Performance Improvement of SHWS by Increasing Thermal Efficiency Using Insulation Materials and Optimum Position of Solar Collectors

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Declaration

We hereby declare that the thesis title "Performance Improvement of SHWS by Increasing Thermal Efficiency Using Insulation Materials and Optimum Position of Solar Collectors" submitted to the dept EEE of BRAC University, Dhaka, in partial fulfillment of Bsc in EEE, is our original work and was not submitted anywhere for the award of any other degree or diploma in any other publication.

Signature of the Supervisor   Signature of the Author

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Abstract

The word itself "Solar" describes that we are dealing with some renewable energy source for a hot water system. A Solar Hot Water System (SHWS) has been already designed; further implementation has been done by working on its insulation at variable time, temperature and solar radiation so that there is a minimum temperature drop over night decreases. A suitable material is found for insulation which is feasible, cost effective and available. For this project an instrument named "Pyranometer" has been used to measure solar radiation flux density (in watts per meter square) and the experimental data collected from pyranometer will be used to find the optimum position of SHWS.

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Chapter 1

Introduction

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).Renewable energy has come forward like blessing to everybody. Two effective reasons makes it popular, it is renewable and its green energy [1]. As per geometrical position solar power is the most potential renewable energy for Bangladesh. Bangladesh is a developing country and it suffers from acute shortage of electricity[2]. To save electrical energy we can use solar energy for our heating systems and it will cost effective and easy to maintain. Solar hot water system has been popular throughout the world but a little research has been done on solar hot water system in Bangladesh. These things motivated us to research on solar hot water system and find the possible option of decreasing consumption of electricity and natural resources like gas and fuel.

1.1 Overview

1.1.1 Solar Energy Today and For the Future

People decide to buy solar energy systems for a variety of reasons. Many want to help preserve the earth's finite fossil-fuel resources and reduce pollution. Buying a solar energy system is a powerful and direct way for us to help protect the environment, and make a long-lasting commitment to the planet's future.

Others would rather spend their money on an energy-producing improvement to their property than to send their money to a utility or fuel company. Some people like the security of renewable energy, because it makes them less vulnerable to future increases in electricity and fossil fuel prices. Others are interested because renewable energy systems can provide emergency power in case of storms or other power system failures. Finally, some people just don't like paying utility bills and appreciate the independence that renewable energy provides [3].

1.1.2 Reasons for using solar energy in Bangladesh

Energy is a vital requirement for our daily lives and we also need energy to make our everyday life easier by using technologically enhanced machines. The sources of this energy are mainly minerals and ores which are limited in quantity and since we use them every day, they cannot last forever. As a result of this scarcity that will arise in the future, people are always looking for new sources of renewable energy that will never run out and will also be environment friendly.

Along with the major developments in the alternative sources of energy, a major breakthrough was the "Solar Energy." This energy is always there in surplus. If we can only harvest and utilize this energy to its full potential, we will be able to solve the energy crisis.
Solar energy is inexhaustible and available in all the countries of the world, Greatest amount of solar energy is available in two broad band's encircling the earth between 15 degree and 35 degree latitude north and south. The next best position is the equatorial belt between 15degree N and 15degree S latitude. Bangladesh is situated between 20.34degree and 26.38degree latitude north and as such has a good solar energy potential. Bangladesh is a country of enormous sunshine. Average annual solar radiation on a 240 inclined surface is estimated as 4.2 $kWh/m^2/day^{-1}$. But the availability of an energy source does not mean much, if the necessary technology to harness it is not available. During the last decades considerable advances in some of the solar energy technologies have been made and some have already reached the commercial stage [4].

1.1.3 Solar Radiation on the Earth's Surface

Solar radiation is received at the earth's surface in an attenuated form because it is subjected to the mechanism of absorption and scattering as it passes through the earth's atmosphere (Figs. 1 and 2). Absorption occurs primarily because of the presence of ozone and water vapors in the atmosphere and to a lesser extend due to other gases (like CO2, NO2, CO, O2 and CH4) and particulate matter. It results in an increase in the internal energy of the atmosphere. On the other hand, scattering occurs due to all gaseous molecules as well as particulate matter in the atmosphere. The scattered radiation is redistributed in all directions, some going back into space and some reaching the earth's surface[4].

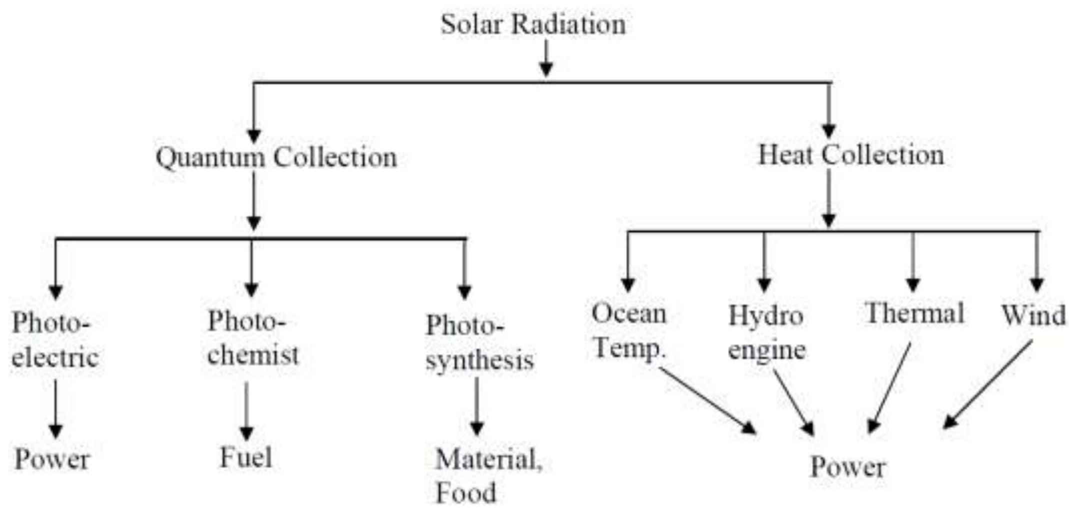

Fig 1: Different collection processes of solar radiation

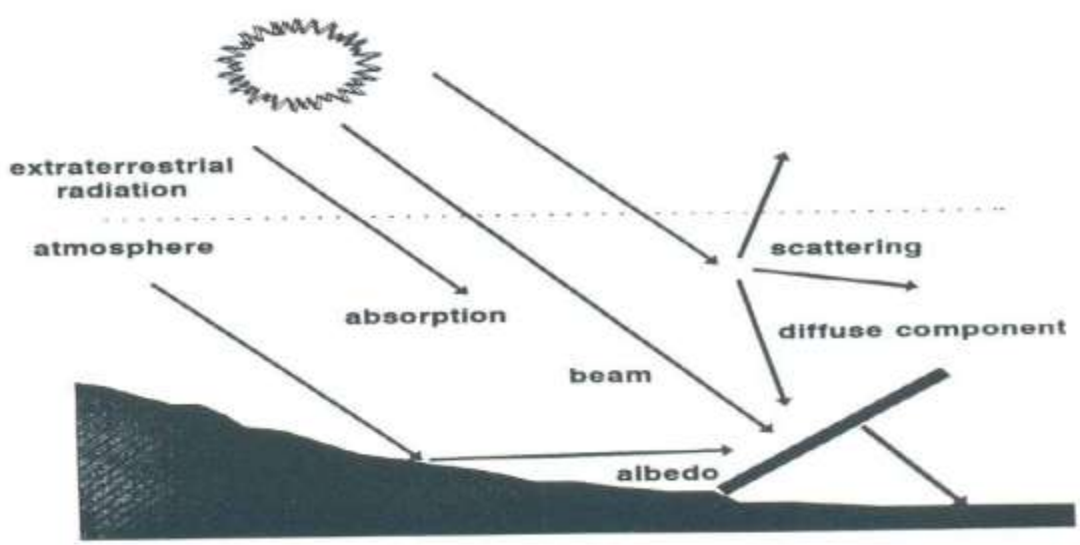

Fig 2: Schematic representation of the mechanism of absorption and scattering, beam and diffuse radiation received at the earth's surface

1.1.4 The reason for using SHWS

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. 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[5].

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[6].

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 it, is evident to use SHWS instead of geezer to save our electrical energy. 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. Solar hot water system has been popular throughout the world but a little research has been done on solar hot water system in Bangladesh. These things motivated us to research on solar hot water system and find the possible option of decreasing consumption of electricity and natural resources like gas and fuel.

1.2 Objectives

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 solar hot water system has been already designed 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.

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 could be reduced and the temperature difference between the solar collector and the tank is reduced. In our thesis we have decided to use different types of insulating material and measure its temperature drop [7,8]. The optimum position for the solar hot water system can be finding using the collected data from Solar and Wind Energy Resource Assessment (SWERA) – Bangladesh Project so that its efficiency level is high throughout the year [9].

