MATHEMATICAL MODELING & SIMULATION OF SOLAR DOMESTIC HOT WATER SYSTEM (SDHWS) WITH THERMAL STORAGE TANK

By

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DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma. Based on this project, a paper entitled “Mathematical Modeling of Solar Domestic Hot Water System (SDHWS) with thermal storage tank” has been published in an international conference.

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APPROVAL

The project entitled, "**Mathematical Modeling & Simulation of Solar Domestic Hot Water System (SDHWS) with Thermal Storage Tank**", submitted by Md. Nazrul Islam, Roll no. 13271003, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering in Electrical and Electronic Engineering on February 22, 2018.

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DEDICATOIN

This thesis is dedicated for my parents.

ABSTRACT

This project work depicts detailed operation of water heating with evacuated tube solar collector has been evaluated experimentally and mathematically. The main source of energy is the renewable energy that does not affect the environment. In order to observe the performance of solar powered water heating system, a precise model of the solar water heating system has been developed. Detailed mathematical analysis is conducted using the developed model considering the obtained experimental data on various parameters such as circulation system, changes of temperature in the collector area, number of storage tank and insulation volume, piping size and mass flow rate of water and ground reflectance those are responsible to assess and evaluate the performance analysis of the solar hot water system. Efficiency of evacuated tube collector and storage tank insulation has been calculated for any changes in size and volume. This project also demonstrates that the produced mathematical model can also be used to obtain numerical solar fraction considering the effects of any changes in the size of a collector and storage tank insulation due to the changes in temperature and mass flow rate of water. Overall efficiency of solar evacuated tube collector is proposed using the produced model for the solar heating system and also annual simulations have been conducted for a typical multifamily installation to assess the performance of the system throughout the year.

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CHAPTER 1

Introduction

1.1 Inspiration and Grounding

Today, sun based thermal frameworks are viewed as an entrenched, low-tech innovation with a colossal potential for vitality creation. Thermal advances for low-to medium temperature applications can be utilized everywhere throughout the world - frosty atmospheres to hot atmospheres. There has been a fast market development as of late for little sun powered heated water frameworks in nations moving towards somewhat programmed or self-loader manufacture of sun based thermal parts. Sun oriented thermal frameworks in bigger structures – multi-family houses and loft squares – and in addition in locale heating plants are presently developing onto the market.

Most critical part of the usage of sun oriented vitality is thought to guarantee in creating nations with appropriate meteorological conditions. Likewise, the potential for decentralized ("remain solitary") vitality frameworks is in creating nations colossal. Along these lines, the utilization of sunlight based vitality for heat and power creation is the initial step for financial improvement. It seems basic to advance the improvement, testing, showing and market presentation of sun oriented advances in creating nations with the help of industrialized nations.

Therefore, renewable energy is starting to gain popularity in countries like Bangladesh. As a commitment to the development of the energy sector of Bangladesh, Control and Applications Research Centre (CARC) of BRAC University has developed a Solar Hot Water System (SHWS) that would utilize solar energy to heat water, which could be used for several purposes like sterilization of medical equipment, cleaning of dishes, etc. An automated pilot project has been implemented on the rooftop of BRAC University and research work has been conducted for increasing the efficiency of the whole system by increasing the captured insolation and reducing wastage of heat overnight through insulation of the storage tank [1].

Similar work is done by a project of Alternative Solar Hot Water System with Multi-Storage Tank [2]. In their task is to implement a solar water heater along with a backup water heater controlled by a controller to ensure the constant hot water supply in the cheapest possible way and it also provides a solution to increase the efficiency of solar water heater by implementing high capacitive multiple hot water storage tanks. The total efficiency is obtained by using closed loop thermosyphone method in solar collector and thermostat technology for controlling the SDHWS [3]. Another thesis work is done for the Characteristics and Cost Analysis of an Automatic Solar Hot Water System in Bangladesh [4]. In their work, a comparative analysis has been presented for different types of Evacuated Tube Solar Collector (ETSC) and also has calculated the payback of the system to determine its feasibility.

Several research works have been conducted in recent years focusing on mathematical modelling of Solar Domestic Hot Water Systems (SDHWS). A transient mode has been applied and validated experimentally on the developed system based on the daily transient conditions in order to achieve the precise and exact design criteria of the solar domestic hot water plants [5]. The analysis carried out on the SDHWS showed an overall increase in the efficiency of the system with an in overall area of the system which resulted in the rise of total volumetric flow [6]. Thus, this parameter has been used to also evaluate the total amount of water that has been heated with time. Another study has been conducted to analyze the performance of the centralized solar domestic hot water system (SDHWS) both by using field data obtained experimentally and producing a simulation model [7]. The result of the model obtained through the simulation has been validated and compared with experimental data. It has also been found through research works that in many climatic conditions, a solar heating system can provide around 85% of the overall domestic hot water supply [8].

1.2 System Overview

In this project, to store the produced hot water by the collector throughout the day 150L collector is used along with 300L storage tank. Each day hot water is transferred into the 300L storage tank when 150L water is heated up by the collector and also loss in the storage tank is referred. This way, we have collected the energy gained, the amount of hot water that can be produced by our system and the operating temperature of our designed automatic solar hot water system is the temperature of the outlet water of the storage tank which can always be able to provide to the users. We have set a point for required water temperature of 50°C as an operating temperature. Figure 1.1 is the complete block diagram of our system. When the system undergoes unavoidable circumstances like sun is not present for cloudy weather, the solar hot water system will not be able to meet the aimed temperature for the user. An automatic electric water heater is used as backup. So this SDHWS is an interruptible automatic circulation system. Here the temperature sensors will detect the temperature and send signals to the microcontroller accordingly to turn the electric water heater on or off. Since we have used microcontroller for our control system, our total expense has been reduced compared to the systems using thermostat technology [3]. The overall cost of our designed system is found to be BDT 1, 08,000, which constitute of the cost most of some major parts including evacuated tube collector, hot water storage tank and electric water heater.

