be shown as a separate system functional block. This block may also be used in figure shown to function as a rectifier to charge the battery from the utility feeder when needed and when no insolation was present.

Applications of Solar Photovoltaic System

Various solar photovoltaic systems have been developed and installed at different sites for demonstration and field trial purposes. The *terrestrial* applications of these include provision of power supply to :

(*i*) water pumping sets for micro irrigation and drinking water supply,

(*ii*) radio beacons for ship navigation at ports,

(*iii*) community radio and television sets,

(*iv*) cathodic protection of oil pipe lines,

(*v*) weather monitoring,

(*vi*) railway signalling equipment,

(*vii*) battery charging,

(*viii*) street lighting.

The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of :

(*a*) a photovoltaic (PV) array,

(*b*) storage battery,

(*c*) power control equipment,

(*d*) motor pump sets, and

(*e*) water storage tank.

Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages : (*i*) Direct room temperature conversion of light to electricity through a simple solid state device.

(*ii*) Absence of moving parts.

(*iii*) Ability to function unattended for long periods as evidence in space programme.

(*iv*) Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.

(*v*) Maintenance cost is low as they are easy to operate.

(*vi*) They do not create pollution.

(*vii*) They have a long effective life.

(*viii*) They are highly reliable.

(*ix*) They consume no fuel to operate as the sun's energy is free.

(*x*) They have rapid response in output to input radiation changes ; no long-time constant is involved, as on thermal systems, before steady state is reached.

(*xi*) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.

(*xii*) They are easy to fabricate, being one of the simplest of semi conductor devices.

(*xiii*) They have *high power to weight ratio*, this characteristic is more important for space applications than terrestrial, may be favourable for some terrestrial applications. The roof loading on a house top covered with solar cells, for example, would be significantly lower than the comparable loading for a conventional liquid solar water heaters.

(*xiv*) Amenable to on site insta persed power ; thus the problem of power distribution by wires could be eliminated by the use of solar cells at the site where the power is required.

(*xv*) They can be used with or without sun tracking, making possible a wide range of application possibilities.

Disadvantage

Their principal disadvantages are their *high cost*, and the fact that, in many applications, energy storage is required because of no insolation at night. Efforts are being made world-wide to reduce costs through various technological innovations.

5.7. Agriculture and Industrial Process Heat

Introduction. By supplying heat, as hot water, hot air or stream, for agricultural and industrial purposes, solar energy has the potential for replacing substantial amounts of fossil (non-renewable) fuels. Solar water heating and air heating are rather well establishe and well known by now. With all sophistications and modern technique solar thermal energy systems are bulkier and still speak of only lo efficiencies. In general in low grade thermal applications, where hea energy can as such be utilised. Solar energy devices could be used wit advantages. Rising oil prices, combined with combustion generate pollution and fast depleting fossil fuels, have forced the developin countries like India to adopt atleast gradually, the low temperatur applications of solar energy. A number of organisations are now offerin a variety of solar systems for domestic, commercial and industrial us essentially in the low and medium temperature range. Apart fro providing hot water or preheating boiler feed water as required, th solar systems are also being installed for more involved application like maintenance of a certain temperature in process, tanks etc.

Solar energy for thermal applications in industries has prove to be economically viable at present for temperatures less than 100° With intensive development in the area of fixed and tracking con centrators, temperatures 0° upto 300°C will be feasible. The technolog is expected to be matured in near future. In the present energy contex it is desirable to provide thermal energy below 300°C from solar. Th is mandatory since high quality fuel, such as coal or oil, with high flan temperature when used for low temperature applications result in ve low efficiency. Therefore the choice of solar energy for direct therm applications upto 300°C in industries is quite obvious. The high quali fuel (coal, oil etc.) can be diverted for more important high temperatu tasks. With this concept, the development of economically viable sol devices become more meaningful.

Agricultural and Industrial Applications and Potentials

These applications of solar energy may be considered in three general categories, according to the temperature range within which the heat is supplied.

1. Low temperatures below 100°C.
2. Intermediate temperatures 100 to 175°C.
3. High temperatures above 175°C.

Low temperature applications. These are based on the use of flat-plate collectors, with either air or water as the heat transport medium. The general principles are the same as for space and water heating. The hot water may be utilized directly or the heat may be transferred to air. Provision must be made for storage of excess heat in water or in rocks or gravel. Among the potential applications of low temperature heat in the *agriculture* are the following :

Heating and cooling of commercial green houses.

Space heating of livestock shelters, dairy facilities and poultry houses.

Curing of bricks, plaster board etc. Drying grain, soybeans, peanut pods, fruits, tobacco, onions and kiln (Lumber). Solar energy can also be used to convert salty water (or other impure water) into potable water by distillation. Such solar stills have been operated for farm and community use, in several countries.

Intermediate Temperature Applications. Food processing, textile, laundry, and other industries often require both hot water and low pressure steam. For such applications, water can first be heated in flat-plate collectors followed by an array of parabolic trough concentrating collectors. In this way, water under moderate pressure, can be heated to temperatures above 100°C. Some of the processes which fall in the category of intermediate temperature applications are the following :

Laundries, Fabric drying, Textile dyeing, Food processing and can washing, kraft pulping (in paper industries), Laminating and drying glass fibre. Drying and baking in automobile industries, pickling (in steel industries) etc.

High Temperature Applications. Steam at temperatures above 175°C is used extensively in Industry particularly in the generation of electric power. The same general methods for producing high temperature steam with the aid of solar energy are applicable in all cases ; they are described in the section of *Thermal Electric Conversion*. A high temperature application of solar energy is in pumping of irrigation water.

The several advantages of industrial applications over residential or commercial ones are :

(i) Industrial loads are mostly on continuous basis throughout the year.

(ii) Industrial plants have maintenance crew, or in small plants skilled people, who can attend to smooth operation of solar systems.

(iii) Total quantum of energy replaced by solar is significantly more causing higher reduction in oil imports and diversion of coal for high temperature tasks.

However there are some limitations :

(i) Intermittent availability of solar energy.

(ii) Instantaneous area. In all the cases roof area may not be adequate to accommodate required collector area. Additional costly land may have to be used. In some cases, roof have east west slopping, instead of north glazing type, rending placement of collectors to be costly and unaesthetic.

(iii) Industrial effluents can be harmful to the transparent covers and reflecting surfaces.

(iv) Through pay back period has come down to 3—5 years (hot water and air only), high initial capital investment is a major impediments.

5.8. Solar Distillation

Fresh water is a necessity for the sustenance of life and also the key to man's prosperity. It is generally observed that in some arid, semi arid and coastal areas which are thinly populated and scattered, one or two family members are always busy in bringing fresh water from a long distance. In these areas solar energy is plentiful and can be used for converting saline water into distilled water. The pure water can be obtained by distillation in the simplest *solar still*, generally known as

