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Design of a Solar Powered House

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Abstract:

In this high energy crisis age there is need to develop such a building mechanism such that maximum solar energy can be used to power the building which will be eco-friendly and cost effective. Solar energy is the most easily available and most eco friendly source of energy. For past three decades, tapping the energy from the sun has been considered as great potential resource to meet the future demand of energy but large scale utilization has faced many bottlenecks such as cost of technology, energy storage, distribution of solar power and daily/seasonal variation of solar resource.

This paper presents an analysis of the state-of-art technology for a solar photovoltaic distributed energy source appliance for domestic residential buildings. It suggests ways to incorporate solar design into multi-unit residential buildings, and provides calculations and examples to show how early design decisions can increase the useable solar energy.

Photovoltaic is a solar power technology that uses solar cells or solar photovoltaic arrays to convert light directly into electricity with no emission of dangerous gases and with least amount of industrials waste. Solar cells are a key technology in the drive towards cleaner energy production. Unfortunately, solar technology is not yet economically competitive and the cost of solar cells needs to be brought down. Growth of the photovoltaic (PV) market is still constrained by high initial capital costs of PV. One way to overcome this problem is to reduce the amount of expensive semiconductor material used.

The success of implementation of photovoltaic (PV) power project is increased when PV module system is integrated with building design process and is used as multi purpose appliance for use with building elements. The improvement in overall system efficiency of building integrated PV modules embedded in building façade is achieved by minimizing and capturing energy losses. A novel solar energy utilisation technology for generation of electric and thermal power is presented by integration of ventilation and solar photovoltaic device with the heating, ventilating and air conditioning (HVAC) system.

Keywords: Renewable energy, Solar Photovoltaic cell, semiconductor material, solar tracking

1.0 Introduction.

In this age of energy crisis there is a need of using renewable source of energy. With increase in cost of fuel and electricity and increased greenhouse gas productions, there is a rise in activity trend towards use of solar energy utilization technologies for energy and environment conservation. Sun is the main source of energy available on the earth (Fig.1). A virtually infinite amount of energy from the sun arrives on the earth each year but we use only a fraction of it. So there is need to appreciate the use of solar energy.

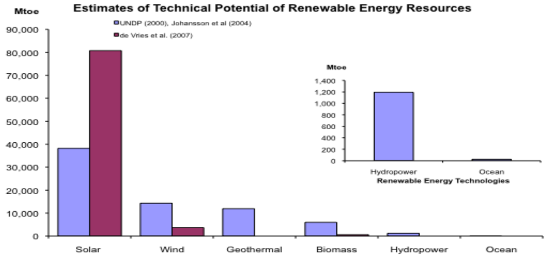


Fig.1, Data source: UNDP (2000), Johansson et al. (2004) and de Vries et al (2007)

There are so many ways of using solar energy but the most useful way is to use it as electricity with the help of solar panel. There is need to design an ideal solar powered building which can use solar energy effectively. Day by day as technology improves, prices of pv cell decreases. There are two types of solar energy technologies; photovoltaic and thermal. Photovoltaic systems convert the sun's energy into electricity through the use of photovoltaic (PV) cells, typically composed of crystalline silicon, which are connected together into panels and mounted on a frame. Electricity generated from the cells are normally passed through an inverter which converts the direct current (DC) produced by the panels into alternating current (AC). That current is then consumed, stored, or routed into the grid system. In solar thermal systems, one or more solar collectors or panels heat water, air, or antifreeze. The solar heated air or liquid is then transferred into rooms or water supply. [1]

This paper presents an analysis of the state-of-art technology for a solar photovoltaic distributed energy source appliance for domestic residential buildings. It suggests ways to incorporate solar design into multi-unit residential buildings, and provides calculations and examples to show how early design decisions can increase the useable solar energy.

2.0 Thermal.

From the ancient time solar energy is being used in the form of direct heating house, cloth, and in so many manufacturing processes. By designing the building in a certain way solar thermal energy can be used for domestic purposes. Solar buildings work on three principles: collection, storage and distribution of the solar energy.

