Performance improvement of solar hot water system by reducing solar irradiation from solar collector and solar tank.

Submitted to

Dr. AKM Abdul Malek Azad

Associate Professor, Department of EEE

BRAC University

Submitted by

Bonny Amin Khan

09221065

Md. Sanzidul Islam

09221058

Jannatul Ferdous

09221171

Nabil Shaker Rahi

09221069

Department of Electrical and Electronics Engineering

April 2011

BRAC University, Dhaka, Bangladesh

Declaration

We hereby declare that the pre-thesis report has been written based on the work till then we have done. Materials of the work have been written depending on the research we have done and it is provided with the references.

Signature of Supervisor — Signature of Author

ACKNOWLEDGEMENT

We are very thankful to our thesis coordinator Dr. AKM Abdul Malek Azad, Associate Professor, Department of Electrical and Electronic Engineering, BRAC University for guiding us throughout our pre-thesis work. Special thanks for helping us by giving appropriate advice with the system device, system designing and other documentation. Special regards to our project engineer, Mr. Raeid Hassan for being with us through the work with his extreme hard works and innovation ideas. Also thanks to Marzia Alam, Lecturer, Dept. of EEE Asifur Rahnan for giving us advice and support. We all have worked extremely hard on the pre-thesis as a team and hopefully our work will be appreciated by our supervisor and we will be able to complete the thesis perfectly.

Abstract

The word itself “Solar” describes that we are dealing with some renewable energy source for a hot water system. The solar hot water system has been a popular throughout the world as it is cost effective and easy to maintain. The system is always successful when its efficiency level increases. This system efficiency level can be increased by reducing its heat loss A hot water system has been already designed, we need to do further implementation by working on its insulation at variable time, temperature and solar radiation so that there is a minimum temperature drop over night which in turn determined the operating temperature of the system.

For this thesis we will be using an instrument named “Pyranometer” which is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square)

Depending on the temperature change of solar hot water system with respect to solar radiance, we will improve our insulation so that the temperature fall of 300 liters storage tank is only 2 degrees, which is the minimum temperature drop amongst any other stored water temperature.

Table of contents

List of figures

List of tables

Introduction

In just one second, the Sun gives off 13 million times the energy that is generated by all the electricity consumed in one year. Only one millionth of the Sun's energy reaches Earth, but this scant amount would be more than sufficient to meet the energy requirements of our entire planet. The relative difficulty in extracting energy from the Sun, when compared to systems that derive energy from fossil fuels or nuclear power, has hindered its development as a widespread source of energy. On a smaller scale and in many experimental projects, however, solar energy has proven highly effective in producing both electricity and heat. Solar energy has proven more effective and has been more widely utilized for both water and space heating and cooling systems.

The word "Solar' it describes that we are dealing with something which is using renewable energy sources. Heating system has been popular for long time but it was not cost effective and energy efficient. Rather than developing a system which are using natural resources like coal, gas or fuel etc it is convenient and efficient system would be developed when it is using solar power if maximum solar energy could be grabbed and heat loss could be reduced by providing proper way.

Solar hot water system is dominating over the solar heating system as it is easy to maintain, relatively low manufacturing and maintenance cost. Being a part of a developing country, which has crisis of electricity and for unavailability of natural gas connection remote places? To reduce the pressure on the power sector where we already have a lot of crisis, we need an alternative water heating system that provides continuous hot water supply without consumption of electricity.

A solar hot water system has been already on the top of BRAC University building. The system can be implemented perfectly, when a system has greater efficiency value. The motivated matter of doing thesis with this topic is to get an efficient hot water system with a limited cost and natural resource like gas and fuel and how to decrease the consumption of electricity. The system can be made efficient by decreasing the difference in temperature between solar collector and tank could be reduced by providing a proper insulating material.

Objectives

The solar hot water system has been a popular throughout the world as it is cost effective and easy to maintain. As we are harvesting solar energy we can provide surplus energy so that we can be able to solve the energy crisis the system is always successful when its efficiency level increases. This system efficiency level can be increased by reducing its heat loss.

Hot water system need energy to be supplied here we are using solar energy so that during energy crisis we can use this renewable energy as a source of energy for this system.