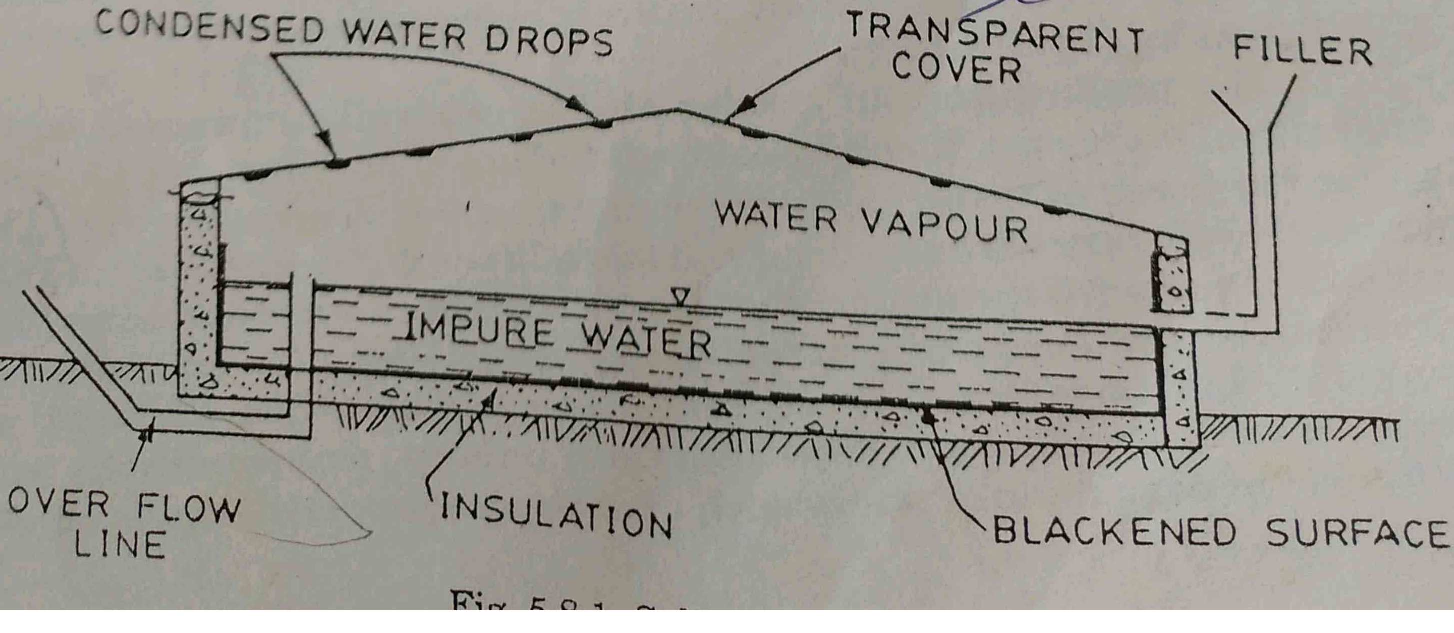


Fig. 5.8.1

the "basin type solar still". It is shown schematically in Fig. (5.8.1). Solar stills have been operated for farm and community use in several countries. It consists of a blackened basin containing saline water at a shallow depth, over which is a transparent air tight cover that encloses completely the space above the basin. It has a roof-like shape. The cover, which is usually glass, may be of plastic, is sloped towards a collection trough. Solar radiation passes through the cover and is absorbed and converted into heat in the black surface. Impure water in the basin or tray is heated and the vapour produced is condensed to purified water on the cooler interior of the roof. The transparent roof material, (mainly glass) transmits nearly all radiation falling on it and absorbs very little; hence it remains cool enough to condense the water vapour. The condensed water flows down the sloping roof and is collected in troughs at the bottom. Saline water can be replaced in the operation by either continuous operation or by batches. Although there are numerous configurations of basin type units, their basic theory is identical. The basin type solar still has produced distilled water at a cost per unit of product lower than other types of solar equipment and is the only type in operation. Operating efficiencies of 35 to 50% for basin type still have been achieved in practical units, as compared with a theoretical maximum of slightly more than 60%.

The performance rating and efficiency of the solar still is determined by plotting the graph of the amount of fresh water produced per unit of basin area in one day versus the solar radiation intensity over the same period. Such curves for several stills are drawn. Efficiency is defined as

$$\eta = \frac{w\Delta h}{H} \qquad \ldots(5.8.1)$$

where w = weight of distillate per square meter per day.

Δh = enthalpy change from cold water to vapour.

H = Solar radiation intensity per square meter per day.

Here area of the water surface is to be considered. Δh includes the latent heat of vaporization, which is being taken as average value 594.5 kcal/kg (2489 kJ/kg).

The performance of a solar still is generally expressed as the quantity of water produced by each unit of basin area in a day *i.e.* cubic meters of litres of water per square meter of basin area per day. This quantity will vary with the design of the still, with the intensity of solar radiation and with the atmospheric conditions in the surroundings. The production rate depends primarily on the amount of solar radiation available but is affected by several other factors ; like ambient air temperature, wind speed, atmospheric humidity, sky conditions etc., the effect of design parameters such as orientation of still, single sloped or double sloped, inclination of glass cover, insulation of the base etc and the effect of operating parameters such as water depth in the tray absorption emittance properties of the still, preheating of water etc.

Solar still installations may provide about 15 to 50 litres per day per 10 sq. m.

5.9. Solar Pumping

Solar pumping consists in utilizing the power generated by sola energy for water pumping, useful for irrigation.

Solar energy offers several features that make its utilization fo irrigation pumping quite attractive. First, the greatest need for pum ing occurs during the summer months when solar radiation is greate Second, pumping can be intermittent to an extent. During periods low solar radiation when pumping decreases, evaporation losses fro crops are also low. Finally, relatively in expensive pumped storage ca be provided in the forms of ponds.

A number of recently constructed solar irrigation pump insta lations are now operational. The major obstacle to increase use of sol irrigation systems at this time is their relatively high capital cost. If th costs of solar pumps can be substantially reduced and assuming th conventional fuel costs continue to rise, solar irrigation could becon economical, and increased use of such systems might be anticipated future.

The basic system consists of the following components :

1. The solar collectors, may be
    - (*a*) Flat plate collectors or solar pond
    - (*b*) Stationary concentrator (CPC)
    - (*c*) Sun-tracking concentrators, (cylindrical parabolic troug concentrator or heliostats).
2. The heat transport system.
3. Boiler or Heat Exchanger.
4. Heat engine, it may be
    - (*a*) Rankine engine
        - → Reciprocating engine
        - → Vapour turbine
    - (*b*) Stirling hot gas engine
    - (*c*) Brayton cycle gas turbine
    - (*d*) Rotary piston engine.
5. Condenser.

6. Pump, it may be
   - (a) Reciprocating pump
   - (b) Centrifugal pump
   - (c) Diaphragm pump
   - (d) Rotary pump.

The solar pump is not much different from a solar heat engine working in a low temperature cycle. The sources of heat is the solar collector, and sink is the water to be pumped. A typical solar powered water pumping system is shown in Fig. (5.9.1). The primary components of the system are an array of flat-plate collectors and an Rankine engine with an organic fluid as the working substance. During operation a heat transfer fluid (pressurized water) flows through the collector arrays. Depending upon the collector configuration, solar flux and the operating conditions of the engine, the fluid will be heated in the collector to a higher temperature, the solar energy which is thus converted to the thermal energy. The fluid (water) flows into a heat exchanger (boiler), due to temperature gradient, and comes back to the collector. This water yields its heat to an intermediate fluid in the boiler. This fluid evaporates and expands in the engine before reaching the condenser, where it condenses at low pressure. The condenser is cooled by the water to be pumped. The fluid is then reinjected in the boiler to close the cycle. The expansion engine or Rankine engine is coupled to the pump and it could of course be coupled to an electric generation.

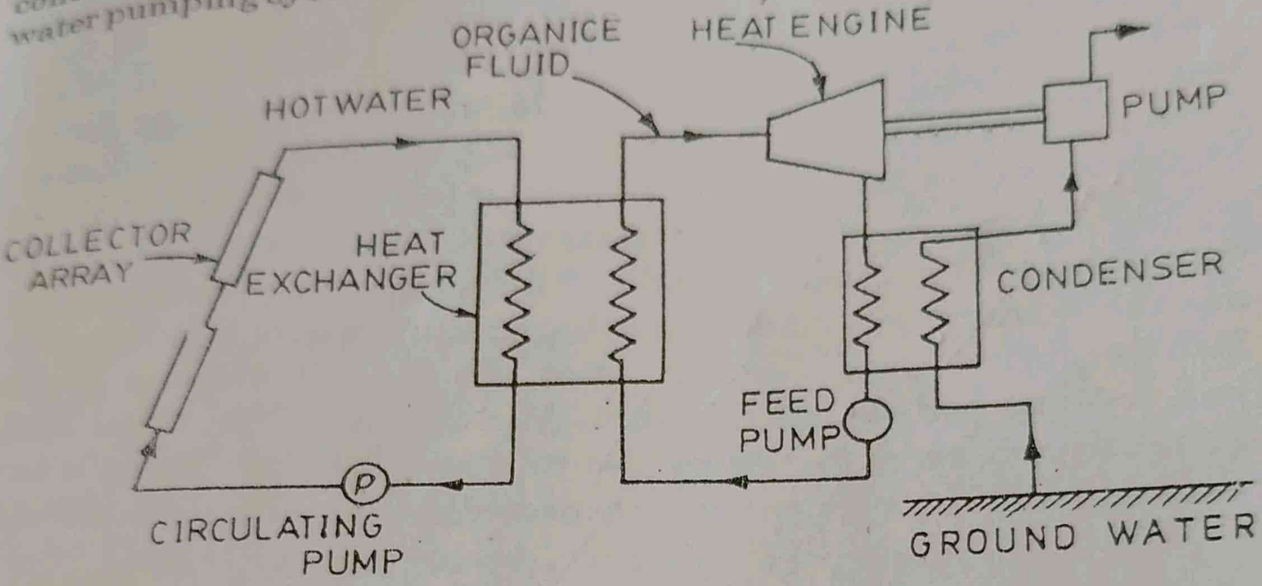


Fig. 5.9.1. Schematic of a solar pump.