2.1 Passive solar building.

In this system solar energy is used for heating and cooling our building using natural energy flow through air and material like as radiation, conduction, absorption, convection, etc. In this system mechanical device is not used.

2.1.1 Thermal mass.

In the simplest way thermal mass is used which absorbs heat of solar radiation coming through the window and releases heat during night. An ideal thermal mass posses high heat capacity, moderate conductance, moderate density and high emissivity. Passive solar design in single-family residences shows that operational energy can be reduced by 30 to 50 per cent through window sizing and thermal mass storage [2].

2.1.2 Window designing.

The object is to design window in such a manner such that maximum heat can enter inside the room. By applying glazing mechanism to the window, the efficiency of heating effect is improved [3]. The Solar Heat Gain Coefficient (SHGC) is a useful measure of a window's ability to admit solar energy. SHGC is the amount of solar gain a window allows; divided by the amount of solar energy available at its outside surface, higher the SHGC better will be window's performance as solar collect. A recent glazing development is switchable glazing. These can vary their optical or solar properties according to light (photo chromic), heat (thermo chromic) or electric current (electro chromic). Visible light transmittance (VT) measures the visible spectrum admitted by a window (Fig.2). Typical daylight strategies require windows with a high VT. A low SGHC is also desirable where heat gain is a concern. Reflective glass is not recommended for day lighting. Window orientation should be in such a way so that maximum time sun light should fall perpendicular to the window. Spacers separate panes of glass in a sealed window to prevent the transfer of air and moisture in and out of the glass cavity. The low cost and good performance of warm-edge spacers make them suitable for all window systems and should be considered mandatory whenever lower coatings and inert gas fills are used [4].

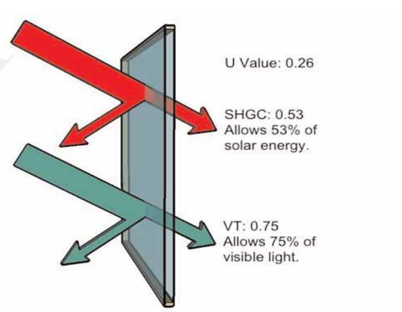


Fig. 2. Double-glazed window

2.2 Passive solar cooling.

Harnessing the *stack* effect, that is the upward movement of warmer, more buoyant air, is possible if a building is designed to capture solar heat and exhaust it at roof level. This warm air can be released to the outside, drawing cooler ground-level air into and up through the building. An atrium can act as a solar chimney which helps prolong the chimney effect well into the night to draw cool air into the building. In Europe, cool night air is passed (using fans) through hollow core floors to store coolness. During the day, room air is re circulated through the cool floor to provide free cooling.

2.3 Active solar building.

In active application of solar energy, solar heat is used by using mechanical devices for the flow of energy for cooling or heating purposes.

2.3.1 Solar domestic hot water system.

This system consists of traditional hot water heating. In this system a glazed, flat plate collector in a closed glycol loop is used (Fig.3). A heat exchanger transfers the energy from the glycol to one or more solar storage tanks. These are usually connected in series to the hot water system. The traditional water heater comes on to keep the water at the required temperature if the solar heat is not enough. The hot water obtained is supplied to swimming pool or for other domestic purposes (Fig.4).