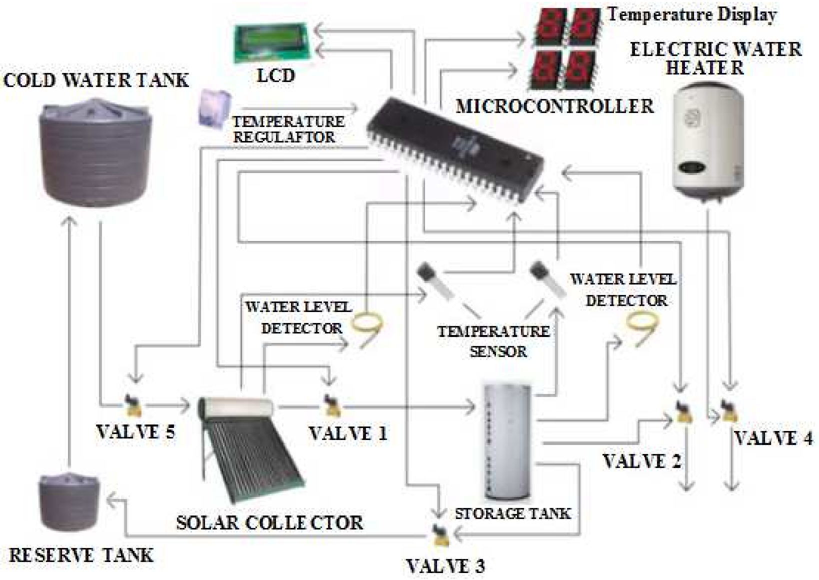


Fig. 1.1: Block diagram of SDHWS [1].

1.3 Commercial Solutions of Using Hot Water in Bangladesh

To mitigate the energy crisis in Bangladesh and creating a revolution in renewable energy sector multiple energy conversion system is needed. In our system, the main source is renewable energy from the sun that does not affect the environment. Economically heated water is required at different areas like at business bottles; private high risers and heater nourish water. In every one of these areas the utilization of high temp water is at a huge scale, so vast amounts of fuel are combusted or power is utilized to hot the water. Sun oriented water heaters can be utilized for a similar reason which will be a proficient and a prudent arrangement.

1.4 The need of the Solar Domestic Hot Water System

The need of hot water in our country is increasing in our country day by day as we are becoming more dependent on our industrial sector. About 500 gallons of hot water is needed daily in the tanneries and in pharmaceuticals. Glass, Ceramic and other factories also need hot water for their production. Beside it has been now a great necessity of hot water supply in the hospitals as well as in hotels. Today all these hot waters are coming from either electric or gas based water heating system. This leads to a lot of consumption of our limited resources. It also creates pressure on the power generation. 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. The Alternative Solar Hot Water System is just the solution we are looking for.

1.5 Overview of Contents

The rest of dissertation is organized as follows:

Chapter 2: Overview of the model
In this chapter, how evacuated tube collector, micro-controller, hot water tank, storage tank, temperature sensors, electromagnetic valves, electric water heater are used in SDHWS project have been shown. Micro-controller is the heart of the project which controls electromechanically operated valves of the system in the case of a two-port valve the flow is switched on or off. The controller gets the signal from the temperature sensors and from the water level detector to control the flow of water into the inlet and the outlet of the valves.

Chapter 3: Insulation and Cost analysis of SDHWS
In this chapter, the insulation of solar domestic hot water system (SDHWS) and regarding cost analysis as well as the cost of the whole system have been shown. The insulation is very essential to reduce the ultimate loss of the system. There are some mechanical and thermal analysis for doing the proper insulation which reduce corresponding losses of the storage tanks and pipes and also which is play a vital role to get a maximum efficiency of the system.

Chapter 4: Modeling of Storage Tank

As the prevalence of solar domestic hot water system expands, they are progressively being considered for use in multi-family private and little business applications (e.g., motels, eateries, laundromats, and so forth.). These bigger frameworks (e.g., 500 to 1500 L) ordinarily require bigger capacity vessels that are essentially more costly than standard private units and that must be built nearby, expanding establishment cost.

Chapter 5: Solar Angles of Collector

From analyst point of view on Earth, the sun is continually changing its position in the sky. It is entirely clear that consistently the sun moves from the east toward the west amongst dawn and dusk. It additionally moves from north to south over the span of the year. To quantify the position of the sun each day at sun oriented twelve (or the season of day when the sun is the most noteworthy in the sky), it would be at an alternate point each day. The correct area of the sun in the sky relies upon where we live, the day of the year, and, obviously, the season of day. These impacts the outline choices are made when sun based emptied tube collector is introduced.

Chapter 6: Methodology of Solar Evacuated Tube Collector

A collector is a thermal gadget for catching sun based radiation. A sun based emptied tube collector gathers heat by engrossing daylight. Sun based radiation is vitality as electromagnetic radiation from the infrared (long) to the bright (short) wavelengths. The amount of sun based vitality striking the world's surface (sun oriented steady) midpoints around 1,000 watts for every square meter under clear skies, contingent on climate conditions, area and introduction.

Chapter 7: Simulation of SDHWS

In this part, a simulation from the foundation hypothesis, particulars and examination related with the multi-tank heat capacity under scrutiny have been displayed. The simulation of the exploratory depiction has been clarified for heat exchange rates and temperature of the water, and additionally the points of interest from the test device and methodology used to assess its execution.

Chapter 8: Discussion of Results

Bangladesh Council of Scientific and Industrial Research (BCSIR) measured Global Horizontal Irradiance at Dhaka and Bandarban for about a year just utilizing programmed information recording framework. Bangladesh Meteorological Department (BMD) has begun Estimation of Global Horizontal Irradiance (GHI) estimation utilizing Eppley Precision Pyranometer for 7 stations over the nation. Programmed recording information have been masterminded under SWERA program utilizing universal subsidizing.