1.3Thesis organization

In the first chapter, we have discussed why solar energy is effective for Bangladesh, solar radiation on earth's surface, reason for using solar hot water system and have given a brief idea of our thesis. In next chapter we will discuss the designed system, in chapter three we will discuss about different insulation materials and factors need to be considered before choosing insulation materials. In chapter four, we will discuss about an instrument "pyranometer" for measuring solar radiance. In chapter five, we will use Global Horizontal Irradiance (GHI) and Diffuse Irradiance (DIF) data to find the optimum position of SHWS. By the end of chapter six we will conclude our thesis work using data collected after insulation, comparing with previous measured data and further work.

Chapter 2

Overview of the system

2.1 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. Using this 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. This procedure is repeated from July 2009 till then. Using this procedure the amount of energy gained by the system and the operating temperature of the system is known.

The operating temperature is that temperature that is provided to the users, or the temperature of the outlet of storage tank. The reference temperature of water for the system is set at 50 degree Celsius.

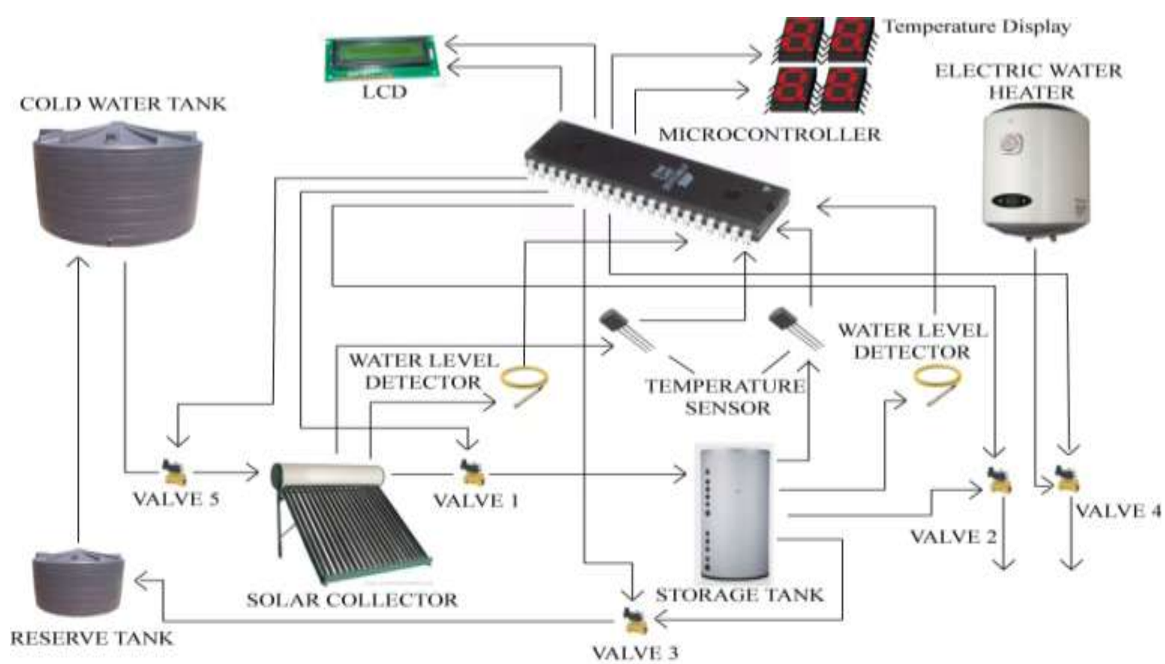

Fig3: Block diagram of solar hot water system

A microcontroller has been used for this system to reduce the expense using thermostat technology. The block diagram shows when the temperature falls below the desired temperature then the water heater is switched on. The temperature sensor will send a signal to the microcontroller when the heater will be switched on or off [7,8].

The main components of solar water heater are:

- Solar collectors
- Water-in-glass evacuated tubes
- Storage tank
- Mounting frame
- External water supply source

2.1.1 Solar collectors

Lots of tubes are commercially available for solar hot water system. For this type of system only two types of collectors are used: evacuated tube collector and flat plate collector. The evacuated tube collector over flat plate collector type is the perfect one for this system because the difference in temperature of flat plate collector is significant when the optimum increases and the efficiency level decreases. Even solar thermal collectors have sub types among all sub types only all glass tube and heat pipe tube demonstrate long life under transient outdoor condition.

The glass tube is the simplest and cheaper one whereas the manufacturing and implantation of heat tube is expensive. The tubes are connected with the heat tank so the heat loss is less in the glass tube than heat pipe evacuated tube collector. Due to thermos phone process, water-in-glass evacuated tube solar collector becomes hot in short period of time [7,8].

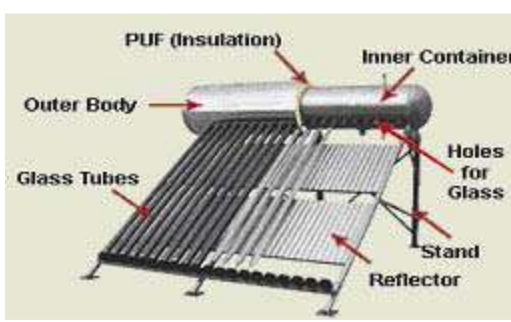

Fig.4. Schematic view of evacuated tube collector

2.2.2 Water-in-glass evacuated tubes:

Evacuated tube consists of glass tubes is made up of strong borosilicate glass with high chemical and thermal shock resistance and the outer tube is transparent which allows maximum light to pass through it with minimal reflection. This is done by coating the outer side of the inner tube with solar selective coating (Al-N/Al or AlN/AlN-SS/Cu). The solar heat is collected and transferred inside the tube.

Fig.5: 150 liters tank with directly connected water-in-glass evacuated tube collectors

2.2.3 Storage tank

This tank stores the water that comes from the external tank. It has two tank inner tank and outer tank and there is a gap between them which is filled with insulating material (rock wool or mineral wool) to reduce heat loss from the heated water inside the tank.

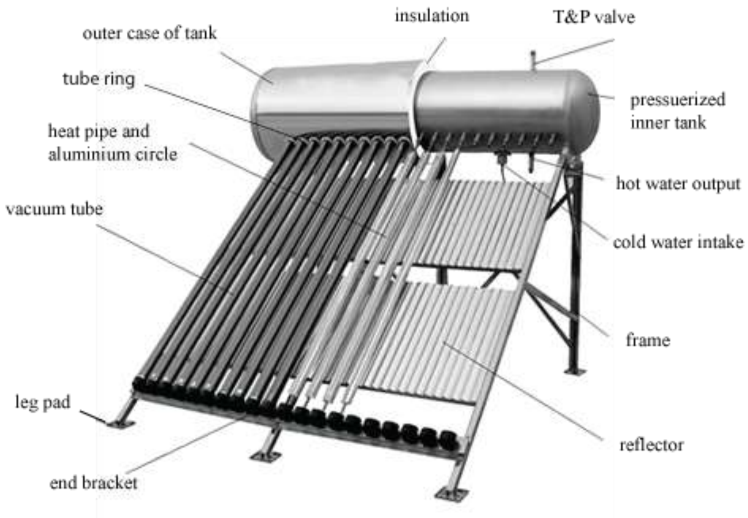

Fig 6- cross-section of the storage tank

2.2.4 Mounting frame

This structure consists of number of plates which are kept at an angle on which storage tank, manifold box, tubes and other components are mounted.

2.2.5 External water supply source

Water is supplied from the external water supply source to the storage tank of evacuated tube.

2.3 Experimental procedure

The whole hot water system is completely automatic; no human control is required during transferring water between tanks. The whole system consists of 5 solenoid valves, which are controlled by microcontroller which is the backbone of the system. One valve is connected between the storage tank and the solar collector. This valve turns on whenever the temperature sensor detects that the operating temperature is reached. The temperature sensor consists of LM35 temperature IC in a copper cladding. Next valve is connected between the user outlet and the storage tank. This valve provides hot water to the user when the storage tank contains water of the operating temperature. Whenever the water temperature inside the storage tank falls below then another valve is open and send back the hot water to the reserve tank. When the storage tank does not have the hot water with the required temperature next valve is open and it provides hot water to the end user. As a result two valves will never work at the same time – they are the substitutes of each other. Because those two valves are connected to storage tank and give the same output that is provide hot water to the user. Last valve is the valve that supplies cold water from the main tank to the 150 liters collector. This valve only opens when the level detector inside the tank detects low level of water in the 150 liters collector and turns off whenever the tank gets filled. When this valve is open, first one is off so that cold water does not mix with the stored water.

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. 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[7,8].

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[9].

2.4 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

Chapter 3
Insulation materials

3.1 What is insulation?

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 [11].

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 [12].

3.2 Factors considered before choosing any insulation

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 [13].

3.2.1 R values and K values

The **R-value** is a measure of thermal resistance used in the building and construction industry. Under uniform conditions it is the ratio of the temperature difference across an insulator and the heat flux (heat transfer per unit area, $\dot{Q}_A$) through it-

$$R = \Delta T / \dot{Q}_A$$

The R-value being discussed is the unit thermal resistance [14]. 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[15].

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[16].

3.3 Different types of insulation materials

Common insulating materials, "R" values, advantages and disadvantages [17].