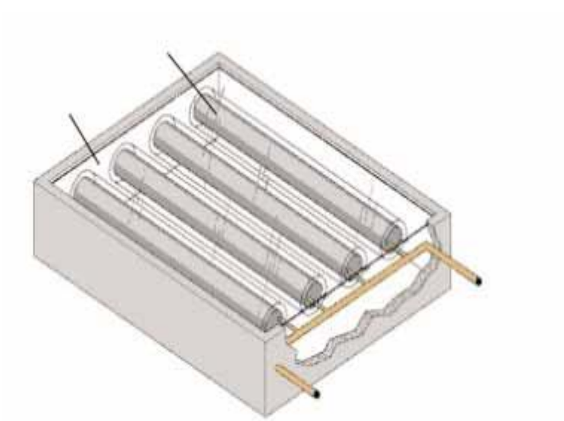


Fig. 3 Evacuated tube collectors *Source: Natural Resources Canada*

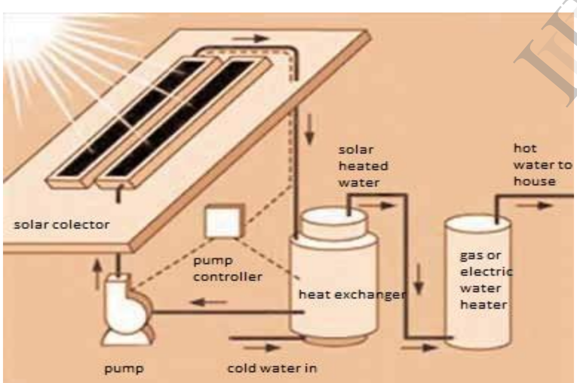


Fig 4.Solar domestic hot water system, *Source: www.AdvanceBuilding.org*

2.3.2 Solar ventilation air heater.

This system provides the simplest and usually least costly way to bring solar heated fresh ventilation air into a building. It uses mainly off-the-shelf components in its design. Its major disadvantage is that it will reduce cost effectiveness of the building's ventilation heat recovery unit. Solar air pre-heat system concept wall is clad with dark metal panels, typically steel or aluminum, perforated with small holes (Fig.5). A gap is left between the cladding and the wall so that outside air passes through the holes in the collector panel. Air is aspirated into the airspace between the collector and the wall is heated, and rises as a result of the stack effect and the lower pressure zone above, which is created by fans moving air through the system to the interior. This pre-heated ventilation air is then incorporated into the building's normal distribution system.

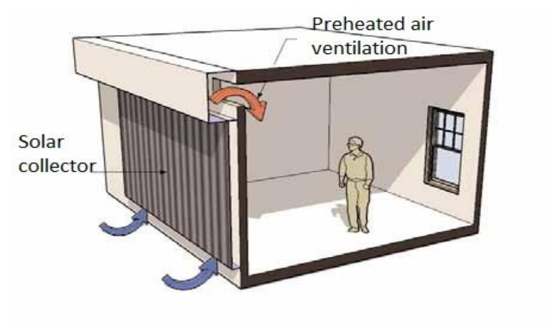


Fig 5.Solar air pre-heat system concept

2.3.3 Solar air heater using double façade.

In a double-envelope or double-façade solar air system, solar heated air is circulated through cavities in the building envelope, surrounding the building with a layer of solar-heated air (Fig.6). This creates a buffer space that reduces the building's heating and cooling load. Inner comfort is improved because inner surfaces of the external walls are warmer. The outer envelope can be made of opaque materials (traditional cladding materials with airspace) or glass.

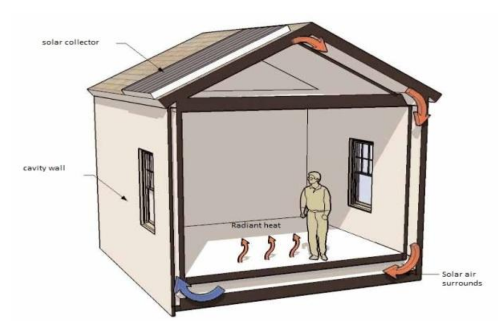


Fig. 6 Solar air heater using double façade.

2.3.4 Solar refrigeration.

There are so many type of solar air conditioning system in practice like as LiBr-water absorption system, silica gel adsorption chillers, etc.

(a) Adsorption chillers using silica gel.