CHAPTER 2

Overview of the Model

2.1 Introduction

Evacuated tube collector, micro-controller, hot water tank, storage tank, temperature sensors, electromagnetic valves, electric water heater are used in SDHWS project. Micro-controller is the heart of the project which controls electromechanically operated valves of the system in the case of a two-port valve, the flow is switched on or off. The controller gets the signal from the temperature sensors and from the water level detector to control the flow of water into the inlet and the outlet of the valves.

2.2 System Components

Appliances of the Solar Domestic Hot Water System are-

1. Solar Water Heater (1 unit of 150 Liters Capacity)
2. Hot Water Storage Tank (1 unit of 300 Liters Capacity)
3. Electromagnetic Valve (5 units)
4. Temperature Sensor (2 units)
5. Water Level Detector (2 units)
6. Electric Water Heater (1 unit of 40 Liters Capacity)
7. LCD display (1 unit)
8. Power Supply 24 volts (1 unit)
9. 24 volts Relay (5 units)
10. Microcontroller At mega 32 (2 units)

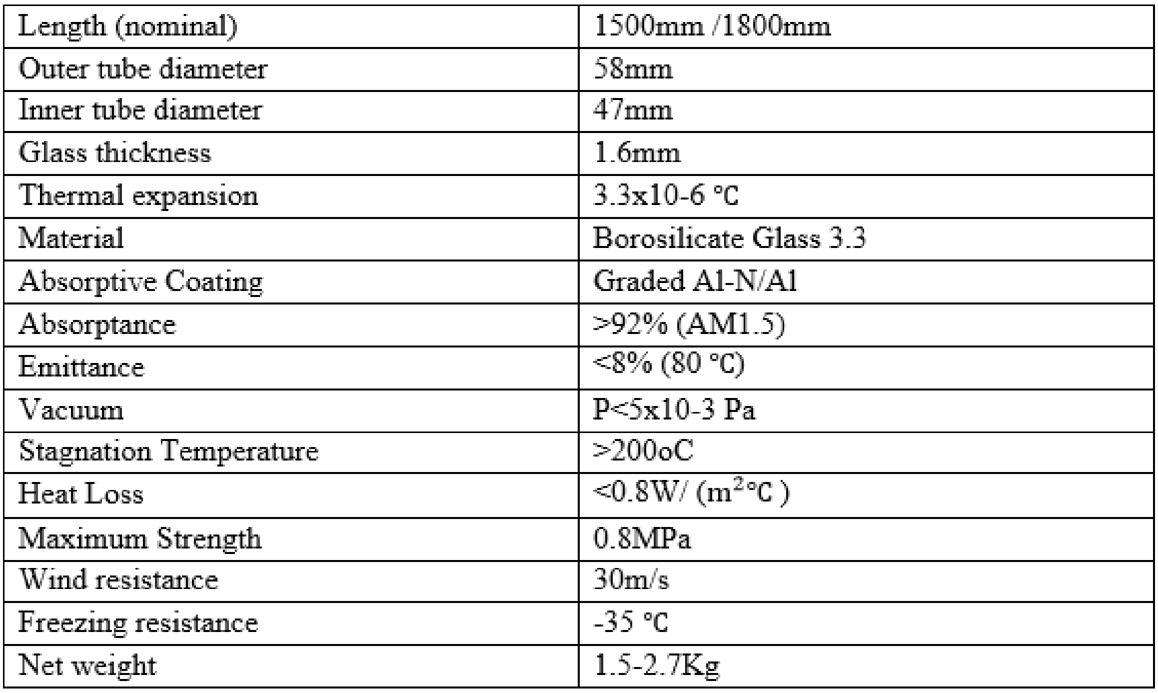
We also needed the plumbing materials for the setup of the system and the electronic and circuitry materials for the controller setup and testing.

2.3 Solar Evacuated Tube Collector

The Solar Water Heater is the main equipment of the Solar Domestic Hot Water System. This Heater has the ability to absorb energy from the abundant rays of the sun and turn this energy into heat. By this transformed heat the water gets heated. For our thesis purpose we have used one Solar Water Heater having the capacity of 150 Liters. The Solar Water Heater has two parts. One is the solar collector and the other is the water tank.

Fig. 2.1: Solar Water Heater installed on the roof of BRAC University [2].

Evacuated Tube Basic Specifications:



Length (nominal)	1500mm /1800mm
Outer tube diameter	58mm
Inner tube diameter	47mm
Glass thickness	1.6mm
Thermal expansion	3.3x10-6 ℃
Material	Borosilicate Glass 3.3
Absorptive Coating	Graded Al-N/Al
Absorptance	>92% (AM1.5)
Emittance	<8% (80 ℃)
Vacuum	P<5x10-3 Pa
Stagnation Temperature	>200oC
Heat Loss	<0.8W/ (m^2℃)
Maximum Strength	0.8MPa
Wind resistance	30m/s
Freezing resistance	-35 ℃
Net weight	1.5-2.7Kg

Table 2.1: Specifications of the solar collector [2].

The diagram shown in Figure 2.2 the principle of solar evacuated tube collector is based on the rules of closed loop thermosyphone system. Thermosyphone refers to method of passive heat exchange based on natural convection which circulated water without the necessity of a mechanical pump. In this case, the cold water comes and stored in the water tank. This water is circulated through the solar collector tubes. When these tubes are exposed to sun rays then they absorb heat and get heated internally. The water flowing through the tubes gets hot also. As the hot water has less density than the cold water, the hot water goes up to the water tank and cold water from the water tank comes down flowing through the evacuated tubes and this process goes on until all the water gets hot enough [3].