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	3.75 to 4.0	Reasonable R-values, lower cost than smooth surfaced sheets	Cannot be used with fibreglass resins unless protected, easily damaged

Isopor, Polypor, etc.			
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

3.3.1 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} $mmHg^{-1}$ [18].

Fig 7- Cork

3.3.2 Glass wool

Glass wool is an insulating material made from fiberglass, arranged into a texture similar to wool. Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. Glass wool is a thermal insulation that consists of intertwined and flexible glass fibers, which causes it to "package" air, resulting in a low density that can be varied through compression and binder content. It can be a loose fill material, blown into attics, or, together with an active binder sprayed on the underside of structures, sheets and panels that can be used to insulate flat surfaces such as cavity wall insulation, ceiling tiles, curtain walls as well as ducting. It is also used to insulate piping and for soundproofing. It has R value around- 2.5[19].

Fig 8- Glass wool

3.3.3 Rock wool

A man-made material consisting of natural minerals like basalt or diabase. Mineral wool, mineral fibres or man-made mineral fibres are fibres made from natural or synthetic minerals or metal oxides. The latter term is generally used to refer solely to synthetic materials including fibreglass, ceramic fibres and rock or stone wool. Industrial applications of mineral wool include thermal insulation, filtration, soundproofing. Rockwool Insulation comes in a variety of roll and slab products which are used to provide acoustic, fire and thermal insulation in walls. It has R value of 3.7 and it is low cost and ease of installation

Mineral wool contains an average of 75% post-industrial recycled content. It doesn't require additional chemicals to make it fire resistant, and it can be used in two different insulation forms: blanket (batts and rolls) and loose-fill[20,21].

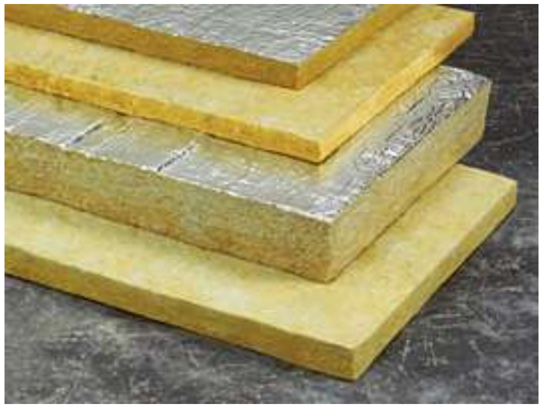

Fig 9- Rock wool

3.3.4 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, 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)[22].

Fig10 – polyurethane foam

3.3.5 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 serve 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[23].

3.3.6 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

Fig11: straw

3.3.7 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.

3.3.7.1 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.

3.3.7.2 Extruded polystyrene (XPS)

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.

Fig12- polystyrene

3.3.8 Rubber

Rubber Insulation offered by us is a flexible as well as light weight elastomeric foam material that is designed primarily for thermal insulation purposes. These Rubber Insulation are generally black in color but can also be made available in a wide variety of colors. Available in tubing or sheet form, foam rubber insulation self-adhesive tapes are also part of product line. These extruded flexible tubing are specially designed to fit standard diameters of steel & copper piping.

3.3.8.1 Features of Rubber Insulation:

- Low thermal conductivity (K value) that makes it highly efficient & effective in insulation
- Cooling/heating systems

- Thermal blister closed cell structure forms impermeable layer that is in itself a good vapour barrier
- It is suitable for application within temperature range of -40degC +105degC
- Material has been specially compounded to be self-extinguishing in nature
- it has excellent ozone & ultraviolet resistance
- It is CFC, asbestos, chlorine & fiber-free and does not cause skin allergy
- It is also inert to most chemical agents & neutral to pipe metals
- The inherent flexibility of material makes installation fast, easy & economical
- It is able to withstand tearing, rough handling as well as sever site conditions
- Much lesser space required for this as thinner wall is required due to its low K value as compared to other insulation types
- The smooth surface of material gives finished installation a neat & aesthetic appearance
- No coating is necessary on most indoor installations

3.3.8.2Technical Specifications:

At -40deg C Closed Cell Insulation becomes hard & as temperature drops below -40degC that will be increasingly brittle; however this hardening characteristic does not affect thermal efficiency/water vapor permeability[24,25].

Fig 13- Rubber

3.3.9 Aluminium foil

Aluminium foil is a conductor of heat energy. However, it does reflect radiation from heat sources, so it can reduce heat transfer through radiation. When aluminum foil is wrapped around something, pockets of air can be trapped. Trapped air is an excellent insulator against conduction and convection. Aluminium foil insulation is based on the radiant barrier that the foil provides. This means it reflects temperature back to where it came from. It doesn't matter if it's hot or cold as the reflective action returns the temperature to the direction of the source. Aluma-Foil reflective radiant barrier reflects up to 97% of the radiant heat that hits its surface. As a result, only 3% of radiant heat gets in which is the primary contributor of heat gain[26,27].

3.3.9.1The benefits of aluminium foil Insulation:

- Reduction of energy loss by approximately 30%
- Costs less than 60% of similar products
- Ease of installation
- Does not absorb dampness.

Fig 14- Aluminium foil

3.4 Insulation of the system

We have insulated the 300 liters storage tank and collector pipes with aluminum foil and cork board underneath. The pipes through which water is transferred from the 150 liters collector tank to 300 liters storage tank is insulated with rubber. We know the temperature drop overnight was 10 degree Celsius and maximum temperature fall was from the back of the collector tank. That's why we insulated the back of the collector tube so that the temperature fall overnight can be decreased. From the front side of the collector tube the heat is radiated by the aluminum foil and the back side of the tube is covered with cork and aluminum foil so that the temperature drop can be reduced.

Fig 15 front side of the storage tank

Fig 16: Back view of the storage tank

Chapter 4

Pyranometer

Fig 17- Pyranometer

4.1 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) [28].

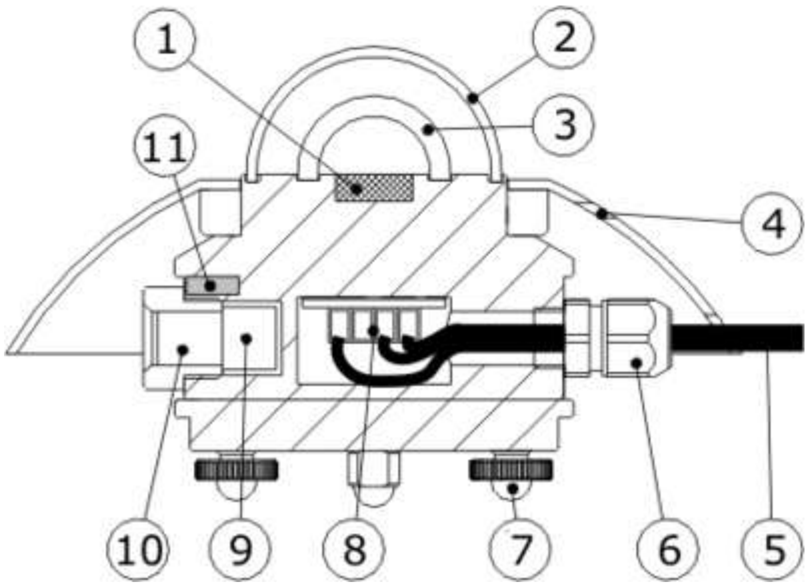

Fig 18- internal diagram of the pyranometer

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).

4.2 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 pass 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 thermistors 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 [29].

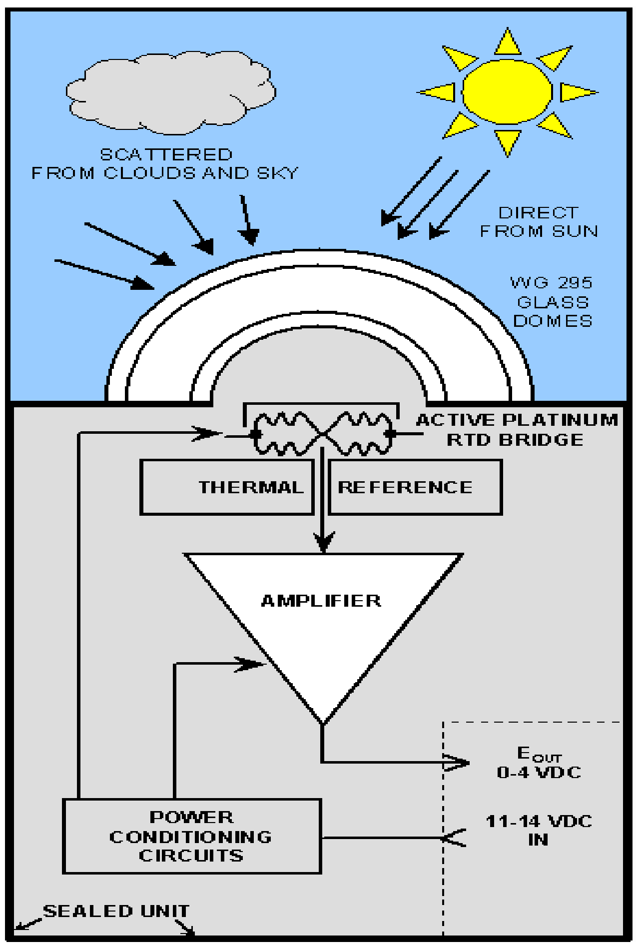

Fig19 – view of the working principle of pyranometer

4.3 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[30].