The solar hot water system has been a popular throughout the world as it is cost effective and easy to maintain. The system is always successful when its efficiency level increases. This system efficiency level can be increased by reducing its heat loss. A water heating system has been already designed, we need to do further implementation by working on its insulation at variable time, temperature and solar radiation so that there is a minimum temperature drop over night which in turn determined the operating temperature of the system. When a system is designed it has got some advantages as well as disadvantages. As the system is not much efficient that's why we are thinking of increasing its efficiency level. When the system is efficient enough then we cannot utilize the system fully. The system would be efficient if the temperature fall of 300 liters storage tank is only 2 degrees which is the minimum temperature drop amongst any other stored water temperature.

The efficiency of the system can be increased by providing a proper insulation material so that the heat loss of the could be reduced and the temperature difference between the solar collector and the tank is reduced. In our project we have decided to use different types of insulating material and measure its irradiance using an instrument named "pyranometer". Thorough this project we will be able to be familiar with a new device which will be measuring solar radiation i.e. pyranometer. We will be measuring solar radiation after it has been insulated by different types of material using pyranometer. (This will help us to identify the operating optimum temperature for our system.)

Overview of the thesis

Description of the system

In this system, a 150 liters solar collector is used along with a 300 liters storage tank to store the water produced by the solar collector throughout the day. From the system, we have analyzed the optimum temperature for storing in the storage tank. The behavior of the solar hot water system varies with regions. Every day the water is heated up by the 150 liters solar collector and is then transferred to 300 liters storage tank and the loss of temperature in the storage tank is noted in the very next morning. In this way the energy gained collected by the amount of hot water that can be produced by our solar hot water system and the operating temperature of our designed automatic solar hot water system.

The operating temperature is the temperature of the outlet water of the storage tank – the temperature that the system can always is provided to the users. A set point for required water temperature is 500 C when the solar hot water system will not be able meets the desired temperature for the user; the electric water heater will heat the water. Here the temperature sensors will detect the temperature and send signals to the microcontroller accordingly to turn the electric water heater on or off. As the system is driven by microcontroller, the cost of the system has been reduced using thermostat technology.

The main components of solar water heater are:

1. Water-in-glass evacuated tubes
2. Storage tank
3. Mounting frame
4. External water supply source

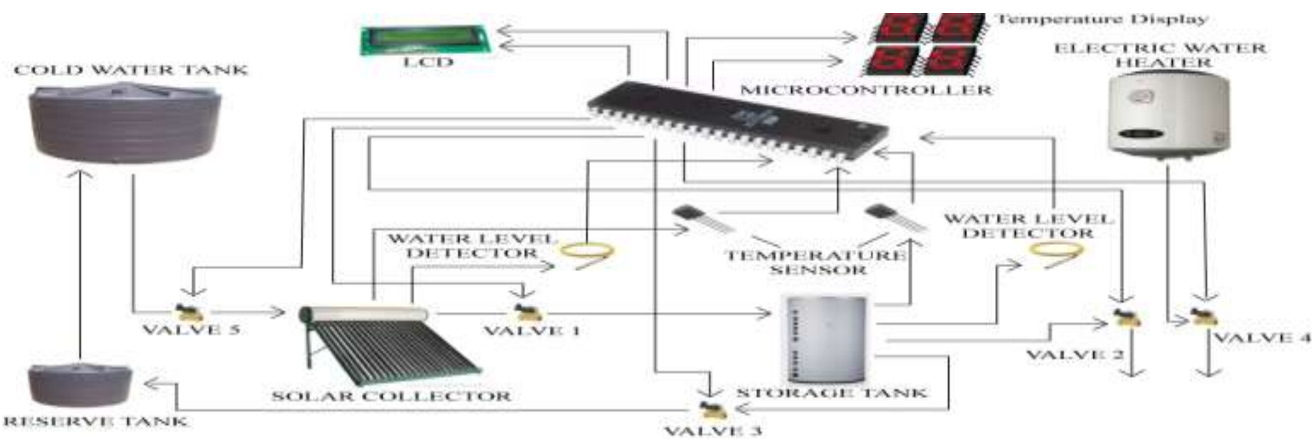

Fig1: Block diagram of solar hot water system

Lots of tubes are commercially available for solar hot water system. Basically, two types of solar thermal collectors are used in such system: evacuated tube collector and flat plate collector efficiency per unit area of evacuated tube collectors at low temperature can exceed that of flat plate collectors and the difference in performance becomes more significant as the average operating temperature increases. The advantages of evacuated tube collector over flat plate collector make this type the perfect one for our system.