Adsorption chillers use silica gel which requires 60-80 degree centigrade hot water directly. The working principle of an adsorption chiller is shown in Fig.7. For a solar cooling system, which adopts silica gel–water adsorption chiller, the most commonly used solar collectors are flat plate collector and evacuated tube collector. It consists of two valves to fulfill the adsorption and desorption processes of a basic adsorption refrigeration system shown in Fig.7 (a). During the desorption process, the valve between adsorber and condenser is opened while the other one is closed, so the refrigerant desorbed from adsorber is condensed in the condenser. After the desorption process, the adsorber is connected to the evaporator via the valve between adsorber and evaporator. In order to get a continuous cooling power output, an adsorption refrigeration system including two adsorbers, one condenser and one evaporator should be adopted shown in Fig. 7(b). Thus at least four valves should be adopted in the system.

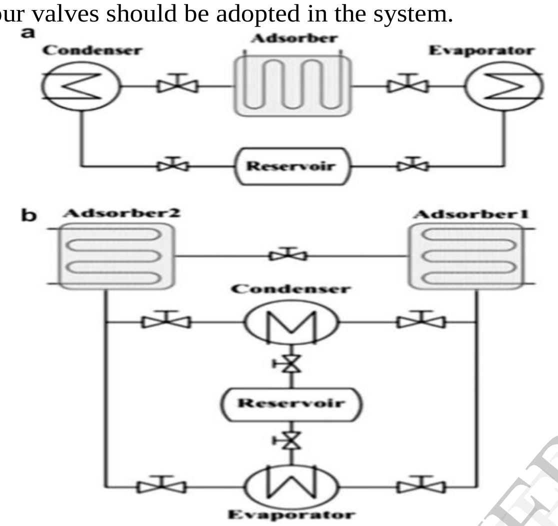
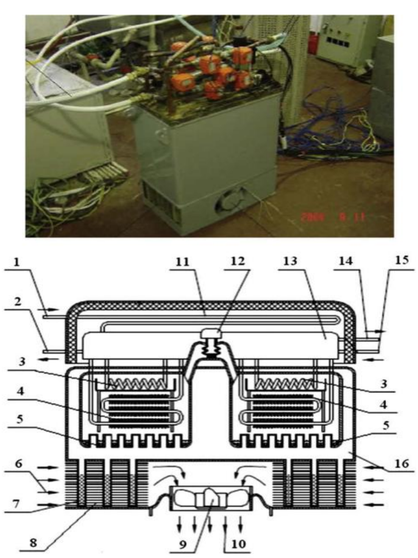


Fig 7.Conventional adsorption refrigeration systems. (a) Basic refrigeration system. (b) Continuous refrigeration system.



1-cooling water inlet tube, 2-cooling water outlet tube, 3-water condenser, 4-adsorber, 5-water evaporator (methanol condenser), 6-the passage of air sucked, 7-methanol, 8-methanol evaporator, 9-fan, 10-the passage of air exhausted, 11-air cooler, 12-mass transfer valve, 13-valve component, 14-hot water outlet tube, 15-hot water inlet tube, 16-methanol chamber

Fig. 8 1 kW silica gel–water adsorption air conditioning unit developed in SJTU (Yang et al., 2006).

(b) Absorption chiller using water ammonia.

Most of the thermally driven cooling systems today, including solar air conditioning systems, are based on absorption chiller. A 2 kW prototype of a low-power ammonia–water absorption driven by solar energy was constructed by University of Madrid in Spain (De Francisco et al., 2002), which is shown in Fig.9.The condenser and the absorber were air-cooled by natural convection, so no cooling tower was involved. The prototype used a transfer tank instead of the solution pump. [5]

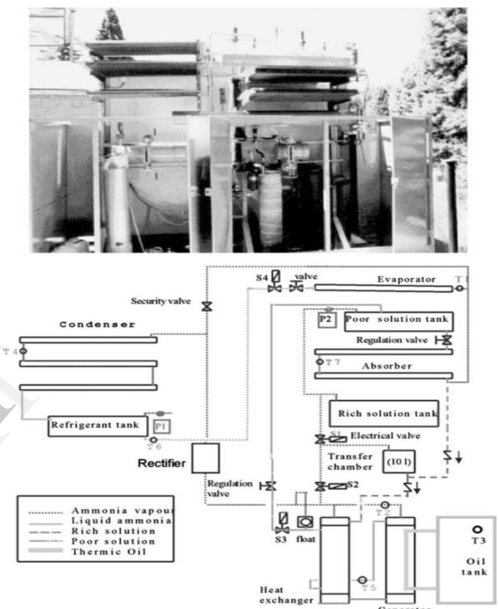


Fig. 9 The prototype and operation principle of the ammonia–water absorption system by University of Madrid in Spain(De Francisco et al., 2002).