Chapter 5

Optimum position

In this chapter we will discuss about the pyranometer readings and finding the optimum position of solar hot water system (SHWS).

5.1 Pyranometer reading

The Pyranometers are placed on roof of a two storied Dhaka University library building having fine surrounding aperture. 2 channels of the same data acquisition card are used for Global Horizontal Irradiance (GHI) and Diffuse Irradiance (DIF) data[9].

5.1.1 Horizontal Irradiance (GHI)

Global radiation is composed of the directly coming solar radiation and of the diffuse radiation itself. The fraction of diffuse radiation which is obstructed by the surrounding obstacles (inclined > 5_0) has been added with the measured GHI values. From a study of the surrounding obstructions it was found that 2% area of the hemisphere is obstructed.

5.1.2 Diffuse Irradiance (DIF)

Diffuse radiation is obstructed from receiving the pyranometer due to the shadow ring used for the measurement and by the surrounding obstacles like trees or buildings. To get reliable diffuse radiation values necessary correction factors have been introduced for measurements, pyranometer and two hand data loggers are used.

5.1.3 Reasons for frequent checking of pyranometer

The pyranometers are frequently checked and some of the data are screened out because:-

1) Misalignments of the shadow ring,

2) Misbehavior of the background or offset values and

3) Dirtying of the glass surface from bird's waste.

Hours/month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5:30			1	5	17	19	11	7	3			
6:30	3	8	29	66	106	93	86	66	58	46	31	11
7:30	57	93	148	198	252	200	198	180	165	169	157	97
8:30	175	254	318	354	406	321	355	288	303	324	331	237
9:30	300	424	489	521	561	416	438	433	435	473	490	382
10:30	411	573	629	666	681	494	503	514	485	487	580	479
11:30	494	672	712	751	727	532	548	537	485	520	614	498
12:30	518	701	722	764	711	543	570	535	486	488	573	489
13:30	483	646	657	693	641	500	503	482	441	406	510	426
14:30	379	528	541	553	577	451	463	453	385	323	377	309
15:30	236	353	377	402	419	329	372	356	281	208	204	183
16:30	94	175	204	237	257	215	244	231	164	76	57	54
17:30	10	37	55	72	93	93	107	89	45	6	1	2
18:30			2	4	11	17	18	8	1			
Daily average (kWh/m^2-day)	3.16	4.46	4.88	5.28	5.46	4.22	4.42	4.18	3.74	3.53	3.92	3.17

Table 3: Monthly average hourly GHI (Wh/m2)

Hour/Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5:30			1	5	16	18	11	6	3			
6:30	3	7	27	58	90	80	70	58	55	37	23	10
7:30	47	70	109	147	183	156	145	140	137	108	87	59
8:30	117	146	189	238	253	228	226	217	229	172	137	109
9:30	172	205	244	308	322	281	287	292	279	238	176	145
10:30	220	250	281	350	356	325	318	343	327	248	205	171
11:30	250	274	297	372	381	339	349	350	333	263	223	194
12:30	257	264	306	367	375	348	356	342	304	268	217	208
13:30	240	254	276	339	345	317	295	319	269	219	206	193
14:30	199	221	245	284	303	282	250	270	259	173	167	156
15:30	139	170	191	217	238	215	211	224	187	122	110	105
16:30	69	104	127	151	164	152	149	157	115	55	43	40
17:30	9	30	46	60	77	75	82	68	38	5	1	2
18:30			1	4	12	15	16	7	1			
Daily average (kWh/m^2-day)	1.72	1.99	2.34	2.90	3.12	2.83	2.76	2.79	2.54	1.91	1.60	1.39

Table 4: Monthly average hourly DIF (Wh/m2)

5.2 Estimation of GHI

The data collected from solar radiation are used to set up solar devices as in the developing countries the number solar radiations measuring stations are not much. The solar radiation values are predicted using meteorological parameters as these parameters are related to nature. Angstrom developed a correlation equation between the solar radiation and sunshine duration as

$$H/h = a + b\, n/N$$

H/h= ratio of monthly averaged daily GHI to monthly averaged daily extraterrestrial radiation on a horizontal surface,

n/N = the ratio of monthly averaged daily sunshine hours to monthly averaged day length hours

a,b = correlation coefficients.

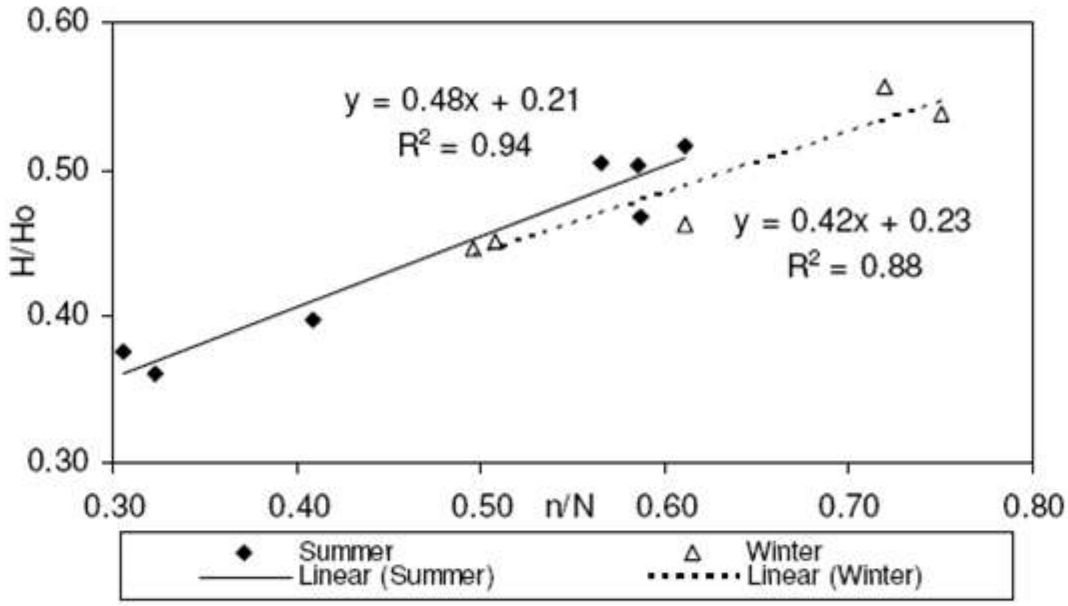

Fig 20: Correlation between monthly

For approximation the annual rms erros is 0.15kWh/m2-day and the percentage error is 3.5%.

Cloud cover can give us the idea of sunshine duration as they are correlated. When cloud cover increases sunshine duration decreases. Estimation of sunshine duration from cloud cover data has been done using the state of the sky technique of Barbaro et. al.. The relative sunshine duration and state of the sky are related by the following equation:

$$n/N' = (an1 + bn2 + cn3)/(n123)$$

n1= number of clear days

n2=number of mixed days

n3=number of forecast days

n=n1+n2+n3, total number of days in the month considerations

N' = is the period when the Campbell-Stokes sunshine recorder remains sensitive over the representative day for the month and

$$N' = (\arccos(\cos 85 - \sin\phi \sin\delta)/\cos\phi \cos\delta)/7.5)$$

δ = the declination

ϕ= the latitude of the station

The numbers of clear, mixed and overcast days in a month were determined according to

Cloud cover amount (in Octa)	**Type of day**
0-2	Clear day
2-4	Mixed day
4-8	overcast day

Table 5: following Barbaro

5.3 Estimation of DIF

The monthly averaged daily diffuse radiation has been calculated using the Angstrom like correlation

$$Hd/H=c+dH/h$$

H=the monthly averaged daily global radiation on a horizontal surface, *c* and *d* are correlation coefficients.