Fig2:150 liters tank with directly connected water-in-glass evacuated tube collectors

At the end of the day, the heated up water is transferred to the 300 liters storage tank. Next morning, the temperature reading of the water in 300 liters storage tank is noted and is emptied by transferring the water to the reserve tank. From this, the maximum temperature of the water is noted that the 150 liters collector can produce and also the stored temperature, which results in the least temperature drop over night, which in turn determined the operating the maximum and the average temperature determines the temperature characteristics of evacuated tube solar thermal collector. The temperature variation of the 150 liters water tank for the whole day for one week has been taken. From that reading it is found that the temperature of the hot water tank rose up to (on a full sunny day) 68 degree Celsius and in cloudy days, the maximum temperature reached up to 56 degree Celsius (Fig. 10.). As the temperature is gradually increases, the hot water can be stored according to needs. The water with the maximum temperature cannot be stored that the collectors can produce. Because, the hot water having the maximum temperatures like 68 degree Celsius is stored, then the temperature difference between the stored temperature and the ambient temperature will be maximum, leading to a greater loss of temperature over time .whenever the stored water temperature is 50 degree Celsius, the temperature fall of 300 liters storage tank is only 2 degree Celsius, which is the minimum temperature drop among any other stored water temperature shown This 300 liters water stored in the water tank changes the temperature with an average of 4% drop over 24 hours, which is very acceptable since solar heating is almost a continuous process.

The minimum efficiency of the system is determined by the amount or temperature of hot water required during winter (when the largest amount of hot water is often required). The maximum efficiency of the system is determined by the need to prevent the water in the system from becoming too hot (to boil, in an extreme case). In addition, there are a number of other system characteristics that distinguish different designs:

- The type of collector used
- The location of the collector - roof mount, ground mount, wall mount
- The location of the storage tank in relation to the collector
- The method of heat transfer - open-loop or closed-loop (via heat exchanger)
- Photovoltaic thermal hybrid solar collectors can be designed to produce both hot water and electricity.

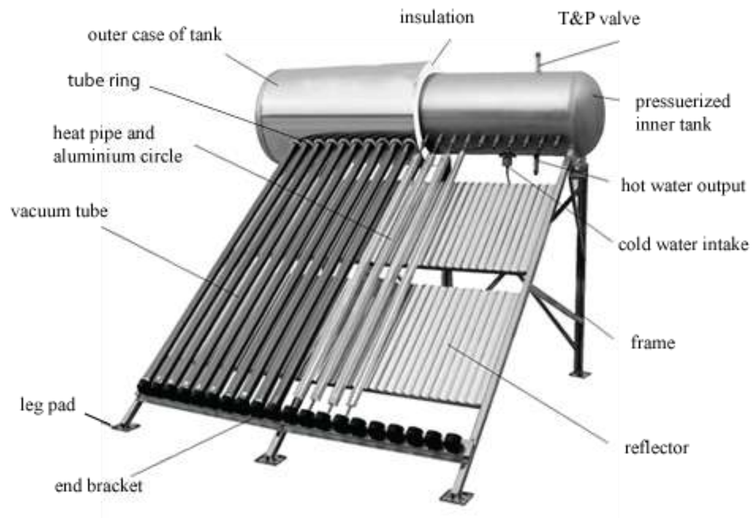

Fig 3- Cross-section of the storage tank

SPECIFICATION OF THE 150 LITERS COLLECTOR AND THE STORAGE TANK

Size of the collector (Length)	5 ft. 6 inch.
Size of the collector (Width)	7ft. 9 inch
Capacity of the Solar Water Heater	150 Liter
Capacity of the Storage Tank	300 Liter
Number of the collector for 150L storage tank.	15 tubes
Diameter	0.045 meter
Length	1.8775 meter
Total area for 15 collector	1.99 sq .meter

Table 1 specification of the tank and the collector

Insulation of the solar hot water system

The word itself insulation defines that the material used to slow the transfer of heat through walls so as to reduce energy costs and help maintain a uniform temperature. Materials or devices to inhibit or prevent the conduction of heat or of electricity. These materials are frequently used as *insulation:* fiberglass, mineral wool, cellulose, foam, and urethane.