3.0 SOLAR PHOTOVOLATIC (PV) PANEL.

The first usable solar cell was invented at Bell laboratories in 1954. By 2010 the capacity of globally installed PV cell had reached up to 40 GW (Fig.10).

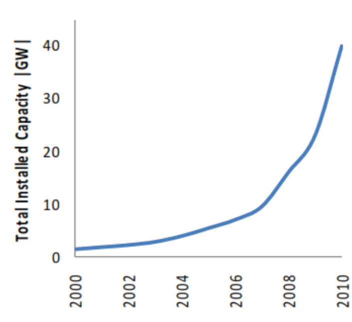


Fig.10 Global installed capacity of PV cells, source: REN21. 2011

3.1 Working of solar cell.

Photovoltaic effect converts solar energy directly into electricity. When sunlight strikes a photovoltaic cell, electrons in a semiconductor material are freed from their atomic orbits and flow in a single direction (Fig.11). This creates direct current electricity, which can be used directly as dc current or converted to alternating current (ac) or stored in a battery.

Fig.11Photo voltaic panel

When ever sunlight arrives at its surface, the cell generates electricity. PV cells normally have a lifespan of at least 20-25 years. However, they usually last longer if frequent overheating temperatures in excess of 70º C are prevented. Main barrier behind the less use of pv cells is its high cost but as the technology is developing the price of pv cell is reducing. There are three types of solar pv cells available in market (Fig.12).

(a) Mono crystalline silicon PV
(b) Poly crystalline silicon PV
(c) Thin film amorphous silicon PV

Currently first two category constitute 93% and the last one constitute the 4.2% of the world market there are some other type of solar cell also but they are in less use.

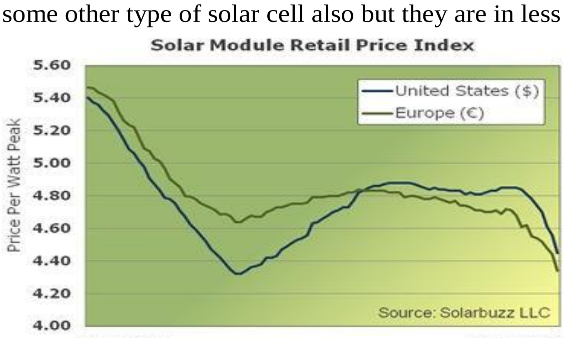


Fig. 12 Graph of Solar Module Price

According to Survey report of Solar Buzz, as of August 2009, there are currently 475 solar module prices below $4.75 per watt. The lowest retail price for a multi-crystalline silicon solar module is $2.48 per watt from a US retailer. The lowest retail price for a mono crystalline silicon module is $2.80 per watt, from a US retailer. At recently held 3rd Renewable Energy India 2009 Expo held at PragatiMaidan from 10-12 Aug 2009, modules of 13% efficiency are available at Rs.120-150/ Wp in bulk.

3.2 Energy path.

Sun--solar panel--battery--inverter—load

Energy coming from the sun in the form of radiation falls on the solar panel where it is converted into dc current. This dc current electricity is then stored in a battery. With the help of an inverter the d.c. current from the battery is converted into a.c. current and is used for the requirements of building inmates (Fig.13).

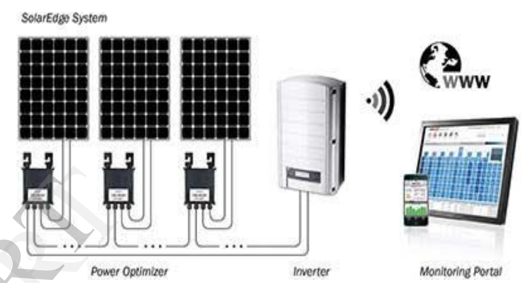


Fig.13 Energy path.