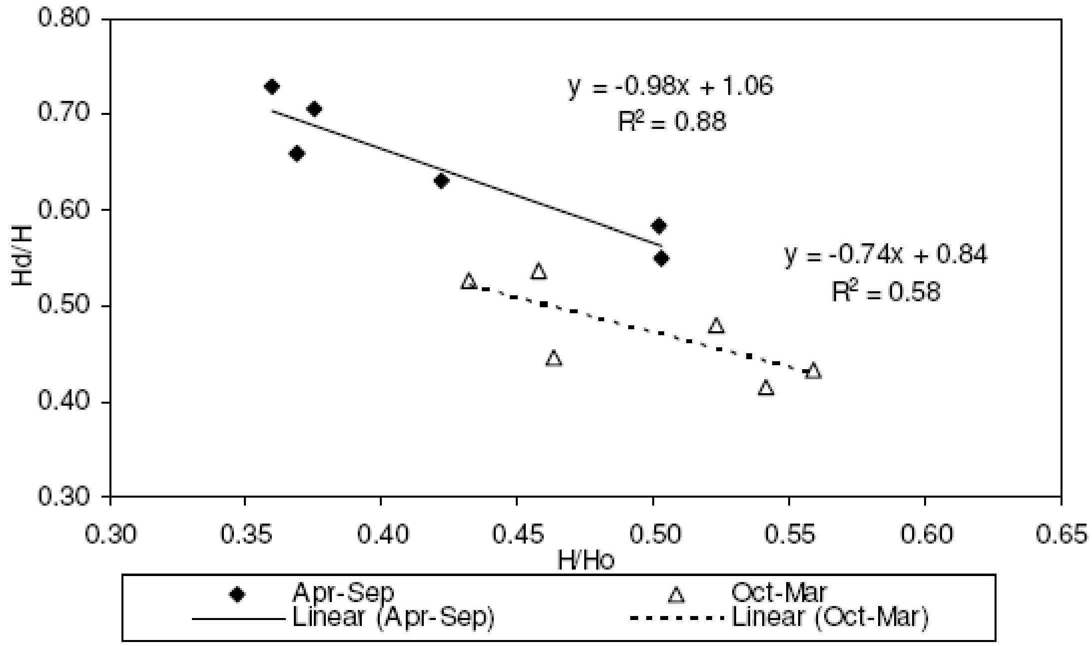

Fig 21: Correlation between monthly

5.4 Estimation of Tilted surface radiation

Flat surface absorbs both beam and diffuse radiation components of solar radiation. To get the total radiation on the tilted surface plane of a collector of fixed orientation we need to know the ratio of the total radiation on the tilted surface to that of the horizontal surface. The amount of solar radiation falling on the tilted surface is the sum of the beam and diffuse radiation falling directly on the surface and the radiation reflected on the surface from the surroundings. If the tilted factor is known then it is possible to assume the radiation on the tilted surface for solar hot water system. The ratio of the beam radiation falling on a tilted surface to that falling on a horizontal surface is called the tilt factor R_b for beam radiation.

For the case of a tilted surface facing south in the northern hemisphere, R_b and is given by

$$R_b = (\cos\theta/\cos\theta z) = (\sin\delta \sin(\phi - \beta) + \cos\delta \cos w \cos(\phi - \beta))/(\sin\delta \sin\phi + \cos\delta \cos\phi \cos w)$$

θ = the angle between the beam radiation on a surface and normal to that surface

θz = the zenith angle

ϕ = the latitude

β = the tilt angle

δ = the declination for the average day of each month

ω = the hour angle for the tilted surface for the average day of the month

The tilt factor R_d for diffuse radiation is the ratio of the diffuse radiation falling on the tilted surface to that of the falling on the horizontal surface. It depends on the distribution of diffuse radiation over the sky and on the portion sky dome seen by tilted surface. We assume that the sky is isotropic source of diffuse radiation.

$$R_d = (1 + \cos\beta)/2$$

We assume that the reflection of the beam and diffuse radiations falling on the ground is diffuse and isotropic and that the reflectivity is ρ , the tilt factor for reflected radiation is given by

$$R_r = \rho\,(1 - \cos\beta)/2$$

ρ = the surface albedo.

The monthly surface albedo values are known from NASA and it lies between 0.12 and 0.16.

Thus the hourly tilt factor, R can be given by

$$R = HT/H = (1 - Hd/H)Rb + (Hd/H)Rd + R_r$$

Hour angle	± 7.5	± 22.5	± 37.5	± 52.5	± 67.5	± 82.5	± 97.5
Jan	1.14	1.15	1.16	1.17	1.20	1.37	
Feb	1.12	1.12	1.12	1.13	1.14	1.21	
Mar	1.05	1.05	1.05	1.04	1.02	1.00	
Apr	0.99	0.99	0.98	0.97	0.95	0.93	0.95
May	0.96	0.96	0.95	0.93	0.91	0.89	0.97
Jun	0.95	0.95	0.94	0.92	0.90	0.88	0.78
Jul	0.95	0.95	0.94	0.92	0.89	0.86	0.76
Aug	0.97	0.97	0.96	0.95	0.93	0.89	0.82
Sep	1.00	1.00	1.00	0.99	0.98	0.96	0.70
Oct	1.06	1.07	1.08	1.08	1.08	1.13	
Nov	1.17	1.17	1.19	1.22	1.27	1.62	
Dec	1.19	1.21	1.23	1.26	1.36	1.53	

Table 6: Hourly Tilt factors for Latitude tilted south facing surface at Dhaka

The tilt angles are chosen in such a way so that solar hot system should get significant solar radiation. In Summer the sun's path is shorter and it shines in the zenith at noon and in winter the sun's path is longer and the path is closer to horizontal at noon. During summer, if we keep solar device horizontally it will get more sunlight and during winter when it is tilted it will get more sunlight. In Bangladesh a study shows that if one simply changes the tilt angle at 40degree for winter (October-February) and 10degree for summer (March-September) then he can achieve higher tilt factors.

Hour angle	± 7.5	± 22.5	± 37.5	± 52.5	± 67.5	± 82.5	± 97.5
Jan	1.16	1.17	1.19	1.21	1.26	1.54	
Feb	1.12	1.12	1.13	1.14	1.17	1.29	
Mar	1.04	1.04	1.03	1.03	1.02	1.01	
Apr	1.01	1.01	1.01	1.00	0.99	0.98	0.99
May	1.00	1.00	0.99	0.98	0.97	0.96	1.00
Jun	0.99	0.99	0.99	0.98	0.97	0.96	0.92
Jul	0.99	0.99	0.99	0.98	0.97	0.95	0.91
Aug	1.00	1.00	1.00	0.99	0.98	0.97	0.93
Sep	1.01	1.01	1.01	1.01	1.00	0.99	0.88
Oct	1.04	1.04	1.06	1.07	1.07	1.16	
Nov	1.19	1.20	1.24	1.28	1.38	1.93	
Dec	1.24	1.26	1.29	1.36	1.52	1.79	

Table 7: Hourly Tilt factors for 10 and 40 degree combination south facing tilted surface at Dhaka

To estimate monthly average tilt factor Liu and Jordan proposed the following equation

$$R = \bar{H}_T/\bar{H} = (1-\bar{H}_d/\bar{H})\,R_b + (\bar{H}_d/\bar{H})\,((1+\cos\beta)/2) + \rho((1-\cos\beta)/2)$$

Here for a south facing surface

$R_b = \bar{H}_{bT}/\bar{H}_b$

$= ((\cos(\phi-\beta)\cos\delta\sin W_s + \pi/180 W_s \sin(\phi-\beta)\sin\delta)/(\cos(\phi)\cos\delta\sin w_s + \pi/180 w_s \sin(\phi)\sin\delta)$

W_s=the sunset hour angle for the tilted surface for
the average day of the month

w_s = the sunset hour angle

$W_s = \min[\cos^{-1}(-\tan\phi\tan\delta),$
$\cos^{-1}(-\tan(\phi-\beta)\tan\delta)]$

“min” means the smaller of the two items in the bracket.

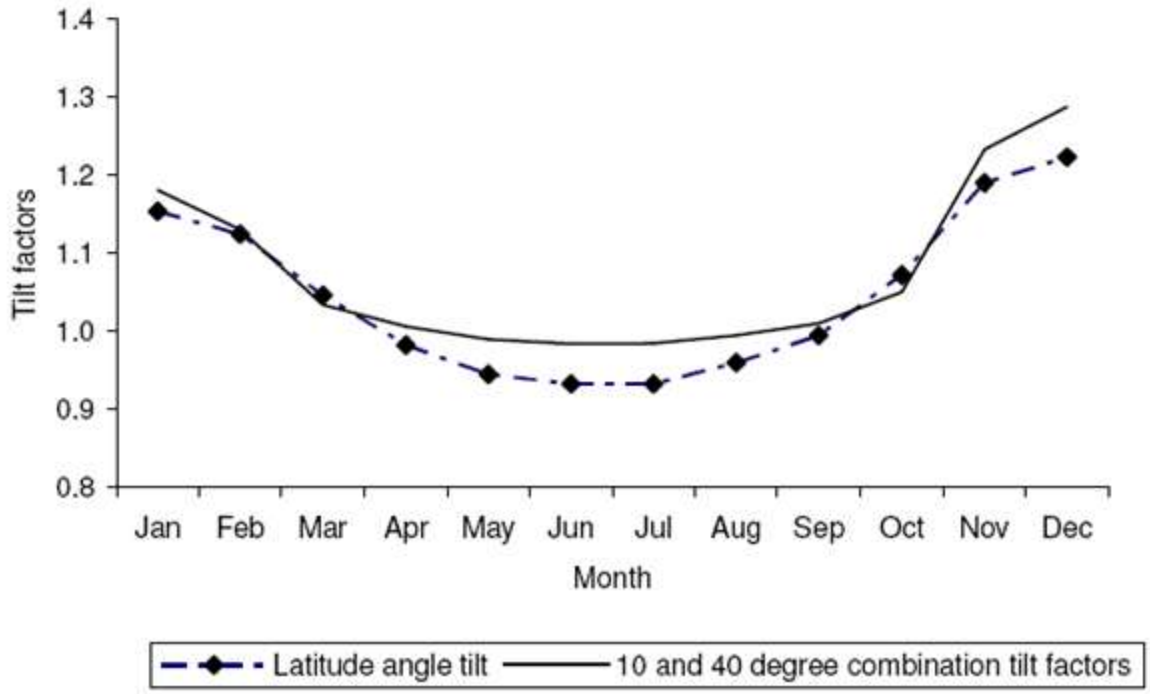

Fig 22: Monthly tilt factors for Dhaka

To know the tilt surface radiation it is needed to multiply GHI data by tilt factor. It is shown in the figure if the surface is kept tilt in summer the radiation decreases. So we need to change the tilt angles of the surface two times in a year to get higher values from the solar hot water system.