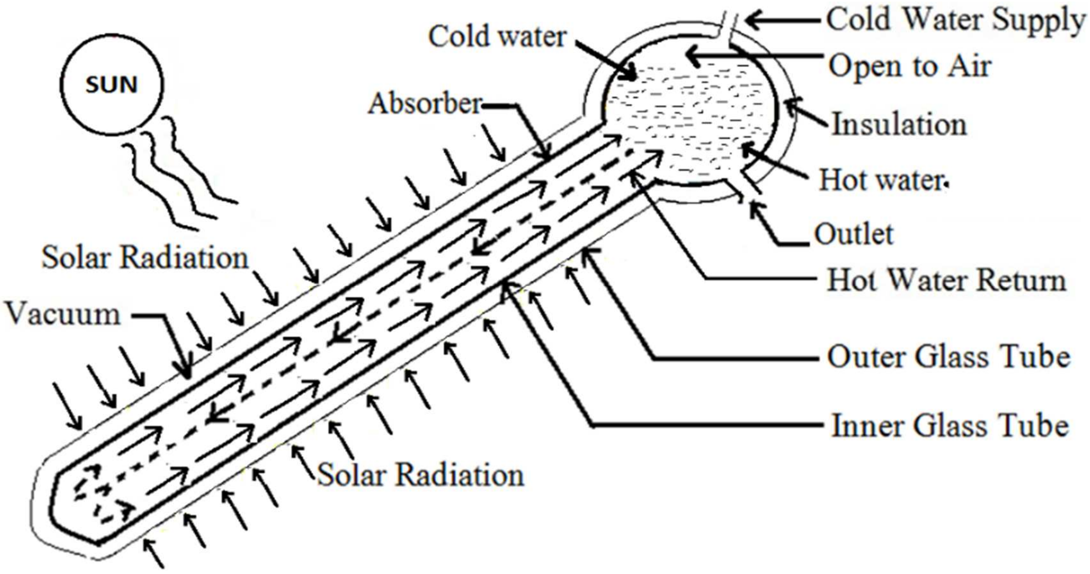


Fig. 2.2: All glass evacuated tube collector [12].

2.4 Micro-Controller

The whole control system is operated by a microcontroller. This is the main part of the control system. A microcontroller is a little PC on a solitary incorporated circuit containing a processor center, memory, and programmable input/output peripherals. Program memory as NOR blaze or OTP ROM is likewise regularly included on chip, and also an ordinarily little measure of RAM. Microcontrollers ordinarily contain from a few to many broadly useful info/yield pins (GPIO). These pins are programming configurable to either an info or a yield state. At the point when GPIO pins are designed to an info state, they are frequently used to peruse sensors or outside signs. Designed to the yield state, GPIO pins can drive outer gadgets, for example, LED's or engines. There is a simple to computerized converter (ADC) is introduced with the microcontroller change over the approaching information into a frame that the processor can perceive.

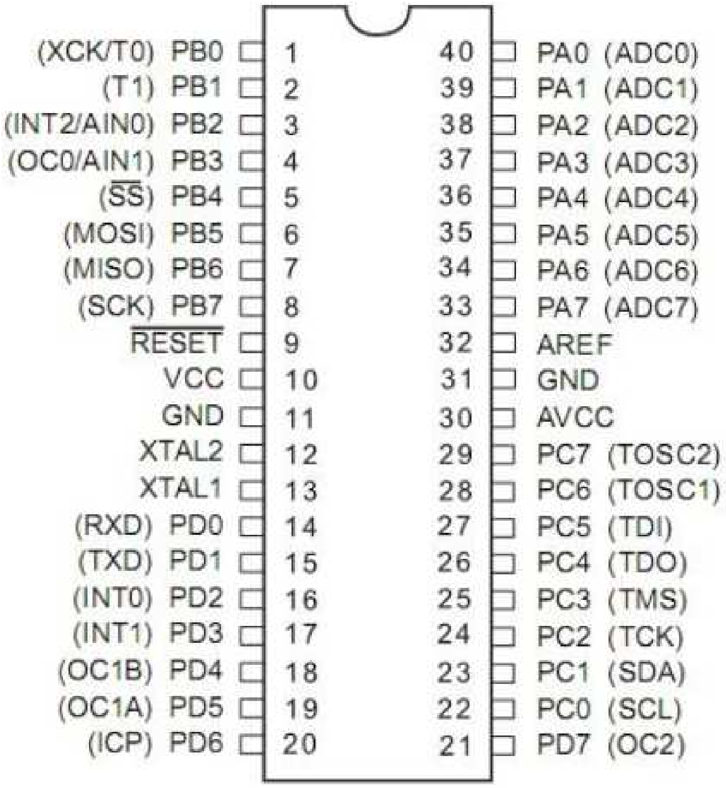


Fig. 2.3: Pin (input/output) configuration of AT mega 32.

The feature of digital-to-analog converter (DAC) is also available which allows the processor to output analog signals or voltage levels. The microcontroller also contains a timer device called Programmable Interval Timer (PIT). This timer is much useful to test or detect temperature periodically. A dedicated Pulse Width Modulation (PWM) block makes it possible for the microcontroller to control power converters, resistive loads, motors etc. For the control system of our thesis we used AVR AT mega 32 Microcontroller [2].