3.3 Photo-Voltaic Principles.

Solar voltaic cell directly converts solar radiation into electric energy. It works on the principal that when solar radiation in the form of photons incident on the semiconductor material then they create free electron and thus due to these free electron an electric field is induced.

The photo voltaic effect can be described easily for a p-n junction in a semiconductor. When the photons are absorbed on this semiconductor the free electrons of n-side tend to flow to the p-side and the holes of p-side tend to flow to the n-side to compensate their respective deficiencies. This diffusion creates an electric field from n-region to p-region.

If electrical contacts are made with two semiconductor material and the contacts are connected through an external electrical conductor then the free electron flow from n-type material through the conductor to the p-type material. The flow of electrons through the external conductor constitutes an electric current which continues as long as free electrons and holes are being formed by the solar radiation.

The combination of n-type and p-type semiconductor material constitute a photo-voltaic (PV) cell or solar cell.

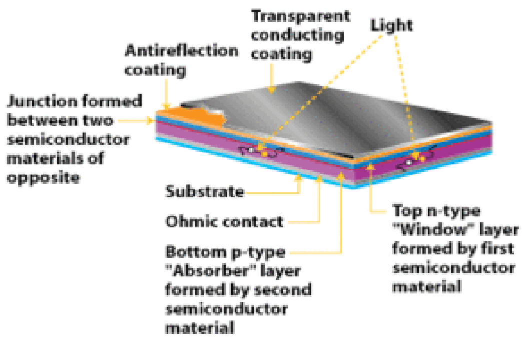


Fig.14 p-n junction in a semiconductor.

3.4 Power output and Conversion efficiency.

A solar cell usually uses a p-n junction. All the solar radiation energy falling on the solar cell can't be converted into electrical energy. Weak, low frequency photon does not possess sufficient energy to dislodge electrons. Strong, high frequency photons are too energetic and although they dislodge electrons, some of their energy is left over unused. Thus only about 45% of the energy in the solar radiation available at sea level is capable to produce electrons and holes in the Silicon. However, because of the electrical resistance of the semiconductor material, i.e. electrical losses and other losses such as some part of the solar energy is reflected back to the sky, absorbed by non photo-voltaic surface. So the actual efficiency is much lower. The best single-crystal cell yields the efficiencies of 16% to 17%. Mass produced modules yield efficiencies seldom exceeding 10%. Efficiency of solar pannel also decreases as temperature increases for example for a commercial it is about 8% at 100 degree Celsius. Cells made of GaAs are superior to silicon cell for operation at elevated temperature.

3.5. Method of increasing efficiency.

In recent years, an increasing number of multi-level buildings are being built instead of older traditional two-storey terraced houses, due to space limitations, high land cost and greater demand for smaller dwellings. In turn, less roof area per household would be available for installing solar systems. (Fig. 15)

Fig.15, A 360 Wp single-axis PV tracking

Moreover, the older buildings that may be adjacent to these high-rise constructions would have less effective sunny areas on their roofs due to shading. In such cases, solar tracking may be attractive since it would maximize on the production of energy from solar radiation in a limited space. An added incentive would be the relatively cheap cost of the tracking system, as is the case today, when compared to a stationary system that would need more solar modules to produce an equivalent amount of output power. The tracking mechanism consists of a dc motor encapsulated in an aluminum pipe forming part of the structure and being driven by a bi-facial solar photovoltaic module, fixed at an angle of 75° relative to the PV array. When the sun shines on one face of the pilot solar module, a potential difference is created and the motor rotates the tube towards the sun. When the modules face the sun, the bi-facial pilot solar module would be almost perpendicular to the solar beam and the potential difference between the two facades would not be sufficient to further rotate the solar array. As the sun moves in the sky, it will start shining on the other face of the pilot module and as the day goes by, the tracker closely follows the sun along its path. The full span of the tracker is about 120° from East to West. According to the system installed at the Institute for Energy Technology [6] tracking could yield up to 67% higher outputs between spring and autumn. This implies that in order to produce a certain amount of electric energy, up to 40% less roof area would be needed for a tracking system.