Chapter 6

Calculation

6.1 Data of SHWS without insulation

The data we collected, it was before insulation.

Week 1

		temperature		Water level		
date	time	300 liters	150 liters	300 liters	150 liters	Set temp
13.03.11	8.55	63	37	100	150	75
	10:41	63	38	100	150	75
	11:30	63	39	100	150	75
	12|:37	63	41	100	150	75
	1:44	63	47	100	150	75
	2:42	63	51	100	150	75
	3:48	63	55	100	150	75
14.03.11	10:59	28	54	0	150	70
	11:25	28	55	0	150	70
	12:44	28	56	0	150	70
	1:16	28	59	0	150	70
	1:33	28	61	0	150	70
	2:04	28	62	0	150	70
	2:27	28	64	0	150	70

	3:11	28	68	0	150	70
	4:16	29	70	0	150	70
15.03.11	10:53	59	45	100	150	69
	11:57	59	49	100	150	69
	12:56	59	54	100	150	69
	2:09	60	59	100	150	69
	3:01	60	62	100	150	69
	4:05	60	64	100	150	69
16.03.11	10:40	52	59	100	150	69
	11:34	52	60	100	150	69
	12:44	52	63	100	150	69
	1:56	53	67	100	150	69
	2:58	53	68	100	150	69
	3:30	53	68	100	150	69
	4:31	67	38	200	150	69
17.03.11	10:22	56	39	200	150	69
	11:14	56	42	200	150	69
	12:26	56	45	200	150	69
	1:34	56	51	200	150	69
	2:22	57	54	200	150	69
	3:14	57	56	200	150	69
	4:16	57	57	200	150	69