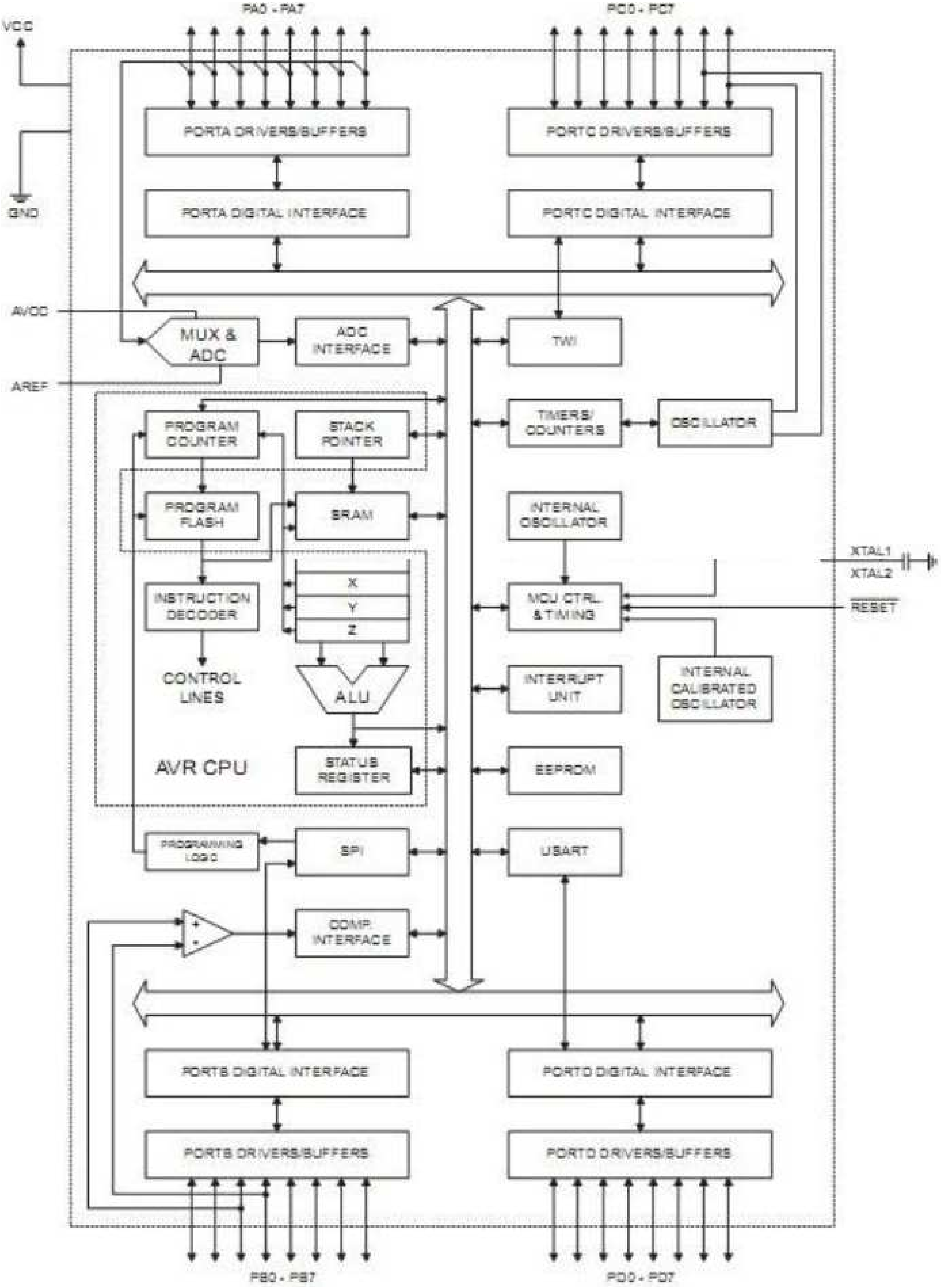


Fig. 2.4: Block diagram of an AVR AT mega 32 Microcontroller [2].

2.5 Hot Water Tank and Storage Tank

The Hot Water Storage Tank is the second most important and expensive material of the Solar Domestic Hot Water System. It’s a special integrated water tank which is capable of keeping water without changing the temperature for maximum three days or 72 hours. This heat preservation is done mechanically without any power consumption. There would be multiple layers of heat insulation in the tank. There are many types of hot water storage tanks. But unfortunately we could manage none for its unavailability in Bangladesh. So we had to come up with another idea.

Fig. 2.5: 300-liter solar water heater with insulated collector on the roof top of BRAC University [1].

The water tank that comes with an evacuated tube solar water heater is actually an integrated thermal storage tank which has the capacity of preserving the water temperature for almost 72 hours. This naturally gives us the advantage to use the tank separately as the thermal storage tank. But the tank could not be separated from the collector tubes for its remaining holes. So we bought a 300 Liter capacitive evacuated tube solar water heater and thermally insulated the collector tubes with a layer of Asbestos wrapped up by Aluminum foil. That is how we got a Hot Water Storage Tank.

To store the hot water by the collector throughout the day 150L collector is used along with 300L storage tank. Each day hot water is transferred into the 300L storage tank when 150L water is heated up by the collector and also loss in the storage tank is referred.

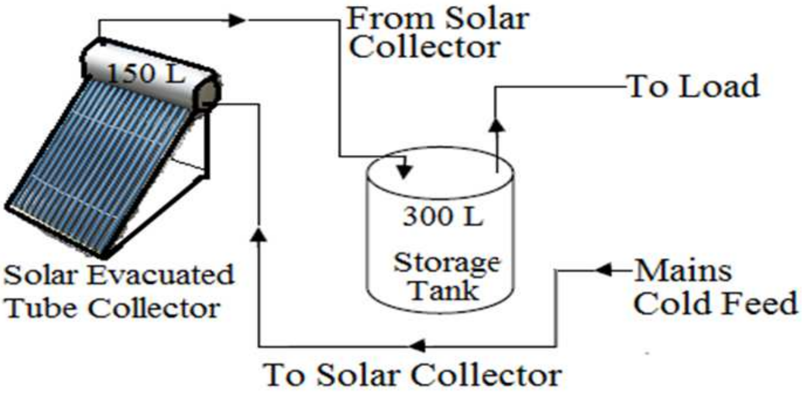
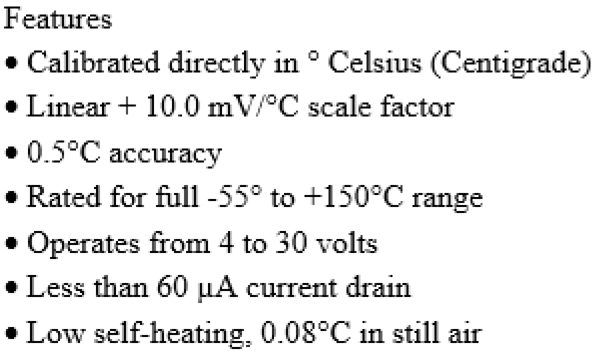


Fig. 2.6: Connection of solar storage tanks plumbed in charge and discharge configuration.