The collector area to a large extend is determined by the overall efficiency of the system, η_o

$$\eta_o = \eta_e \times \eta_c$$

where η_e is the efficiency of the engine

η_c is the efficiency of the collectors.

The working fluids used in the cycle are toluene (CP-25), monochlorobenzene (MCB) trifluoro ethanol (TFE-100 and 85), hexafluro benzene (HFB), pyridine (CP-32), refrigerant-11 (R-11), refrigerant-113 (R-113), and thiopene (CP-34). R-113 is preferable to all, because of high cycle efficiency, non-toxic in nature and due to low cost.

A simplified outline of a turbine—driven pump system utilizing solar energy is shown in Fig. (5.9.2). In a particular system in New Mexico, the heat transport fluid (Exxon Caloria HT—43) is heated to 216°C in parabolic trough collectors with a total operature area of 624 sq. m. Part of the heated liquid is stored for use when the sun is not shining. The turbine working fluid (Freon type R-113) leaves the boiler and enters the turbine as vapor at a temperature of 160°C and 15 atm (1.5 MP_a) pressure. After expansion in the turbine, the vapor leaves at 93°C and 0.7 atm (0.07 MP_a) ; it is converted back to liquid in the condenser and returns to the boiler.

The irrigation pump operates at a rated power of 19 kW (25 horse power) and delivers water at 500 to 600 gal/min (32 to 38 litres/sec) from a well roughly 30 m deep. The energy efficiency (*i.e.* percentage of solar energy collected that is converted into useful work). is 13 to 14 per cent, this low value is largely a result of the relatively low temperature of the working fluid entering the turbine. Rankine efficiency will be within acceptable limits, if the temperature of the order of 200 to 400°C is obtained, using proper focusing collector system.

5.10. Solar Furnace

Introduction. A solar furnance is an instrument to get high temperatures by concentrating solar radiations onto a specimen. Solar furnaces have long been used for scientific investigations. French scientist Lavoisier used it in 1774, with a lens as tall as man, for carrying chemical studies at high temperatures. In 1921, German scientist Straub le devised a solar furnace composed of a paraboloidal concentrator and a lens. Then he built another furnace. In which he used paraboloidal concentrator, 2 m in aperture and 86 cm in focal length, was fixed facing downward and the solar radiation was conveyed upward by heliostats (turnable mirrors). The first large solar furnace, with a thermal power of 45 kW was completed in France in 1952. A similar furnace with a power of about 35 kW, was constructed for the U.S. Army at Natick, Massachusetts, in 1958 ; thus was moved to the white Sands Missile Range, New Mexico, in 1976 where it is used to study thermal radiation effects. Solar furnaces have also been built in Japan and the U.S.S.R.

The world's largest solar furnace, with a design thermal power of 1000 kW, commenced operation at Odeillo in the French Pyrenees in

1973. It consists of 63 heliostats, each having an area of 45 sq. n arranged in eight tiers. The heliostats reflect the solar radiation in parallel beam toward a paraboloidal mirror 40 m high and 54 maximum width. This mirror is made up of 9500 pieces which a curved to produce a minimum image of the sun at the focus. Th maximum temperature, attained at the focal point of the mirror, estimated to be over 3800°C ; the maximum heat flux is 16,000 kW/sq.

Principle of Working

The principle of the solar furnace is outlined in Fig. (5.10.1). number of heliostats (turnable mirrors) are arranged in terraces on slopping surface (*e.g.*, on a hill side) so that, regardless of the su position, they always reflect solar radiation in the same direction on a large paraboloid (or spherical) reflecting collector made up of ma fixed mirrors) attached to the face of a structure. The collector th brings the radiation to a focus within a small volume (receiver). In fig a heliostat type furnace with horizontal optical axis is shown which comparatively convenient and widely used in large furnaces. The m desirable mirror is that obtained by grinding and polishing a glass pl into an optical flat, aluminizing or silvering by vacuum evaporati and cooling with a suitable film. The change of elevation and tha azimuth can be obtained by the rotation of frame about a horizon axis and about a vertical axis respectively. In order to rotate the fra

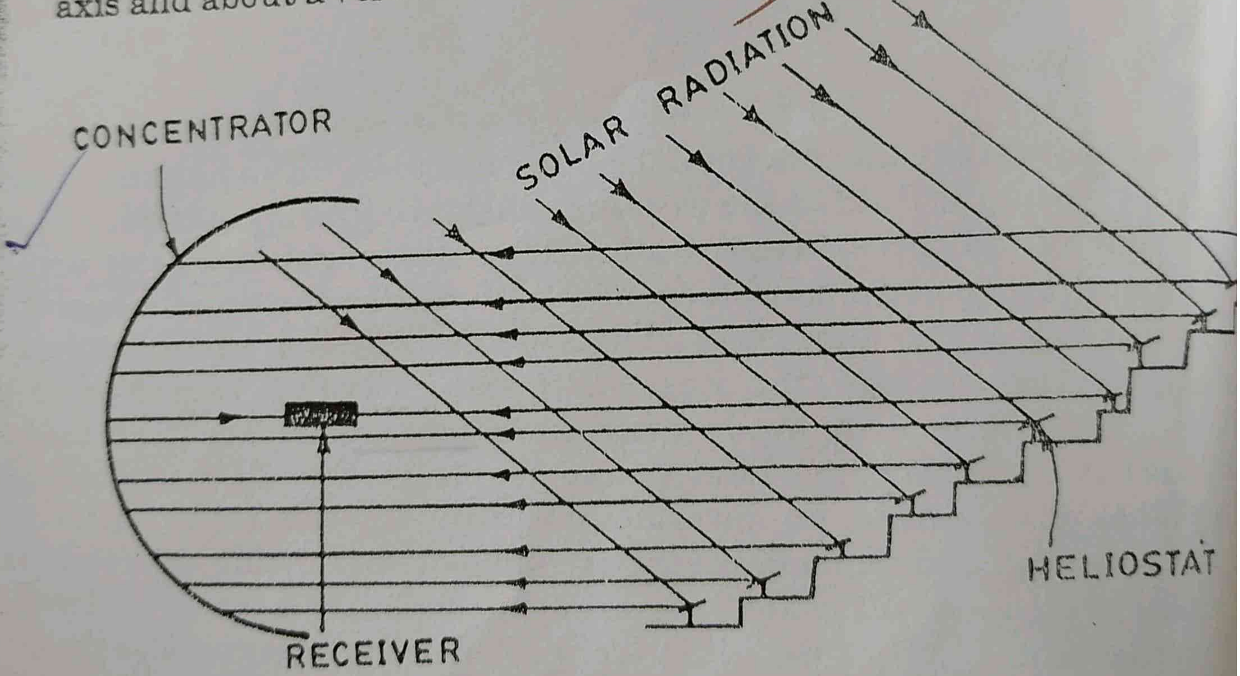


Fig. 5.10.1. Principle of Solar Furnace.

hydraulic or electric driving is used which is coupled with a servo syst or a time system for sun following. The other method is to use ma heliostats to convey the solar radiation into a concentrator.