3.6 Building Integrated PV system.

In this system the PV cells are incorporated into a building element. Currently there is much development in PV roofing, PVshading elements (Fig. 16) and PVcladding or semi-transparent curtain wall components (Fig. 5). With PV cladding it is best to have a vented cavity behind the panels so as to operate at lower temperatures. By following such a construction approach one may also develop an effective rain screen system which hinders rain penetration. PV roofing is installed much the same way as conventional roofing (Fig 17).

Fig.16 PV integrated in curtain wall elements at the Mataró Library, Mataró, Catalonia, Spain. (The facade is also used for fresh air pre-heating).

Fig.17 BIPV metal-standing seam roof, Toronto

PV shading is affective as a window shading element, PV panels can be opaque, used where no light transmission is needed, or semi transparent for areas where light is wanted, such as atriums or skylights.

3.7 PV-thermal system.

A typical silicon PV panel has only 10-15% efficiency. PV solar panel produces heat more than 4 times as it produces electricity and this heat is lost to atmosphere. By increasing the temperature surrounding the panel, its efficiency decreases. If this heat is removed to use in HVAC (heating, ventilation and air conditioning) system, more combined efficiency is achieved and similarly the decrease in the temperature of PV panel, there is increase in its efficiency.

3.8 Solar cell connecting arrangement.

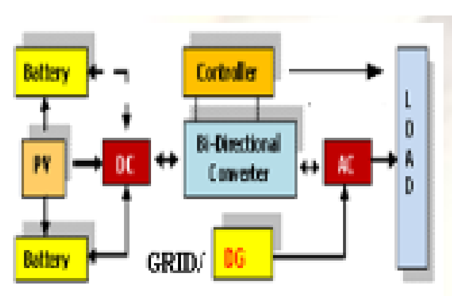
The optimum operating voltage of a photo-voltaic cell is 0.45 volt at normal temperature, and the current in full sunlight is taken as 270 ampere/ sq.m. The individual cells of size 10 cm × 10 cm are connected into modules of about 30 cells. Thus each module has capability to produce an emf of about 15 volts, and current of about 1.5 ampere. Solar cell arrays are assembled from a combination of individual modules in parallel. Thus the current output from the arrangement increases in the multiple of 1.5 ampere, which is safe and convenient for charging 12 volt batteries. These modules are sealed for protection against corrosion, moisture, pollution and weathering. [7]

4.0 ENERGY STORAGE SYSTEM.

Once the electric energy is produced through PV cell, this energy is stored to be used at night or when solar radiation is not falling on the panel. For this chemical batteries are used which is being charged during the day time and provide us power at night. For better performance fuel cell are used. In a battery, the electrical energy is stored using a chemical redox couple whose free energy is increased while the battery is being charged, and the decrease in free energy is used for supplying current during discharge. The chemical redox couple, which is the fuel for the battery, is usually in the solid form and is enclosed along with an ion conducting electrolyte. The battery life is determined by the number of charge-discharge cycles and the entire unit needs to be replaced after certain number of cycles. In contrast to this approach, it is possible to have electrical storage devices in which the chemical redox couples are supplied continuously and such devices are called fuel cells.

5.0 ENERGY SUPPLY SYSTEM.

Once the battery is charged, either it can be used as dc voltage or as ac current using an inverter. The inverter turns DC electricity obtained from PV cell or battery into 220V, 50Hz AC electricity needed by home appliances. The block diagram of PV power supply and its integration with grid inverter is shown in Fig.18. For hassle free power supply a diesel engine generator is installed in case when sky is cloudy for more than 2 or 3 days.