2.6 Temperature Sensors

A temperature sensor is a device that converts any temperature to a corresponding electric voltage signal. There are many types of temperature sensors available like Thermistor, Thermocouple, Silicon Bandgap Temperature Sensor, Resistance Temperature detector, Integrated Circuit Temperature Sensor etc. For our system we used LM35 which is an Integrated Circuit Temperature Sensor. The LM35 does not require any outside alignment or trimming to give run of the mill correctnesses of ±¼°C at room temperature and ±¾°C over a full - 55 to +150°C temperature run. Minimal effort is guaranteed by trimming and adjustment at the water level. The LM35's low yield impedance, direct yield, and exact innate adjustment make interfacing to readout or control hardware particularly simple. It can be utilized with single power supplies, or with in addition to and less supplies. As it draws just 60 µA from its supply, it has low self-heating, under 0.1°C in still air. The LM35 is appraised to work over a - 55° to +150°C temperature go.



Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy
- Rated for full -55° to +150°C range
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air

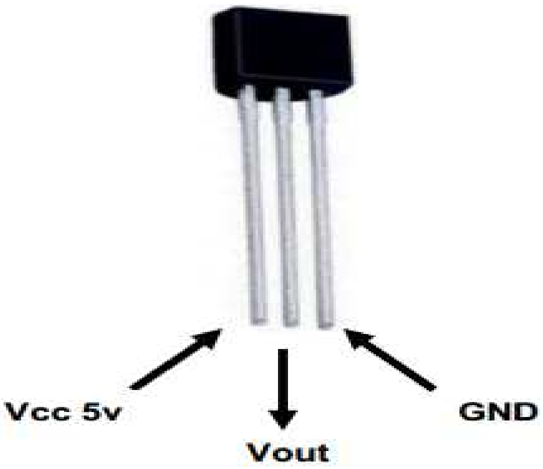


Fig. 2.7: LM35 temperature sensor

2.7 Water Level Detectors

Water Level Detector is the device that let us know the level or height of the water inside the water tank. For the automated controlling purpose of the system, like the temperatures we have to know the filled and empty levels of water inside the Solar Water Heater Tank and the Hot Water Storage Tank. So we built a very simple circuit of water level detector. This circuit is useful to measure the water height unless it is corrosion free. The circuit depends on five transistor switches. Every transistor yields a 5V voltage when its base is provided with ebb and flow through the water through the electric tests.

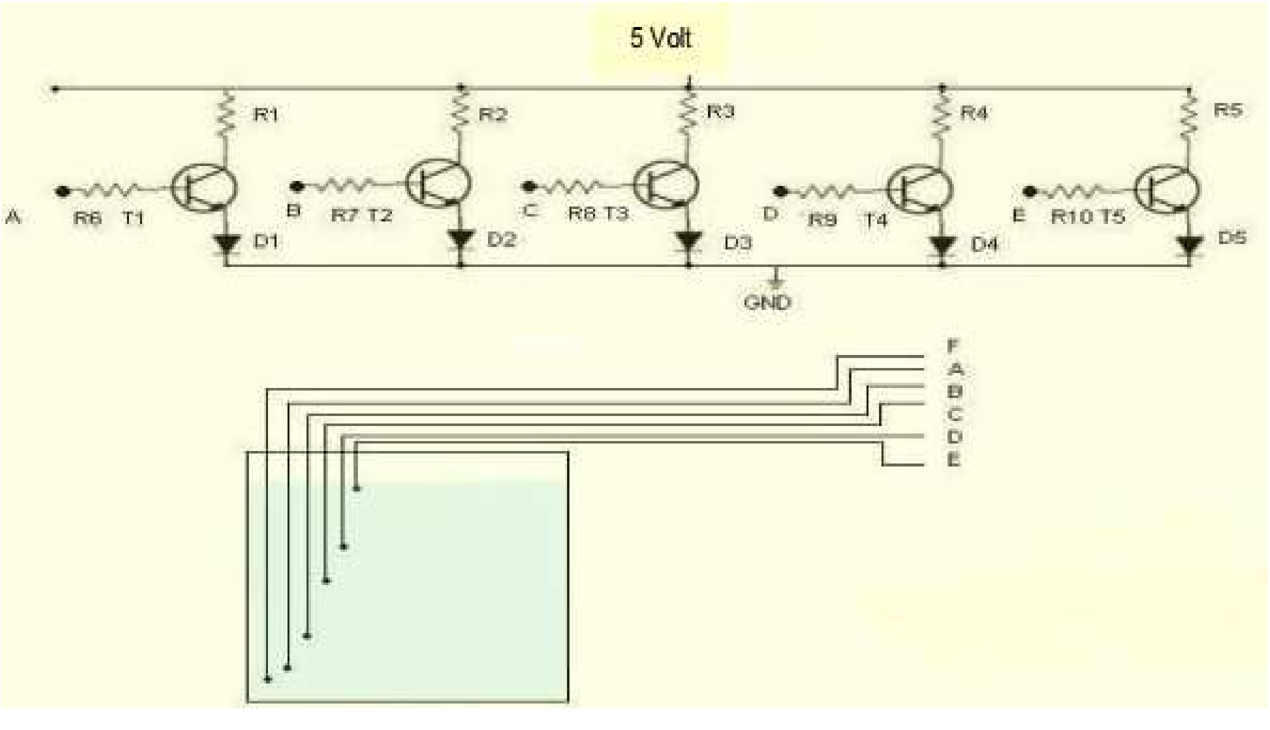


Fig. 2.8: Circuit Diagram of the Water Level Detector [2].

One anode test is (F) with 5V DC is set at the base of tank. Next tests are put well-ordered over the base test. At the point when water is rising the base of every transistor gets electrical association with 5V DC through water and the comparing test. That thus influences the transistors to direct to provide for a 5-volt yield that demonstrates the level of water. The closures of tests are associated with comparing focuses in the circuit as appeared in circuit outline. Protected Aluminum wires with end protection evacuated will improve the situation the test. Mastermind the tests all together on a PVC pipe as indicated by the profundity and submerge it in the tank.