Uses. The solar furnace is an excellent means for study properties of ceramics at high temperatures above the range ordinar measured in the laboratory with flames and electric currents. Physical measurements include melting points, phase changes, specific heat, thermal expansion, thermal conductance, magnetic susceptibility and thermionic emission. Several useful metallurgical and chemical operations have been carried out at high temperatures in the solar furnaces. The melting and sintering of temperature ceramics such as zirconia is easily accomplished. Direct high temperature production or zirconia from zircon and alkali, beryllia from beryl, and tungstend from wolframite is carried out in solar furnaces. Purification of a refractory (Al_2O_3) by sublimation at high temperatures also has been carried out.

Advantages and Limitations of a Solar Furnace

Advantages: A solar furnace is a unique instrument which has the following characteristics or advantages :

(*i*) In a solar furnace heating is carried out without any contamination and temperature is easily controlled by changing the position of the material in focus.

(*ii*) It gives an extremely high temperature.

(*iii*) It provides very rapid heating and cooling.

(*iv*) Various property measurements are possible on an open specimen.

(*v*) Contamination by ions does not occur in fusion which might happen in the case of plasma or oxy hydrogen flame.

(*vi*) Proper desirable atmosphere can be provided to the specimen.

The main limitations with a solar furnace are :

(*i*) Its use is limited to sunny days, and to 4-5 hours only (maximum bright sun shine hours), and

(*ii*) high cost.

The high cost of solar furnace is still a barrier to their wide industrial use under present economic conditions. Numerous future applications, production of nitric acid and fertilizers from air, to give just one example are in sight. In the mean while, the enormous efforts going into space research has greatly accelerated the development of large, light weight, focusing collectors for producing high temperatures in outer space.

5.11. Solar Cooking

Introduction. In our country energy consumed for cooking shares a major portion of the total energy consumed in a year. In villages 95% of the consumption goes only to cooking. Variety of fuel like coal, 7)

kerosene, cooking gas, firewood, dung cakes and agricultural waste are used. The energy crisis is affecting everyone. It is affecting the fuel bills for those who use it for heating the houses and cooking their food. The poor of the developing countries who have been using drywood, picked up from the fields and forests as domestics fuel, have been affected in their own way, due to scarcity of domestic fuel in the rural areas. At present, firewood and cow dung cakes are the most important sources of fuel to cook food. Cowdung too precious to be allowed to be used for burning and cooking. It is very useful to improve the fertility of the soil, it should be used in proper way. The supply of wood is also fast depleting because of the indiscriminate felling of trees in the rural areas and the denudation of forests. There is a rapid deterioration in the supply of these fossil fuels like coal, kerosene or cooking gas. The solution for the above problem is the hardneesing of solar energy for cooking purposes.

Thus solar cookers have a very relevant place in the present fuel consumption pattern. Various designs of solar cookers have been developed in our country. The first solar cooker was developed in the year 1945 by Mr. M.K. Ghosh of Jamshedpur a freedom fighter. He developed a box type solar cooker with a reflecting mirror and a copper coil inside, on which the food materials used to be placed in pots. Mr. Ghosh also designed a parabolic reflector which was used for sometime as a boiler of Neera (palm juice). Later in 1953 NPL of India developed a parabolic solar cooker. The main reasons for non-acceptance of these devices was the cheap availability of cooking fuel during these days. The problem of harnessing and utilisation of solar energy arised after the fuel crisis of the 1970s, which also affected the rural areas.

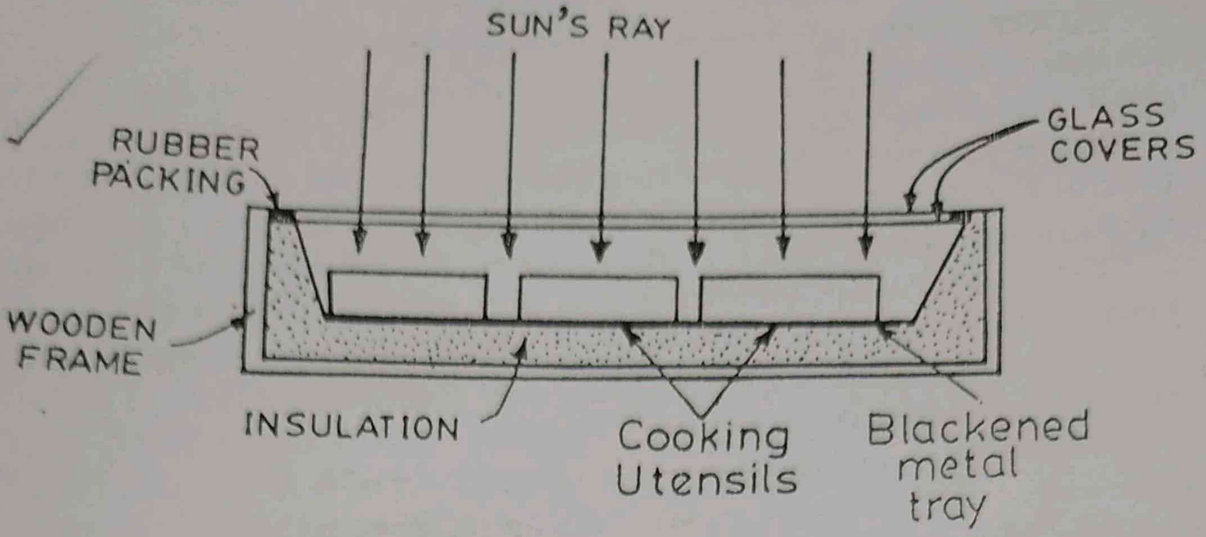
Basically there are three designs of solar cooker :

(*i*) Flat plate box type solar cooker with or without reflector,

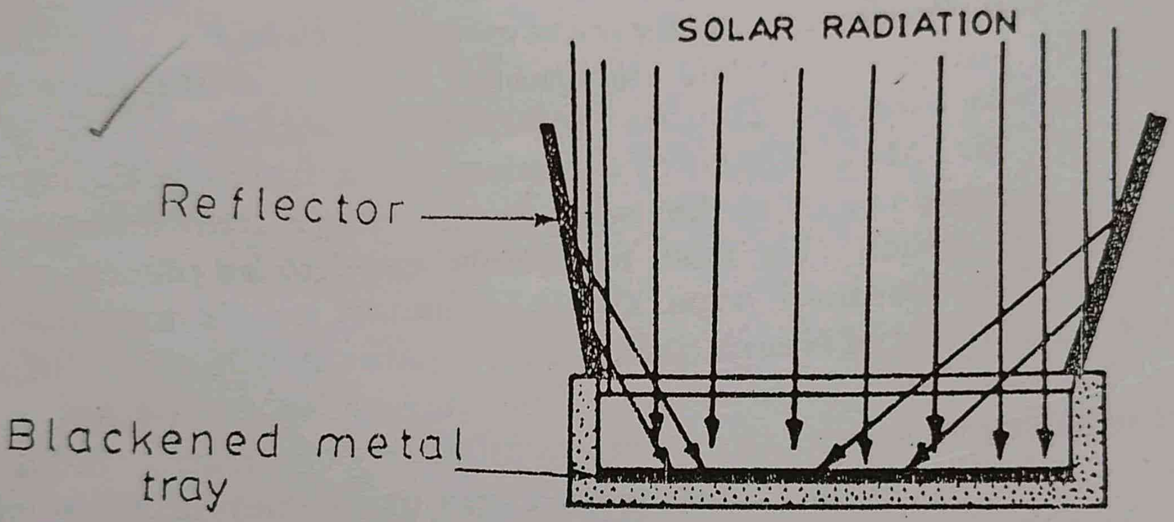
(*ii*) Multi reflector type solar oven and,

(*iii*) Parabolic disc concentrator type solar cooker.