Thermal insulation is the reduction of the effects of the various processes of heat transfer between objects in thermal contact or in range of radiative influence. Heat is the transfer of thermal energy between objects of differing temperature. The means to stem heat flow may be especially engineered methods or processes, as well as suitable static objects and materials.

Heat flow is an inevitable consequence of contact of objects of differing temperature. Thermal insulation provides a means to maintain a gradient of temperature, by providing a region of insulation in which heat flow is reduced or thermal radiation is reflected rather than absorbed.

There are many insulating materials suitable for loft and attic insulation. Two issues matter the most, these being:

- Cost
- Ease of installation

Other issues, which might influence the choice of material, are issues like:

- Permeability - is the material waterproof
- Thermal efficiency i.e. how thick does the material need to be to achieve adequate insulation when we are considering different types of insulation material we will be familiar with R values, and K values.

R values and K values are closely related in that they are different representation of the inherent insulating ability of the material. They describe how good a conductor of heat the material is. Obviously for insulation a poor conductor so that heat is retained within it. The K value or thermal conductivity is usually measured in Watts per meter per degree Celsius (Kelvin to be 100% correct) abbreviated as W/m.k; the lower this number, the better the insulator.R values are simply 1 divided by the k value and measures the resistance to the transfer of heat through the material. The higher the R value the better the insulator.

A wide range of insulation materials is available; selection of insulation material should be based on initial cost, effectiveness, durability, the adaptation of its form/shape to that of the collector and tank and the installation methods available. From an economic point of view, it may be better to choose an insulating material with a lower thermal conductivity rather than increase the thickness of the insulation in the hold walls. By reducing the thermal conductivity, less insulation will be required.

Common insulating materials, "R" values, advantages and disadvantages

Insulating material	"R" value per inch (2.54 cm)	Advantages	Disadvantages
Polyurethane, board	6.25	Very good R-value, can be used with fibreglass resins	Not always easily available, relatively expensive
Polyurethane, spray on	7.0	Very good R-value, can be used with fibreglass resins, easy application with spray equipment	Not always easily available, expensive, requires special spray equipment
Polyurethane, poured (two-part chemical)	7.0	Very good R-value, can be used with fibreglass resins, relative ease of application	Not always easily available, expensive, requires very careful volume calculations
Polystyrene, sheets (smooth) Trade name "Styrofoam"	5.0	Readily available, low cost, reasonable R-value	Cannot be used with fibreglass resins unless protected, easily damaged
Polystyrene foamed in place and expanded moulded beads. Known as Isopor, Polypor, etc.	3.75 to 4.0	Reasonable R-values, lower cost than smooth surfaced sheets	Cannot be used with fibreglass resins unless protected, easily damaged
Cork board	3.33	Availability in many markets, reasonable cost, can be covered with fiberglass	Lower R-values than polyurethane for styrene foams
Fibreglass wool batts	3.3	Low cost, ease of installation	Readily absorbs water or other fluids, loses insulating value when wet
Rock wool batts	3.7	As above	As above
Wood shavings	2.2	Readily available, low cost	Absorbs moisture and loses R-values when wet, decays
Sawdust	2.44	Readily available, low cost	Absorbs moisture and loses R-value when

			wet, packs down under vibration
Straw		Readily available, low cost	Absorbs moisture and loses R-value when wet, host to insects, etc.
Air space	1.0 approx.	No cost	Has to be completely sealed to prevent air circulation causing heat infiltration

Table 2- different types of insulation material

Polyurethane foam

One of the best commercially available choices of insulation material is polyurethane foam. It has good thermal insulating properties, low moisture-vapour permeability, and high resistance to water absorption, relatively high mechanical strength and low density. In addition, it is relatively easy and economical to install.

Polyurethane foam is effective as an insulator because it has a high proportion (90 percent minimum) of non-connected closed microcells, filled with inert gas. Until recently, the inert gas most commonly used in polyurethane foams was R-11 (trichlorofluoromethane).

Fig4 – Polyurethane foam

Fibreglass

Fibreglass matting is also used as insulating material and offers the following advantages:

- high resistance to fire;
- high resistance to microbiological attack;
- good resistance to most chemicals;
- high heat resistance;
- available in a variety of presentations (e.g. blankets, mats, loose fill and boards);
- low thermal conductivity

Fibreglass insulation is available in rolls of different thickness, also called blankets and mats. The width of the blankets and mats will depend on the way they are to be installed and some come faced on one side with foil or Kraft paper, which serves as vapour barriers.