2.8 Electromagnetic Valves

An Electromagnetic Valve is an electromechanical gadget which takes into account an electrical gadget to control the stream of a gas or fluid. The valve is likewise called Solenoid Valve. The valve is controlled by an electric current through a solenoid loop. This present stream thusly brings about an attractive field which causes the relocation of a metal actuator. This actuator is mechanically connected to a valve inside the solenoid valve. The valve at that point changes state, either opening or shutting to enable a fluid or gas to either course through it. A spring is utilized to restore the actuator and valve back to their resting state when the present stream is expelled.


(a) (b)

Fig. 2.9: (a) 1.5 inches Electromagnetic Valve, (b) Electromagnetic Valves installed in the system at the rooftop of BRAC University [2].

2.8.1 Specifications

Operating Mode	Normally Closed
Orifice Size	1.5 Inches
Body	Stainless Steel
Operating Voltage	24 volt DC
Voltage Tolerance	+10% to -15% of applicable voltage
Temperature Rating	Fluid Temperature : -50o C to 150o C
Maximum Operating Pressure	150 PSI (for water)
Power Consumption	9 Watt

2.8.2 Operation of the Valve:

A solenoid valve has two principle parts: the solenoid and the valve. The solenoid changes over electrical vitality into mechanical vitality which, thus, opens or shuts the valve mechanically. An immediate acting valve has just a little stream circuit, appeared inside area E of this graph (this segment is specified beneath as a pilot valve). This stomach guided valve increases this little stream by utilizing it to control the move through a considerably bigger opening. Solenoid valves may utilize metal seals or elastic seals, and may likewise have electrical interfaces to take into account simple control. A spring might be utilized to hold the valve opened or shut while the valve isn't actuated. The outline to the correct demonstrates the plan of an essential valve. At the best figure is the valve in its shut state. The water underweight enters at A. B is a versatile stomach or more it is a feeble spring driving it down. The capacity of this spring is unessential for the time being as the valve would remain shut even without it. The stomach has a pinhole through its middle which permits a little measure of water to course through it. This water fills the hole C on the opposite side of the stomach so weight is equivalent on the two sides of the stomach. While the weight is the same on the two sides of the stomach, the power is more noteworthy on the upper side which powers the valve close against the approaching weight. In the figure, the surface being followed up on is more prominent on the upper side which brings about more noteworthy power. On the upper side the weight is following up on the whole surface of the stomach while on the lower side it is just following up on the approaching channel. These outcomes in the valve being safely closed to any stream and, the more prominent the information weight, the more noteworthy the closing power will be.

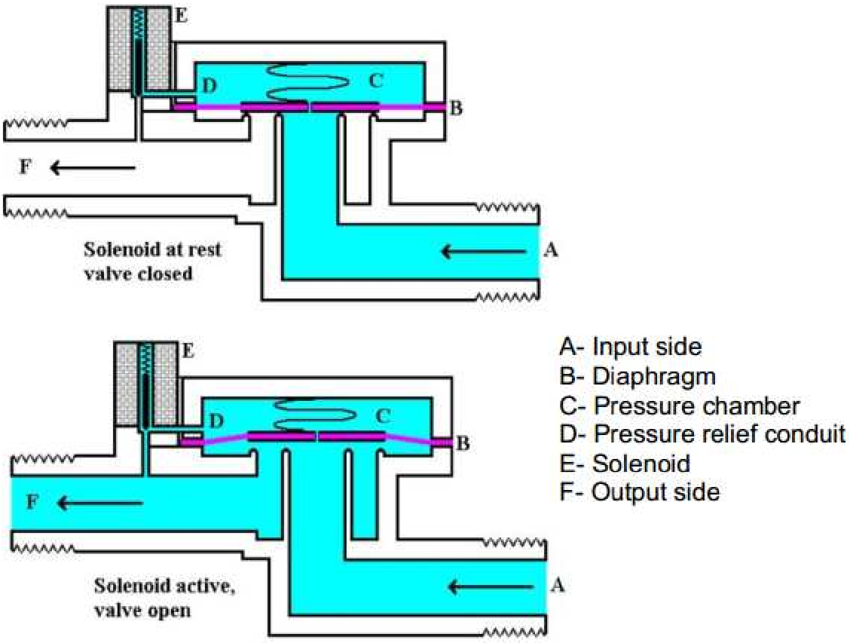


Fig. 2.10: Internal Mechanism of an Electromagnetic/Solenoid Valve [2].

In the past arrangement the little channel D was hindered by a stick which is the armature of the solenoid E and which is pushed around a spring. In the event that the solenoid is initiated by drawing the stick upwards by means of attractive power from the solenoid ebb and flow, the water in chamber C will move through this course D to the yield side of the valve. The weight in chamber C will drop and the approaching weight will lift the stomach along these lines opening the principle valve. Water now streams straightforwardly from A to F. At the point when the solenoid is again deactivated and the course D is shut once more, the spring needs almost no power to push the stomach down again and the fundamental valve closes. By and by there is regularly no different spring, the elastomer stomach is formed so it works as its own particular spring, liking to be in the shut shape.

From this clarification it can be seen that this kind of valve depends on a differential of weight amongst information and yield as the weight at the information should dependably be more prominent than the weight at the yield for it to work. Should the weight at the yield, for any reason, transcend that of the information then the valve would open paying little heed to the condition of the solenoid and pilot valve [2].

2.9 Electric Water Heater

The electric water heater acts as the backup hot water supplier of our system. When the system undergoes unavoidable circumstances like sun is not present for cloudy weather, the solar hot water system will not be able to meet the aimed temperature for the user then the user will get his/her required hot water from this electric heater. The heater comes along with a stainless steel water tank which can preserve 45 Liters of water. The heater operates at 220/240 volts AC voltage supply. The power consumption is 1200 watt. There is a thermostat from which we can set the water temperature from 30 ºC to 80 ºC [1].

Fig.2.11: The Electric Water Heater [2].

2.9.1 Working Principle

An electric water heater has many parts that influence it to work. It contains a plunge tube that enables icy water to enter the tank. A pipe enables high temp water to stream out of the tank. An indoor regulator controls the water's temperature inside the tank. Heating components heat up the water.