Table 8: The data collected without insulation for week 1

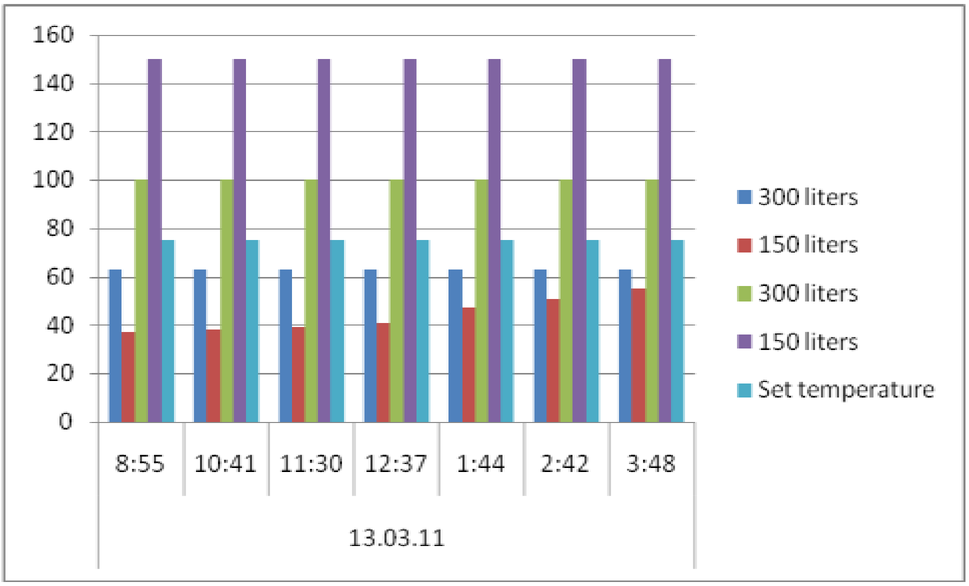

Fig 23: Data collected without insulation on 13th march, 2011

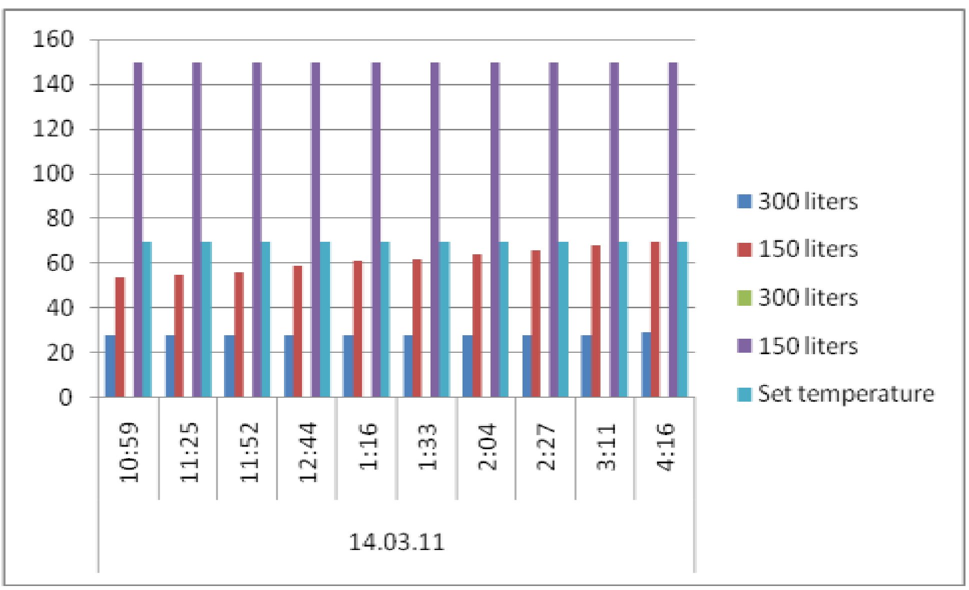

Fig 24: Data collected without insulation on 14th march, 2011

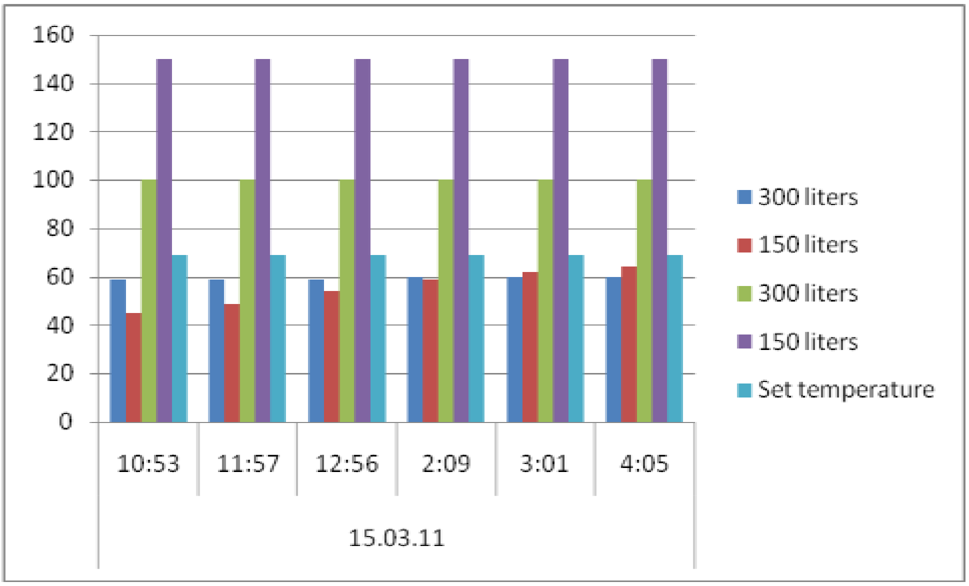

Fig 25: Data collected without insulation on 15th march, 2011

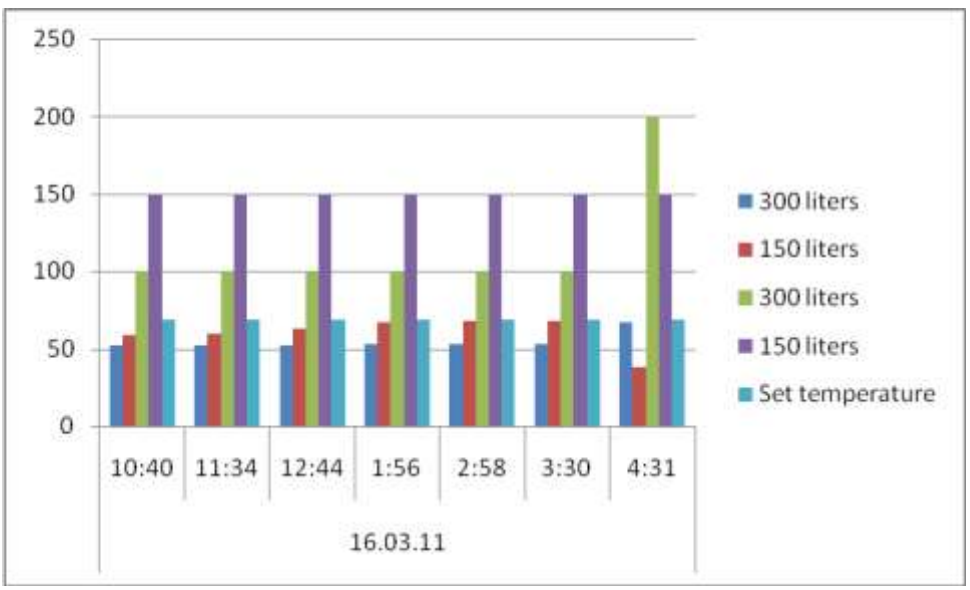

Fig 26: Data collected without insulation on 16th march, 2011

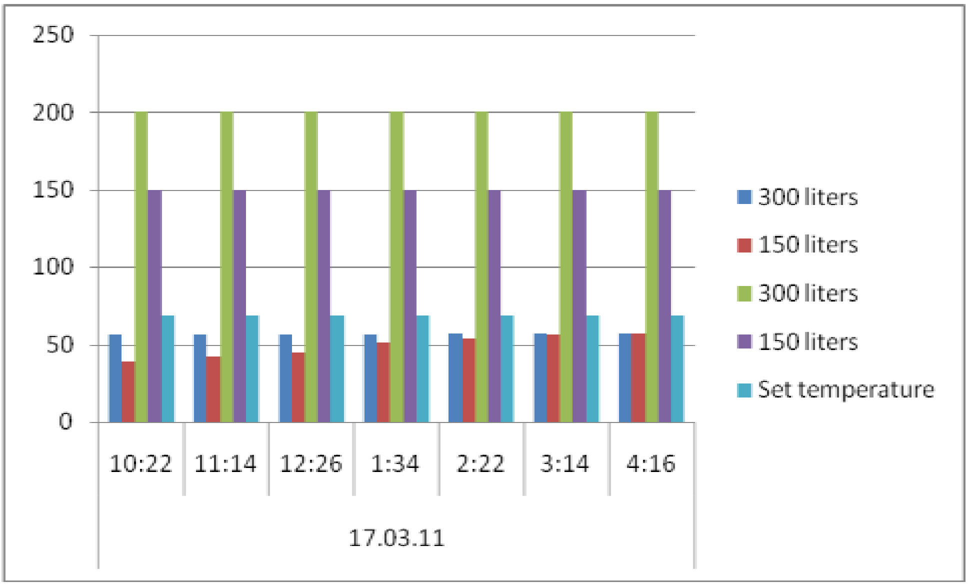

Fig 27: Data collected without insulation on 17th march, 2011

Week 2

date	time	300 liters	150 liters	300 liters	150 liters	Set temp
20.03.11	10:02	55	59	200	150	69
	11:08	55	62	200	150	69
	12:10	55	63	200	150	69
	1:17	55	66	200	150	69
	2:11	56	69	200	150	69
	3:13	56	69	200	150	69
	4:06	56	69	200	150	69
21.03.11	10:59	28	54	0	150	70
	11:25	28	55	0	150	70
	11:52	28	56	0	150	70
	12:44	28	59	0	150	70

	1:16	28	61	0	150	70
	1;33	28	62	0	150	70
	2:04	28	64	0	150	70
	2:27	28	66	0	150	70
	3:11	28	68	0	150	70
	4:16	29	70	0	150	70
22.03.11	10:53	59	45	100	150	69
	11:57	59	49	100	150	69
	12:56	59	54	100	150	69
	2;09	60	59	100	150	69
	3:01	60	62	100	150	69
	4:05	60	64	100	150	69
23.03.11	10:40	52	59	100	150	69
	11:34	52	60	100	150	69
	12:44	52	63	100	150	69
	1:56	53	67	100	150	69
	2:58	53	68	100	150	69
	3:30	53	68	100	150	69
	4:31	67	38	200	150	69
24.03.11	10:13	58	39	200	150	69
	11:16	58	44	200	150	69
	12:12	58	47	200	150	69
	1:25	58	55	200	150	69
	2:34	59	59	200	150	69