However, the main technical limitations of fibreglass matting as insulation are:

- Poor structural strength or compression resistance;
- A tendency to settle after installation if not properly installed;
- Its permeability to moisture.

Rigid board panels can be made with compressed fibreglass. These lightweight insulation boards have relatively high R-values for their thickness.

Fig 5- Fibreglass

Cork

Cork is probably one of the oldest insulation materials used commercially, and in the past it was the most widely used insulation material in the refrigeration industry. At present, due to the scarcity of cork-producing trees, its price is relatively high in comparison with other insulating materials. Therefore, its use is very limited, with the exception of some machine foundations to reduce the transmission of vibrations. It is available as expanded slabs or boards as well as in granular form, its density varies from 110 to 130 kg/m^3 and it has an average mechanical resistance of 2.2 kg/m^2. It can only be used up to temperatures of 65 °C. It has good thermal insulating effectiveness, is fairly resistant to compression and is difficult to burn. Its main technical limitation is the tendency to absorb moisture with an average presence to water vapour of 12.5 g cm m^{-2} day^{-1} $mmHg^{-1}$

Fig 6- Cork

Straw Insulation Material

Straw has been used as insulation for over 100 years. It has a deep history as an insulation material. And for good reason, as it provides an R – value between 2.0 and 3.0. Generally straw insulation material comes in the form of compressed straw bales. Straw insulation material is quite economical as well. To truly be effective the straw must be tightly compacted and fully dried. If the straw is not tightly compacted and fully dried it will be significantly less effective than other insulation material. Straw that has been packed with clay has been used as an insulation material. The clay that covers the straw insulation material acts as a fire retardant and has been known to fight off fire for up to twenty minutes

Fig 7: Straw

Polystyrene

A colorless, transparent thermoplastic — is commonly used to make foam board or beadboard insulation, concrete block insulation, and a type of loose-fill insulation, which consists of small beads of polystyrene. The chemical makeup of polystyrene is a long chain hydrocarbon with every other carbon connected to a phenyl group (the name given to the aromatic ring benzene, when bonded to complex carbon substituent). Polystyrene's chemical formula is $(C_8H_8)_n$; it contains the chemical elements carbon and hydrogen.

The thermal resistance or R-value of polystyrene foam board depends on its density. They typically range from R-3.8 to R-5.0 per inch. Polystyrene loose-fill or bead insulation typically has a relatively lower R-value (around R-2.3 per inch) compared to the foam board Expanded polystyrene (EPS).

Expanded polystyrene (EPS) is a rigid and tough, closed-cell foam. It is usually white and made of pre-expanded polystyrene beads. Rigid insulation which is used most widely in structural insulated panels. It has an R value~ R-4. The density range is about 16–640 kg/m^3 It is the least expensive insulation.

Extruded polystyrene foam (XPS) consists of closed cells, offers improved surface roughness and higher stiffness and reduced thermal conductivity. The density range is about 28 – 45 kg/m^3. Rigid Insulation with R value ~ R-5 per inch. Its cost is considered intermediate.

Fig8- Polystyrene

Pyranometer

Fig 9- Pyranometer

Overview of the pyranometer

A pyranometer is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view of 180 degrees. It is a sensor that is designed to measure the solar radiation flux density in W/m2. The solar radiation spectrum extends approximately from 300 to 2,800 nm. Pyranometers usually cover that spectrum with a spectral sensitivity that is as "flat" as possible.

For a irradiance measurement it is required by definition that the response to "beam" radiation varies with the cosine of the angle of incidence; i.e. full response at when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 degrees angle of incidence), zero response when the sun is at the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and 0.5 at 60 degrees angle of incidence. It follows from the definition that a pyranometer should have a so-called "directional response" or "cosine response" that is close to the ideal cosine characteristic.

A typical pyranometer does not require any power to operate and are frequently used in meteorology, climatology, solar energy studies and building physics. They can be seen in many meteorological stations, often installed horizontally and next to solar panels, and the sensor is mounted in the surface plane of the panel. The pyranometer, has a glass dome shaded from the Sun's beam and the shading is accomplished either by an occulting (concealing) disc or a shading arm.