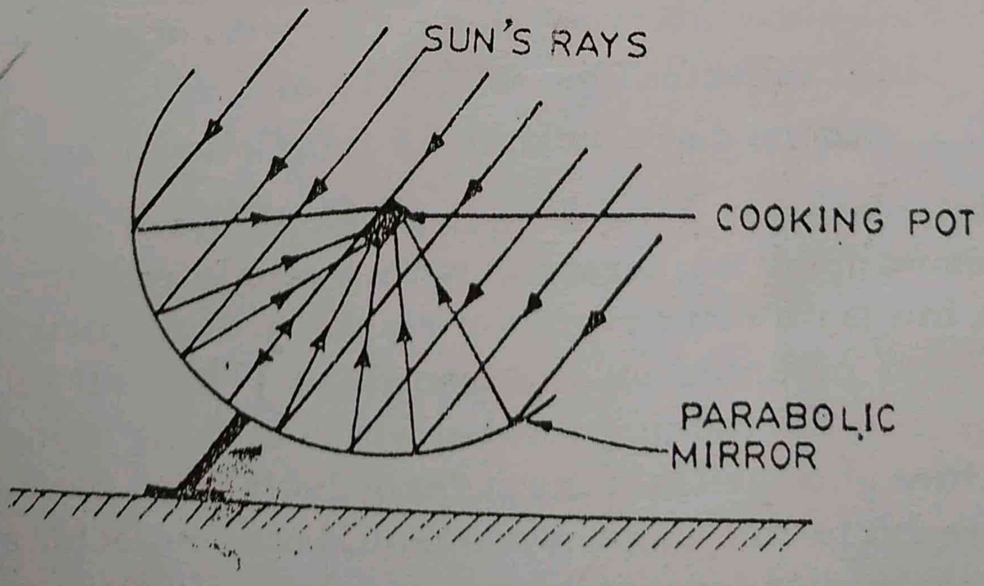
Flat plate box type design is the simplest of all the designs. Maximum no load temperature with a single reflector reaches upto 160°C. In multi reflector oven four square or triangular or rectangular reflectors are mounted on the oven body. They all reflect the solar radiations into the cooking zone in which cooking utensils are placed. Temperature obtained is of the order of 200°C. The maximum temperature can reach to 250°C, if the compound cone reflector system is used. With parabolic disc concentrator type solar cooker, temperatures of the order of 450°C can be obtained in which solar radiations are concentrated onto a focal point. Principle of operation of solar cookers is shown in Fig (5.11.1).



(a) Principle of box type cooker.



(b) Reflector type solar cooker.



(c) Principle of concentrating type cooker.

Fig. 5.11.1. Principle of operation of Solar cookers.

Design Principle and Constructional Details of A Box Typ Solar Cooker

The principle of operation of box type solar cooker is illustrated in Fig. 5.11.1) (a). The solar rays penetrate through the glass cover and absorbed by a blackened metal tray kept inside the solar box. Th solar radiation entering the box are of short wavelength. The highe wavelength radiation is not able to pass through the glass cover i.e reradiation from absorber plate to outside the box is minimized b providing the glass cover. Two glass covers are provided to agai minimize the heat loss. The loss due to convection is minimized b

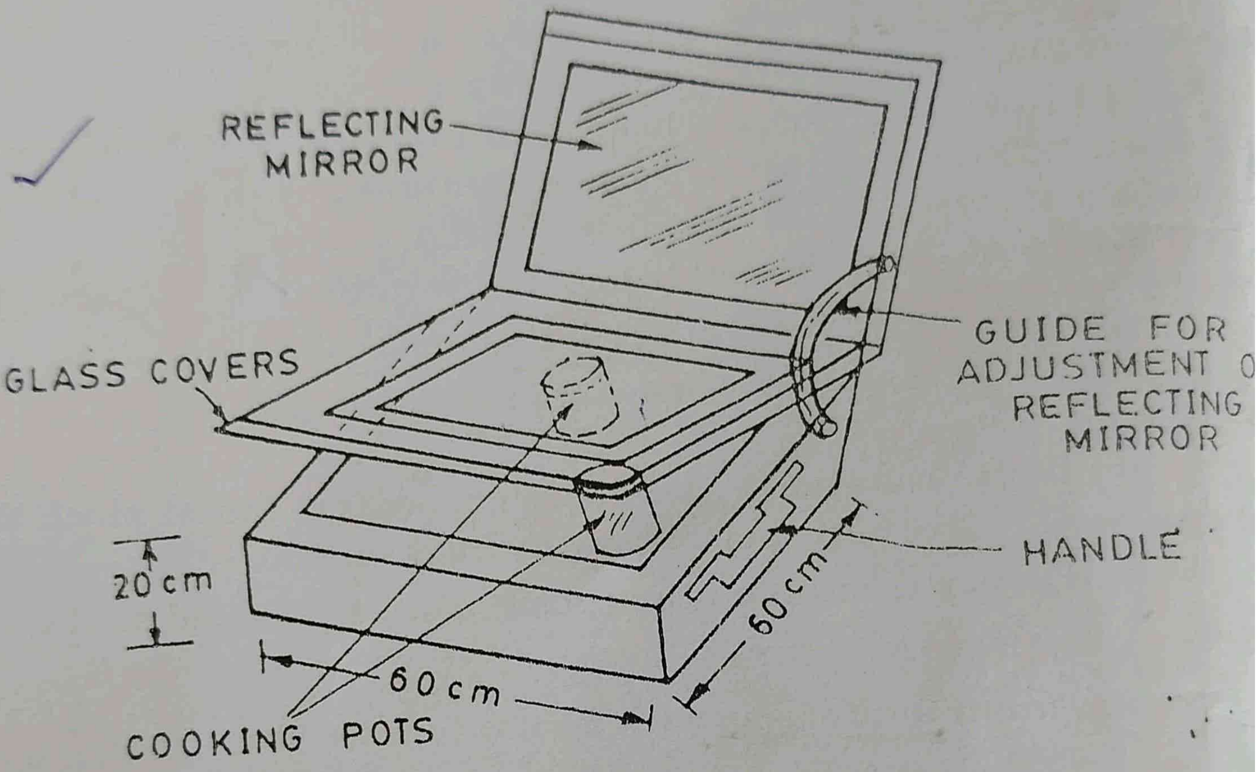


Fig. 5.11.2. Details of a box type cooker.

making the box air tight by providing a rubber strip all round bet the upper lid and the box. Insulating material like glasswool, p husk, saw dust or any other material is filled in the space bet blackened tray and outer cover of the box. This minimizes heat los to conduction. With this type of cooker is placed in the sun blackened surface starts absorbing sun rays and temperature insi box starts rising. The cooking pots, which are also blackened are p inside with food material, get heat energy and food will be cooke certain period of time depending upon the actual temperature att inside. The temperature attained depends upon the intensity of radiation and material of insulation provided. The amount of radiation intensity can be increased by provided mirror or mirror solar cooker is made up of inner and outer metal or wooden box double glass sheet on it. Absorber tray (blackened tray) is painted with suitable black paint like boiler interior paint. This paint sho dull in colour so that it can withstand the maximum temperature attained inside the cooker as well as water vapour coming out of the cooking utensils. The top cover contains two plain glasses each 3 mm thick fixed in the wooden frame with about 20 mm distance between them. The entire top cover can be made tight with padlock hasp. Neoprene rubber sealing is provided around the contact surfaces of the glass cover and the cooker box. A small vent for vapour escape, in provided in the sealing. Collector area of the solar cooker is increased by providing a plane reflecting mirror equal to the size of the box, and hinged on one side of the glass frame. A mechanism (guide for adjusting mirror) is provided to adjust the reflector at different angles with the cooker box. A 15 to 25°C rise in temperature is achieved inside the box when reflector is adjusted to reflect the sun rays into the box. In winter, when sun rays are much inclined to horizontal surface, reflector is a most useful addition.

Overall dimensions of a typical model are 60 × 60 × 20 cm height. This type of cooker is termed as family solar cooker as it cooks sufficient dry food materials for a family of 5 to 7 people.