	3:22	59	61	200	150	69
	4:16	**59**	**63**	**200**	**150**	**69**

Table 9: The data collected without insulation for week 2

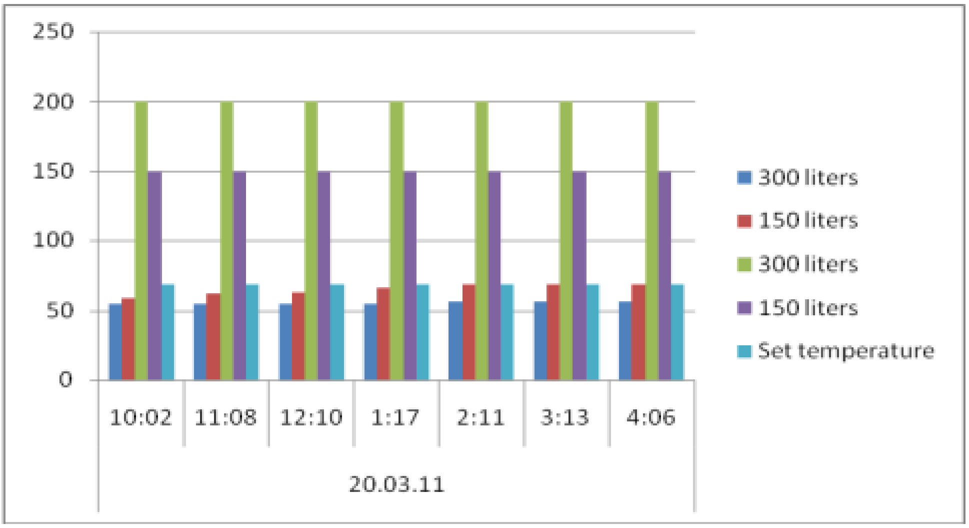

Fig 28: Data collected without insulation on 20th march, 2011

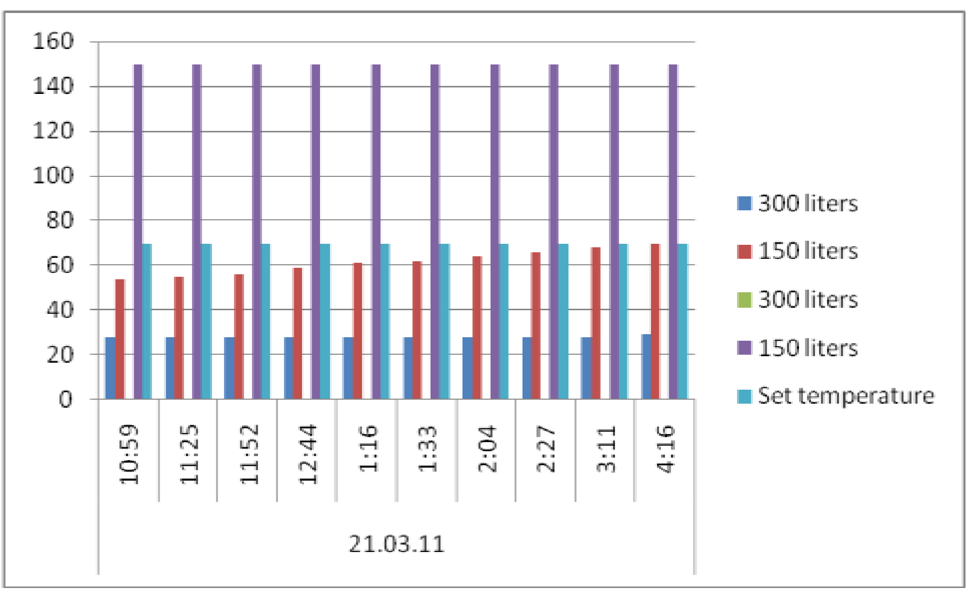

Fig 29: Data collected without insulation on 21st march, 2011

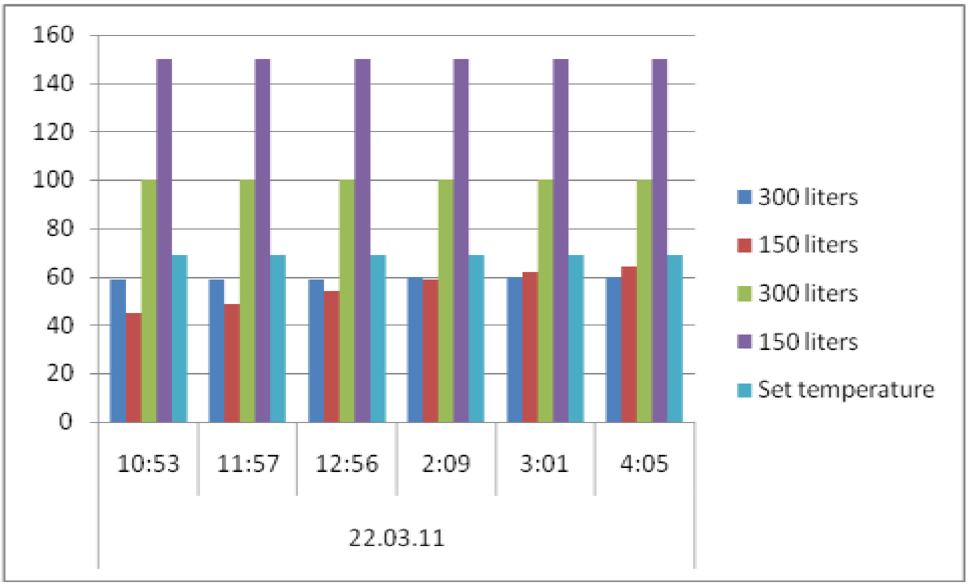

Fig 30: Data collected without insulation on 22th march, 2011

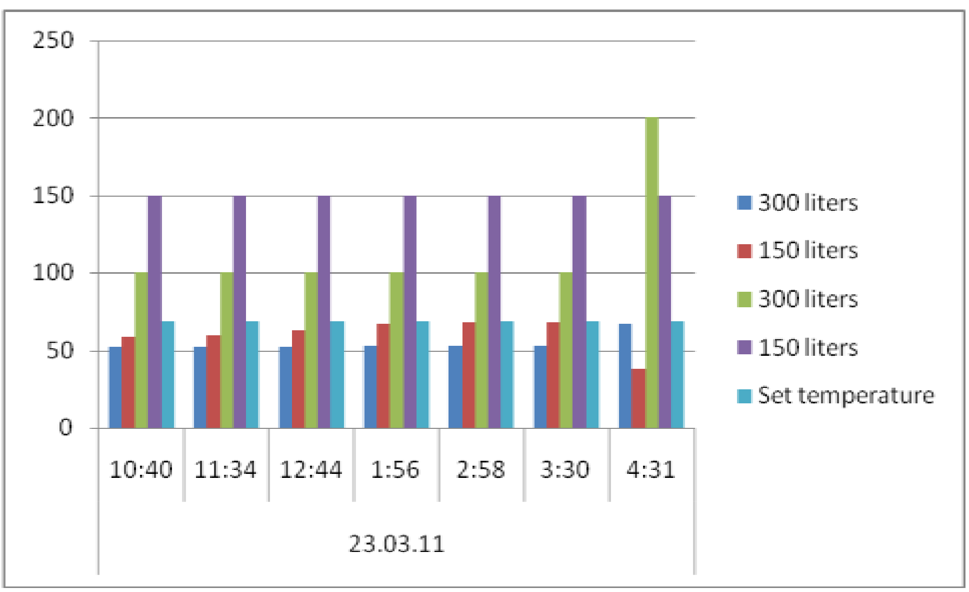

Fig 31: Data collected without insulation on 23th march, 2011

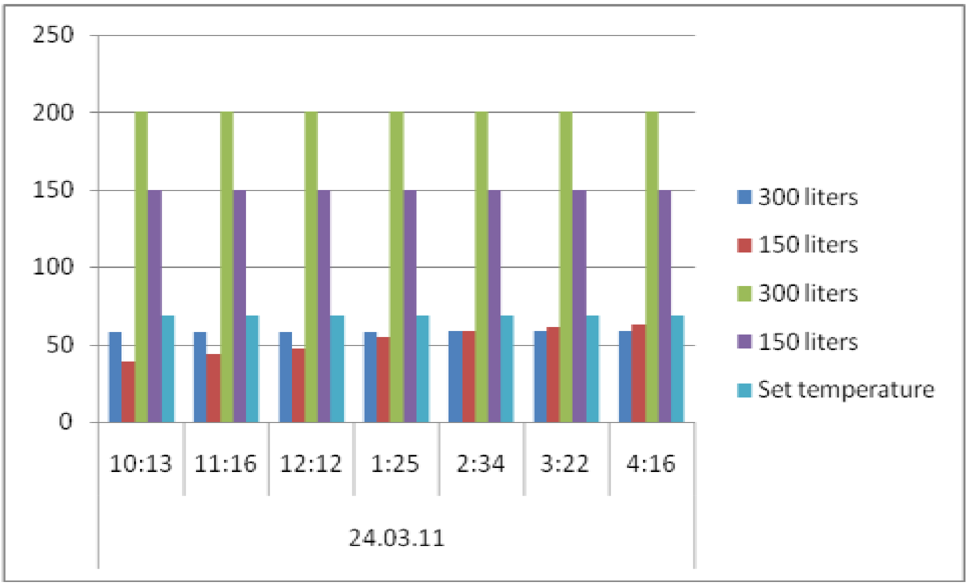

Fig 32: Data collected without insulation on 24th march, 2011

6.2 The data collected with insulation

Day	Collector tank (temp)	storage tank (temp)
Day1(12th dec,2011)	46	0
Day 2(13th dec,2011)	45	38
Day 3(14th dec,2011)	45	39

Table 10: The data collected with insulation

Initialy the storage tank was made empty, then the valve 5 and the motor is turned on. We waited for a while to fill up the collector tank. In the next morning, we measuure thetemperature of the collector tank which is 46 degree celcius. The water is tansferred from 150liters collector tank to storage tank. As the water is transferred to storage tank we need to fill up the collector tank again. To know overnight temperature fall we measure the temperature of storage tank in the very next morning ie 38 degree celcius. The temperature of collector tank is found 45 degree celcius. Again the water is transferred to the storage tank which becomes 300 liter full and the temperature is found 39 degree celcius in the next day.

Comparing the date with or without insulation we found the temperature difference is 8 degree celcius in winter whereas in summer the temperature difference is 10 degree celcius without insulation.

Chapter 7

Conclusion and future work

Through analyzing this paper, rock wool is found an efficient insulating material for SHWS. Using aluminium foil and cork sheet we found the temperature drop overnight is 8 degree Celsius and the optimum angle at 40degree for winter (October-February) and 10degree for summer (March-September) then we can achieve higher sunlight. In average the optimum angle is around 22-25 degree Celsius.

Further works

- To improve further efficiency of solar hot water system by working on its insulation materials like fiberglass, polyurethane, cork etc so that overnight temperature drop is 2 degree Celsius.
- Further development of the solar hot water system using simulation method.
- Extend the system for commercial purpose in Bangladesh.

Appendix

CMP 11

- **Secondary standard pyranometer**
- **Excellent linearity**
- **Fast response time**
- **Low tilt error**



CMP 11 uses the temperature compensated detector technology originally developed for the CMP 22 and is a step up in performance from the CMP 6. It is particularly suitable for meteorological networks and the reduced response time of 1.66 seconds (63%) meets the requirements for solar energy applications.

A waterproof socket is fitted for the signature yellow signal cable, which is available in a range of lengths pre-wired to the waterproof plug.

The integral bubble level is raised to the top of the housing and can be viewed without removing the redesigned snap-on sun shield, which also covers the connector. The connector with gold-plated contacts allows for easy exchange and re-calibration. The screw-in drying cartridge is easy to remove and the replacement desiccant is supplied in convenient refill packets.

The Pyranometer does not require any power, it supplies a low voltage of 0-20mV in relation to the amount of incoming radiation. When a higher voltage level or a 4-20mA signal is required, the AMPBOX is the perfect solution.

PRODUCT SPECIFICATION

Spectral range	285 to 2800 nm
Sensitivity	7 to 14 μV/W/m²
Response time	< 5 s
Zero offset A	< 7 W/m²
Zero offset B	< 2 W/m²
Directional error (up to 80 ° with 1000 W/m² beam)	< 10 W/m²
Temperature dependence of sensitivity (-10 °C to +40 °C)	< 1 %
Operating temperature range	-40 °C to +80 °C
Maximum solar irradiance	4000 W/m²
Field of view	180 °

CMP 22

- **High-end product**
- **Negligible thermal gradient zero-offset**
- **Lowest zero-offset due to FIR radiation**



CMP 22 has all the features of CMP 21 but uses very high quality quartz domes for a wider spectral range, improved directional response, and reduced thermal offsets. Because of the high optical quality of these domes the directional error is reduced below 5 W/m². Kipp & Zonen is confident that CMP 22 is the best pyranometer currently available.

A waterproof socket is fitted for the signature yellow signal cable, which is available in a range of lengths pre-wired to the waterproof plug.

The integral bubble level is raised to the top of the housing and can be viewed without removing the redesigned snap-on sun shield, which also covers the connector. The screw-in drying cartridge is easy to remove and the replacement desiccant is supplied in convenient refill packets.

The Pyranometer does not require any power, it supplies a low voltage of 0-20mV in relation to the amount of incoming radiation. When a higher voltage level or a 4-20mA signal is required, the AMPBOX is the perfect solution.

PRODUCT SPECIFICATION

Spectral range	200 to 3600 nm
Sensitivity	7 to 14 µV/W/m²
Response time	5 s
Zero offset A	< 3 W/m²
Zero offset B	< 1 W/m²
Directional error (up to 80 ° with 1000 W/m² beam)	< 5 W/m²
Temperature dependence of sensitivity (-20 °C to +50 °C)	< 0.5 %
Operating temperature range	-40 °C to +80 °C
Maximum solar irradiance	4000 W/m²
Field of view	180 °

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