When sunlight falls on a pyranometer, the thermopile sensor produces a proportional response typically in 30 seconds or less: the more sunlight, the hotter the sensor gets and the greater the electric current it generates. The thermopile is designed to be precisely linear (so a doubling of solar radiation produces twice as much current) and also has a directional response: it produces maximum output when the Sun is directly overhead (at midday) and zero output when the Sun is on the horizon (at dawn or dusk). This is called a cosine response (or cosine correction), because the electrical signal from the pyranometer varies with the cosine of the angle between the Sun's rays and the vertical.

Sunlight may look yellow, but it actually consists of a very broad spectrum of electromagnetic radiation, ranging in wavelength from about 280 nanometers (nm) up to about 4000 nanometers. This includes both visible "white light" (the familiar rainbow spectrum ranging from red and orange through to indigo and violet) and invisible electromagnetic radiation, including ultraviolet (UV) and infrared (IR). Although our eyes can't see much of this light, pyranometers do their best to detect as much of it as possible, because it all counts as sunlight. The best ones are designed to respond more or less equally to a substantial band of incoming light wavelengths (this is sometimes described as a flat wavelength response).

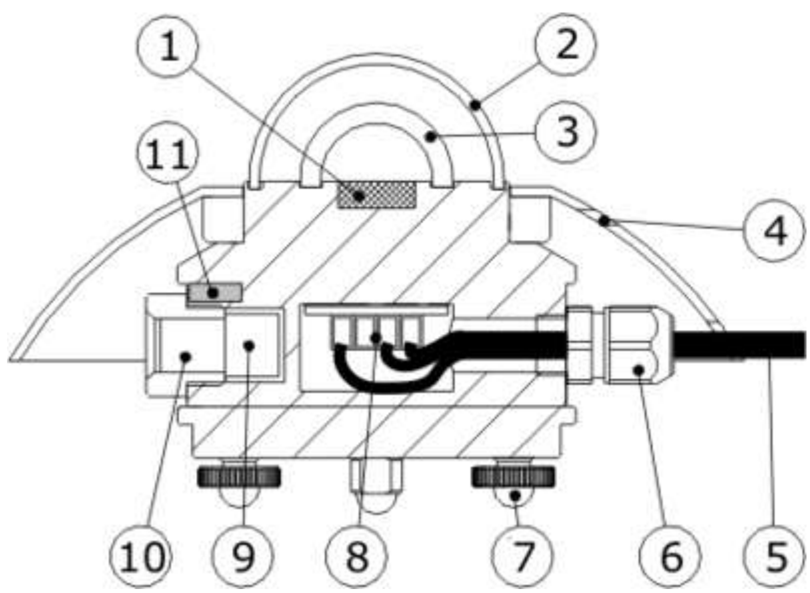

Fig 10- Internal diagram of the pyranometer

Image showing the main components:

Thermopile sensor(1), domes (2), glass dome (2, 3), radiation screen (4),signal cable (5), gland(6), leveling feet (7), printed circuit board(8), desiccant (9), level (11).

Principle of Operation

The basic technique for measuring total solar radiation involves determining the temperature difference between a radiation-absorbing element and an element shielded from solar radiation. This temperature difference is proportional to the incident irradiance. The way the TSP-700 makes the temperature measurement is shown on the left.

▸Both direct and scattered radiation passes through two optically polished glass domes. The domes block long-wave radiation and keep the instrument weather-tight. The two-dome configuration also prevents conductive cooling of the radiation-sensing element that lies beneath the inner dome.

▸The sensing element, a specially designed disk with an optical black coating, absorbs incident radiation from 0.3 to 3 m m.

▸Four laser-trimmed, matched, precision thin-film platinum resistance thermometers form the legs of an active electronic bridge circuit. This circuit produces a signal that is proportional to the temperature difference between the radiation-receiving surface and the shielded thermal reference.

▸A thermally stable amplifier outputs a low-impedance 0 to 4 Vdc signal that is independent of changes in ambient temperature. The inherent linearity of the platinum resistance thermometer scheme means that no thermostats are required to compensate for changes in ambient temperature.

Input circuits are surge and polarity protected to ensure years of trouble-free operation. The instrument housing is O-ring sealed, desiccated, and equipped with a color change humidity plug.