The temperature inside the solar cooker with a single reflector is maintained from 70 to 110°C above the ambient temperature. This temperature is enough to cook food slowly, steadily and surely with delicious taste and preservation of nutrients. Maximum air temperature obtained inside the cooker box (without load) is 140°C, in winter and 160°C in summer. Depending upon the factors such as season and time of the day, type of the food and depth of the food layer, time of the cooking with this cooker ranges from 1 hr to 4 hrs. Meat should be allowed to stay for 3-4 hours. Vegetables take from 1/2 to $2\frac{1}{2}$ hours. All types of Dals can be cooked between $1\frac{1}{2}$ to 2 hours. Rice is cooked between 30 minutes and 2 hours. The best time of the day for cooking is between 11 am and 2 pm. Cooking is faster in summer than in winter due to high ambient temperature.

Following are the some *merits* of a solar cooker :

(*i*) No attention is needed during cooking as in other devices.

(*ii*) No fuel is required.

(*iii*) Negligible maintenance cost.

(*iv*) No pollution.

(*v*) Vitamins of the food are not destroyed and food cooked is nutritive and delicious with natural taste.

(*vi*) No problem of charring of food and no over flowing.

Limitations of a solar cooker are :

(*i*) One has to cook according to the sun shine, the menu has to be preplanned.

On very clear days, maximum plate temperature in the oven reaches to 350°C in the summer season and 250°C in winter season. Practically all types of food preparations like cooking, roasting baking and boiling can be done within 25 to 75 minutes under clear sky conditions. It is reported by a villager using the solar oven that the *Bati*, a local preparation, prepared (baked) in this oven was more tasty than that made with conventional fuel (dung cake).

The main raw materials required are plane aluminium sheets, wooden plank, aluminium and M.S. angle iron, looking glass sheets, castor wheels etc. All are available indigenously. The cost of production of this solar oven is about Rs. 600. The main advantage of this solar oven is that its efficiency is high because its performance is not affected by wind and there are no chances of dust falling in the cooking pot which is a problem in the arid zone of India. Moreover, the food remains warm if kept inside the oven for hours together even after sunset.

From the research work and experiment and testing of the various types of the cookers, it has come to the conclusion that a box type cooker with a single reflector is the cheapest and most effective solar cooker for rural areas.

5.12. Solar Green Houses

Introduction. A green house is a growth chamber which offers the possibilities of year round plant production. These are effective solar collectors. These can also be geared to the needs of the rural, urban and suburban populations. A green house attached to a residence creates a pleasant improvement in the physical and mental environment of its occupants ; designed in a truly passive solar collection manner with a well-applied heat store, this type of solar collector (or power house) may also provide much of the required winter heat. Solar green houses are relatively easy to build with simple technology and low cost materials.

During the winter, in the northern hemisphere, the earth is slightly near to the sun and atmospheric interference is generally less than during the summer ; it is therefore, often feasible to obtain adequate solar energy to sustain plant growth throughout the day and night. Unfortunately, the average green house is so designed that it loses most of the heat it gains to avoid overheating during the day, leaving no spare heat for night time use. A solar green house optimises the received sunlight and heat while reducing heat losses to a practical minimum with the object of providing stored heat for use over night time and on cloudy days.

Green houses provide crop cultivation under controlled environment. A green house is a structure covered with transparent material that utilizes solar radiant energy to grow plants and may have heating, cooling and ventilating equipments for temperature control.

The plant environment refers :

(*i*) Soil temperature (*ii*) air temperature (*iii*) air humidity (*iv*) Soil moisture (*v*) light (*vi*) air composition (*vii*) root medium composition (*viii*) protection from plant enemies (*ix*) exposure to rain (*x*) hail storm etc.

It has been shown that an ability to exercise control over the crop micro climate results in several fold increase in crop photosynthesis. It would then be possible to beneficially produce food even in those areas where and in those periods when field cultivation is not possible. With controlled plant micro-climate crops can be taken over a wider period of time as compared to normal season, thus making fresh food materials, like fruits and vegetables available for larger part of the year.

There is a phenomenal difference between the yields which can be achieved in green houses and those in open fields, especially with the aid of modern horticulatural methods of plant growth. Nevertheless, energy consumption in food production is increasing faster than in most other industries ; processed foods require more energy input to plant, cultivate, fertilise, harvest, package and transport than is available from the energy content of that food. Increasingly, fuel costs in this important industry are reaching levels at which unsubsidised growers are finding it hard to servive in business.

Advantages of Green houses. A green house structure is less expensive to build than a fully insulated structure. It is indeed a live-in solar collector that provides.

(*i*) a source of inexpensive, good quality food that one grows one self,

(*ii*) a source of additional heat (temperature control) for the house attached to it,

(*iii*) a source of moderator for the humidity (humidity control) in the house.

A green house can be separate structure sitting all by itself out in a field or can be an integral part of the houses. Green houses of one form or another have been built since long. They may be coverd with glass or glass substitutes when covered with plastic films, they are called plastic green houses (more popular in temperature areas such as Mediterranean areas) ; when covered with glass fibre reinforced plastic panels, they are called fibre-glass green houses. But generally green house is synonymous with glass houses. Usually south-side is made o glass while north side is insulated. The sky radiation blocked b northside is only a small fraction of the total radiation in most regions. Green house architecture varies widely around the globe. In th countries of northern Europe where days are often cloudy, glass house are employed. However, in other parts of the world where the sky is usually clear or only partly cloudy it is possible to use other designs which capture more heat than light.

Types of Green Houses

Some broad classifications of green houses include the following :

(i) *Attached green house*, which may be joined onto almost any suitable building structure.

(ii) *Porch* type green houses which may be designed as the entrance to a house, factory or office.

(iii) *Free standing* green houses, which may be situated on any convenient patch or piece of waste ground.

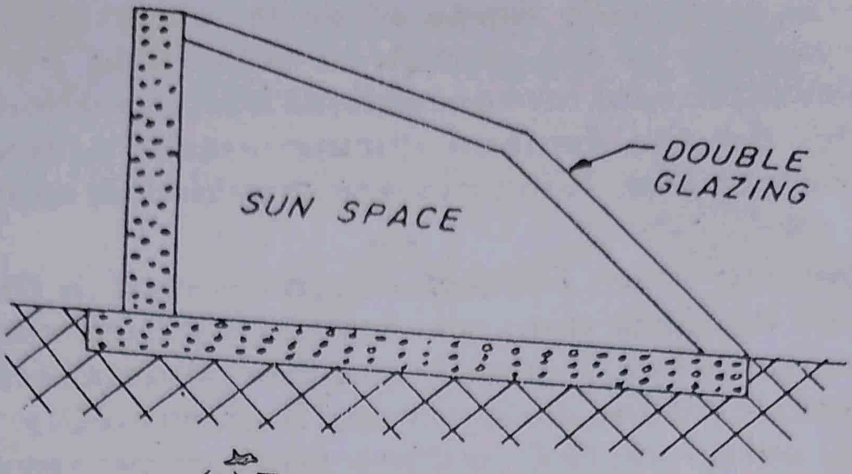
(iv) *Pit* type green houses, which are usually employed on differing level or sloping land scapes, and for the purpose of heat retention.

(v) *Cold frame* type of green houses which are simply hot-beds or plant facing frames equipped with a sloping roof.