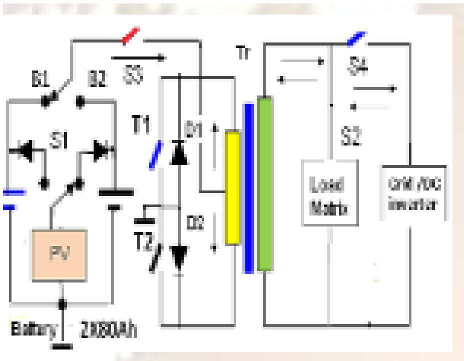


Fig. 18 Energy supply system

6.0 ENERGY REQUIREMENT FOR AN IDEAL HOUSE.

If 2 BHK house is considered then energy requirement can be roughly estimated as follows:

S. N	Name	Quantity	Watt	Time (Hrs)	Energy Requirements (Hour)
1.	CFL bulb	06	15	05	450
2.	Fan	02	80	08	1280
3.	LCD TV	01	50	05	250
4.	Desktop	01	150	03	450
5.	A.C	01	2000	05	10000
6.	Iron	01	750	0.5	375
7.	Pump	01	1000	0.5	500
	Total power consumption per day				13,305 watt hr.

7.0 REQUIREMENTS FOR SETTING PANEL

It is required approx 13,305 watt hour power per day of energy. For this, it may be recommended to install 7 solar panel having capacity of 350 watt each. It is assumed that only 6 hour sun light will fall on the panel effectively per day. So, there is 7×350 × 6 =14700 watt hr power which is sufficient enough to fulfill the energy requirement. Further 2 nos. battery of 24 volt capacity each will be required to store power produced by solar panel, 1 no. inverter of 1500 watt capacity and regulators. However there is a need to install a fuel run generator.

8.0 SETTING OF PANEL.

The solar panel can easily be set on the roof of the building since seven solar panels of 300 watt capacity are used having dimension 1954 × 982 × 40 mm each. So roof having area of 13.5 meter square will be sufficient enough. In case of multi storey building where roof is not available for each flat then panel can be installed on south facing wall of each floor. If tracking mechanism is used then there is 60% more energy, hence, panel requirement decreases from 7 to 5.

9.0 COST ESTIMATION.

1. Solar panel (7 nos.) - INR 7 × 13750
2. Battery (2 nos.) - INR 10000
3. Inverter (1 no.) - INR 9000
4. Regulators and wires INR 2000
5. Total INR 115,500
6. If tracking mechanisms are used then effective cost will be reduced by 13750 × 2 (use of panel is reduced from 7 to 5) - INR 5000 (expense on tracking mechanism).
7. So total cost = INR (115,000-22,500) = INR 92,500.

10.0 SUGGESTED METHODS TO MAKE IT MORE FEASSIBLE.

To run an average sized home completely on solar power thus there is need of some energy or power consumption changes to make the whole project more feasible. Firstly all incandescent globes must be replaced with CFL – low watt fluorescents and even LED lighting. Hot water geysers are seen as a separate entity, as they make use of the heat of the sun to warm water circulating through specially designed heating panels. Many household appliances are becoming more and more energy efficient, examples are.

- LCD TVs
- Laptop computers
- Solar fridges and freezers
- Evaporative air conditioners
- Use electric blankets instead of heaters
- Gas stoves

11.0 CONCLUSIONS.

1. The installation cost is high but it make us self dependent for energy requirement and it is also the best greener energy available on earth so there is need to develop solar powered buildings.

2. The market for technologies to harness solar energy has seen dramatic expansion over the past decade – in particular the expansion of the market for grid-connected distributed PV systems and solar hot water systems has been remarkable.

3. Energy plays the most dominant role in the economic growth and security of any nation. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly.

4. An increase in development activities triggers the increasing demand for energy. India is a growing giant facing the critical challenge of meeting a rapidly increasing demand for energy.

5. With over a billion people, one sixth of the world's population, India ranks sixth in the world in terms of total energy consumption and needs to accelerate the development of the sector to meet its growth aspirations.

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