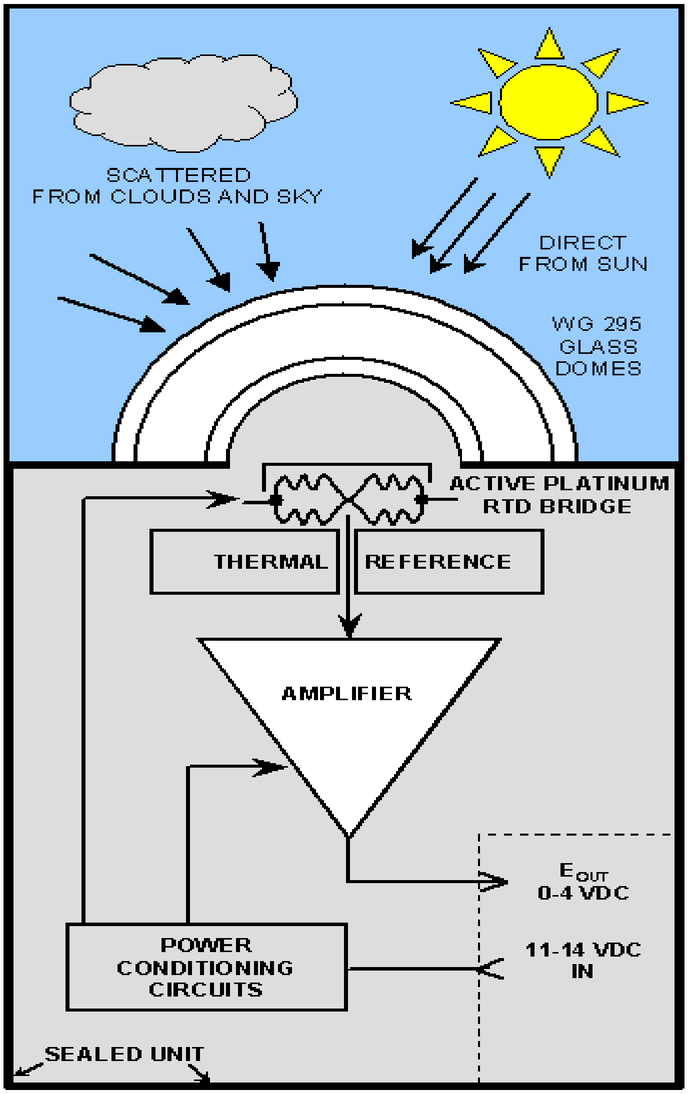

Fig11 – View of the working principle of pyranometer

Advantages of pyranometer:-

- The pyranometer gives an independent, accurate reading of the total available solar radiation
- The pyranometer are classified and calibrated to ISO standards
- A pyranometer can have a very small temperature coefficient

- Performance Ratio or Performance Index calculations are more accurate using a pyranometer
- A high-level, low-impedance output signal

- Superior linearity and long-term stability of calibration
- An excellent cosine response that is *completely* free from axial asymmetry errors
- Freedom from the effects of changes in ambient temperature.

Further works

- To improve the efficiency of solar hot water system by working on its insulation materials like fiberglass, polyurethane, cork etc.
- Using pyranometer, we will measure solar radiance which will helps us to determine the perfect insulation material.
- Further development of the solar hot water system using simulation method
- Extend the system for commercial purpose in Bangladesh

Literature survey:

http://en.wikipedia.org/wiki/Solar_water_heating

http://www.hot-water-heaters-reviews.com/solar-powered-water-heater.html

http://www.builditsolar.com/Projects/WaterHeating/water_heating.htm

http://www.solartubs.com/Solar-heating-system.html

http://www.solartubs.com/Solar-water-heating/

http://www.gaisma.com/en/location/dhaka.html)

http://homepower.com/basics/hotwater/

http://en.wikipedia.org/wiki/Polystyrene

http://www.insulationmaterial.org/Polystyrene%20Insualtion%20Material.htm

Insulation Materials Specification Guide from the NIA National Insulation Training Program

From the report of solar hot water domestic system.

I. Buhihardjo and G.L. Morrison, "Performance of Water-in-Glass Evacuated tube solar water heaters by."

IEEE paper –

- Characteristics and Cost Analysis of an Automatic Solar Hot Water System in Bangladesh
- Solar Domestic Hot Water: Numerical and Experimental Study of the Thermal Stratification in a Storage Tank