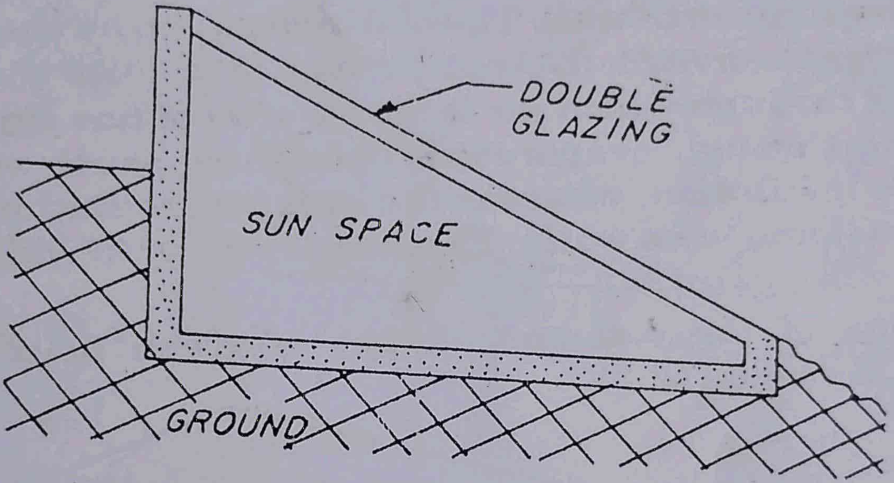
Each of the foregoing types of green house can be designed in a passive solar manner, making it an efficient solar collector and heat storage

The *free standing* and *pit type* of green houses are not directly attached to any other building for green house ; on the other hand, they are separate structures sitting all by themselves. These two types have insulated walls on the north east and west sides. The walls are suitably designed to permit maximum reflection of the incoming radiation onto the plant canopy. Enough storage facilities are provided to meet the requirements. The pit type, however differs from the free standing type being partially sunk. So it has the advantage of being in contact with 'the temperature stability of the deep earth. A green house which does not have a separate structure and is a part of a house. This type is known as *attached type*. As a matter of fact, it is quite cheaper to build a green house as an addition to the existing house. It has the advantage that it can draw heat from an already heated structure when required and can return excess heat when conditions are sunny. Infact, if it is built in the right location with respect to existing windows and doors, it can be a very good heat source for the house. Further this type leads to the maximum return for only a moderate investment in time, energy and money.

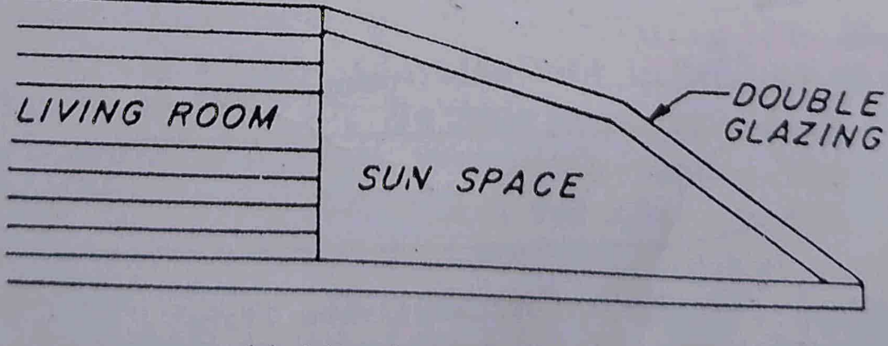
There are various designs of attached type green houses, but one elongated along the east-west axis is the most efficient shape for solar energy collection. Usually the south wall of the building to which the green house is attached as a thermal wall (masonry or water) and its large surface area is exposed to sunlight.



(a) Free standing type



(b) Pit type



(c) Attached type

Fig. 5.12.1. Schematic of some major types of solar green houses.

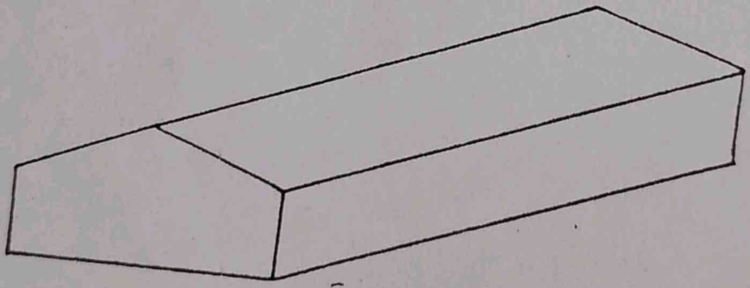
Depending on climatological conditions, green house structure can be divided into two categories :

(1) *Winter green house* and (2) *Summer green house*. The *Winter green house* is constructed in those countries where the outside ambient temperature is very low compared to the requirement of the plant

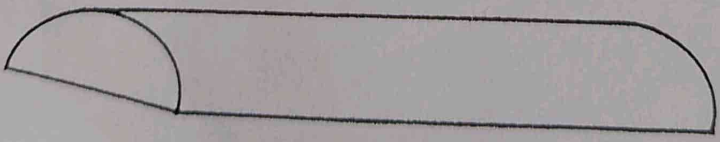
growth obviously it is to be used for heating purposes. Hence attention is to be given to catch enough of the incoming heat from the sun. So south side is usually made of glass, sometimes doubly glazed and interior surface of the northwall is painted white. Use of movable insulation to prevent unwanted heat loss, provision for storage facilities to account for the demand during sundown hours are some of the important features. Windows are provided in east and west walls for ventilation.

Summer green houses: are constructed in those countries where the outside ambient temperature is very high compared to the plant growth temperature. Typically summer climate is characterised by high ambient temperature, clear sky and high humidity. So one has to design the green house such that inside temperature may not reach very high. Usually this type of green house has two sets of windows placed in the south as well as north wall. These windows can be used to cool the green house by free convection. Another way is to duct the windows, in the south wall through which air is blown after it has evaporatively cooled by passing through evaporative pads. Also south wall is covered by removable insulation, whereas the required radiation can be admitted through east and west walls. The interior of north wall is usually coated with reflecting paint.

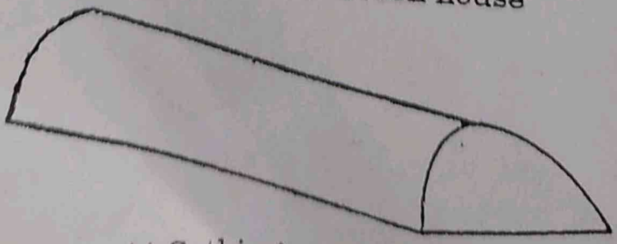
Some of the common shapes of green houses are shown in Fig. (5.12.2) and (5.12.3).



(*a*) Gable Green house



(*b*) Circular Green house



(*c*) Gothic Arch Green house.

Fig. 5.12.2. Some common shapes of Green houses.

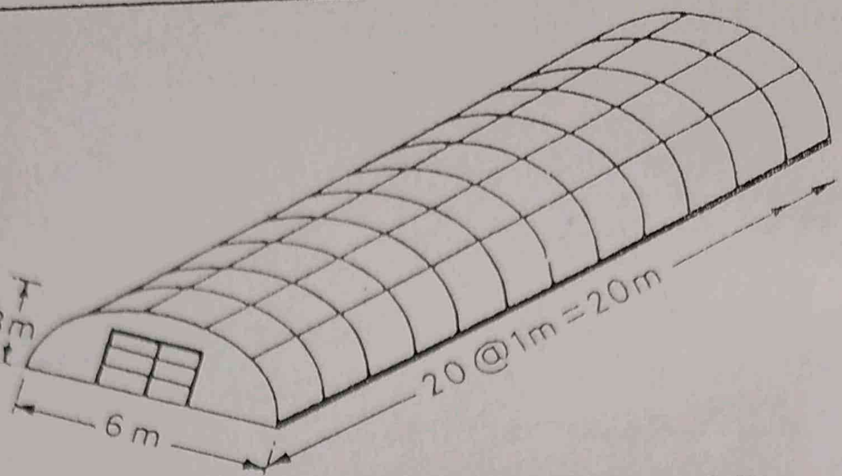


Fig. 5.12.3. Schematic Diagram of Pipe Framed Green House.

Many innovative ideas have been incorpoted into the house designs. Both passive and active methods separately or i bination are made use of for meeting the energy needs of green h One such is soil bed heating from the solar energy. Network o are laid in the soil beds and through these hot water can be circ for soil heating.

Parameters for Plant Growth. In general, various meters affect the plant growth, their discussions will help in the analysis of the green house construction.

(*i*) **Light.** It is essentially required in plant growth. At inte of about 16500 lux, a good plant growth has been observed. Ho plants grow quite well at intensities of 27500 lux (only a quarte sunlight). Plants are found to use only radiant energy in the visi near visible portion of the spectrum.

(*ii*) **Temperature.** In plant grow, temperature is a do environmental factor. There is a different optimum temperat each stage of plant development. This optimum value is related t environmental factors. In controlled environments, however pla grown at temperature between 10 and 25°C.

(*iii*) **Soil temperature.** For most plants, the soil tempera 20 to 25°C has been reported to be optimum. This temperature mines the ability of a plant to absorb water from the soil since l temperatures are widely reported as deterimental in young pl high soil temperatures are recommended for rooting plants or ger ing seeds.

(*iv*) **Air movement.** It influences transpiration, evapora water from soil, availability of carbon dioxide etc. This causes alte of leaf size, internode length and other aspects of plant growth. In growth facilities, at speed of 0.8 to 2 cm/s, optimum growth has reported.

(*v*) **Humidity.** It affects plant growth significantly while l well as high values may cause the plant to be more suscepti diseases due to pathagenic organisms, high humidity result in plants. The low humidities cause increase in evaporation rate and so more water is required. In many plant growth facilities humidities between 55 and 65 percent at 21°C to 25°C is maintained.

Design Principles

Orientation. If an attached green house is built on to a south facing wall in the northern hemisphere at latitudes greater than that of the tropic of cancer (23° 28′ N—the sun's most northerly overheat position), it will receive most of the available sunlight than heat which would fall on a free standing unobstructed green house. The most valuable direct beam radiation component would always emanate from the south and only half of the much less valuable sky dome's diffuse radiation component would be lost. The residence would gain a thermal barrier and protection from northerly winds. If the south facing wall were then painted white, it would reflect sunlight to a growing area at the rear of the green house, enabling certain crops to be produced earlier than with a free standing green houses ; if the south facing wall were painted black, it would instantaneously absorb more radiation and reflect less (acting as a heat store which could then slowly give up its stored heat to the green house). Growers involve in the cultivation of fruit or root crop, might well paint the south-facing wall white to maximise the light availability ; with greens or foliage plants, this may not be considered to be as important as the provision for heat storage.

The shape of a truly passive solar green house is almost self determining, but will vary according to location and weather conditions. A useful theoretical rule of thumb which eliminates the calculation of the numerous variables is simply to add only 20° to the location latitude to determine the desired roof slope. For example, at 30°N, the roof angle to the ground should be 50°. If there is a predominate of clear sunny days during the winter, then no adjustment is theoretically necessary, but there is a predominance of cloudy winter days, the angle should be a little less steep to take advantage of the sky dome's diffuse radiation component. Beacause very steep roof angles lead to high and difficult structures, for practical purposes, it is better to add only 10° to the location or where there are severe structural constraints, merely to ensure that the roof slope is not less than the given location latitude. To evaluate site obstructions, the sunlight availability protractors are used (these are the standard curves from which evaluation of the availability of sunshine is made).

Like any other solar collector, the solar green house should be oriented in a southerly direction, but deviation from true south may be more generally tolerated and for plant growth may even be desirable. Since roof slopes for solar green houses are generally steeper than the roof slopes of dwelling houses, deviation from the true south can be as much as 20° ; deviation upto 45° will result in not more than 20% decrease in the daily radiation total.

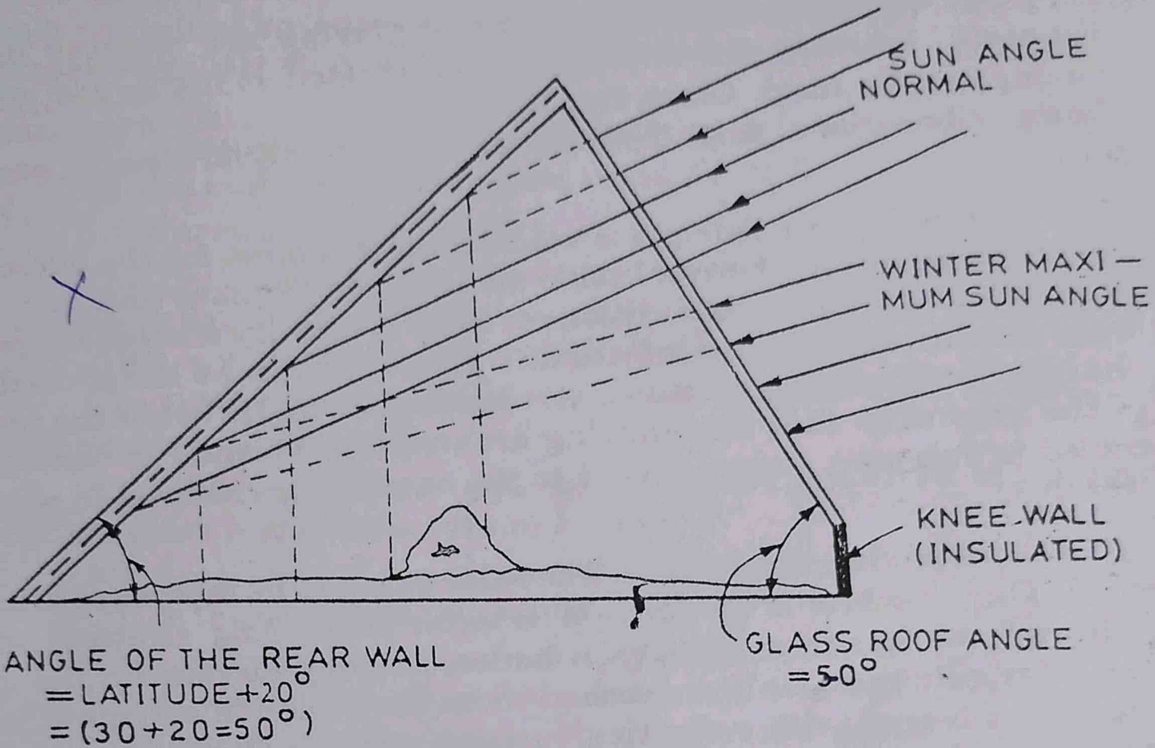


Fig. 5.12.4. Solar—Green house—Optimised slope for orientation 30 N.

There is a good argument for orientation in a south-easterly direction which would allow the green house to benefit more from the early morning sun, especially immediately after a long cold winter night and where the location experience clear morning. So many weather factors and the varying nature of crops can influence the siting of a green house that it is essential for the user to study closely local weather patterns and meteorogical data to provide maximum protection from prevailing winds ; he should ascertain weather scattered or diffuse radiation makes up a large part of the total available radiation, whether it is better to employ insulated opaque northerly corner walling to improve day lighting and whether the southerly corner can then he glazed to maximise the collection of winter solar radiation.

End walls. The south-east or south-west end walls should almost always be glazed. Glazed east-west end walls can allow light from the south glazing to pass straight through and thus there is an argument for insulating these walls.

Site. The designing begins with choosing of a suitable site for its location. It is necessary to understand how the sun travels through the sky at that place. When combined with local whether data, the sun path study will give when and where the sun can be looked for heat gain. This will also help in deciding the requirment of heat storage, insulation and shading facilities.

Glazing. Two or more layer of glazing are required in cold climate. If however movable insulation is used at night, one layer of glazing can be used. Glass has been the most widely used material, though fibre glass, polyethylene, acrylics or polycarbonates are also used.

Ventilation. Adequate ventilation is a most for the successful operation of a green house. Inside air changes per hour and more may be required under some conditions to keep plants dry enough to prevent from moulds and fungus infection. Outside air can be introduced into the interior through air tunnels at a depth of 2.5 to 3 m below the surface of the ground so that the growing area will be warmed in winter and cooled in summer. Exhaust vent to the outside can be used in warmer weather.

Increasing solar gain. The solar gain can be increased in many ways. One method is to provide exterior insulating shutter, which reduces heat loss from the green house, thereby increasing the gain. The solar gain can also be increased when the backside surface of green house is silvered with reflective surface, which will act as a booster mirror and hence can increase the solar gain. The frame of south wall also can be coated with a highly reflecting white paint so as to reflect solar radiation into the green house.

Heat storage. Thermal mass to store solar heat for later use is of prime importance for a solar green house. Where there is enough winter sun, the use of massive walls, floor and growing beds may be sufficient enough for the storage. For regions of low winter sunshine, provisions for remote heat storage are made. In this context use of water is widely practised. Water in drums, tins, cans, moist soil, etc are used for this purpose.

Green house Environment and Control

A schematic of green house environment interaction is
Fig. (5.12.1).