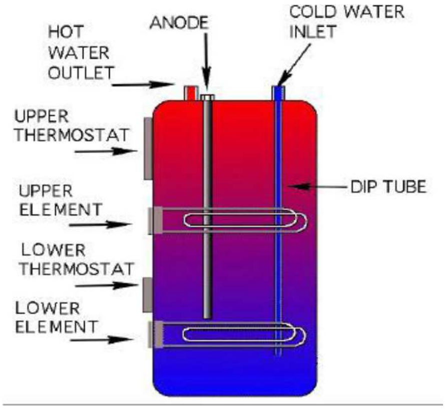


Fig. 2.12: Internal structure of an Electric Water Heater [2].

Chilly water enters the water radiator's tank by means of a pipe associated with the house's water framework. The water gets heated by the heating curl inside the tank. The indoor regulator controls the water temperature once it is inside the tank. At the point when the water temperature ascends to the specific level at that point control gets off naturally with the goal that the heating loop quits heating the water. The water heater can isolate icy water from high temp water. This happens when the icy water enters the tank. It consequently goes to the base of the tank, while the boiling water rises in light of its thickness.

2.10 Power Supply

For the purpose of our thesis we have used one power supply. The operating voltage is 115 volts or 220 volts AC. The device converts 220 volt AC to 24 DC. There are 3 pairs of output line.

Fig. 2.13: 24-volt DC power supply [2].

2.11 Conclusion

So the description and features of all components of the SDHWS system such as evacuated tube collector, micro-controller, hot water tank, storage tank, temperature sensors, electromagnetic valves, and electric water heater has been shown in this chapter. All the component is interconnected and the flow of the water is controlled by the micro-controller using the valves. Automatic circulation of the system has been done using the condition of the user to the controller.

CHAPTER 3

Insulation and Cost Analysis of SDHWS

3.1 Introduction

In this chapter, the insulation of solar domestic hot water system (SDHWS) and regarding cost analysis as well as the cost of the whole system have been shown. The insulation is very essential to reduce the ultimate loss of the system. There are some mechanical and thermal analysis for doing the proper insulation which reduce corresponding losses of the storage tanks and pipes and also which is play a vital role to get a maximum efficiency of the system.

3.2 Insulation of Storage Tank

Insulation is the decrease of heat transfer between objects in thermal contact or in scope of radiative impact. Heat stream is an inescapable result of contact between objects of contrasting temperature. Thermal protection gives an area of protection in which thermal conduction is diminished or thermal radiation is reflected as opposed to consumed by the lower-temperature body.

The protecting capacity of a material is measured with thermal conductivity (k). Low thermal conductivity is comparable to high protecting ability (R-esteem). In thermal designing, other vital properties of protecting materials are item density (ρ) and specific heat capacity (c). The protecting dress materials is utilized froth and aluminum thwart in SDHWS venture.

Strong materials decided for protection have a low thermal conductivity k, measured in watt-per meter per kelvin ($W \cdot m^{-1} \cdot K^{-1}$). As the thickness of protection is expanded, the thermal protection likewise increments.

In SDHWS project, the 300L hot water storage tank has been used using the proper insulation with foam and aluminum foil to reduce the heat loss.

Fig. 3.1: Hot water storage tank insulation with foam and aluminum foil [1].

3.3 Insulation of hot water pipes

Protecting the high temp water funnels diminishes heat misfortune and can raise water temperature 2°F– 4°F more sweltering than uninsulated channels can convey, permitting the lower water temperature. We likewise won't need to sit tight as ache for heated water when we turn on client end, which enables moderate to water.

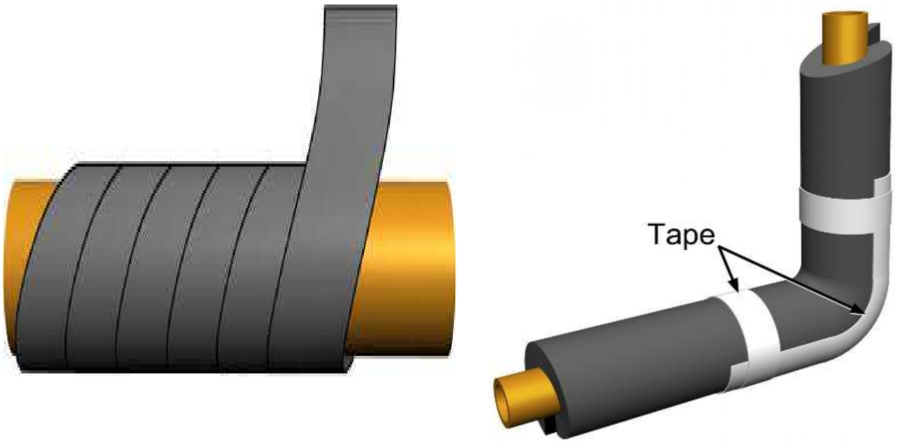


Fig. 3.2: Insulation of the hot water pipes.

3.4 Cost analysis

Total cost of the system

1)	Solar Water Heater	=	30,000 tk.
2)	Hot Water Storage Tank	=	50,000 tk.
3)	Electromagnetic Valves (5 Units)	=	7,500 tk.
4)	Electric Water Heater	=	7,000 tk.
5)	Power Supply	=	1,800 tk.
6)	Microcontroller (2 units)	=	900 tk.
7)	Temperature Sensor LM35 (2 Units)	=	200 tk.
8)	LCD Display	=	250 tk.
9)	Plumbing and other circuitry cost	=	10,000 tk.
10)	Storage Tank insulation	=	500 tk.
	Total Cost	=	1,08,150 tk.

We have calculated the total cost of our system and compared the expenses with electric water heater. The Total cost of the developed system is Bangladeshi Taka, BDT 1,00,000 tk. considering every component of our automatic solar hot water system. To calculate the electricity bill for a guizer, the average electricity bill is taken from one water heater retailer named “Jamil and Co.” in Dhaka, Bangladesh. According to the company, per month electricity bill for an average family consuming hot water is approximately BDT 700 tk.

Therefore, per year electricity cost = 700 x 12 = 8,400 tk. Other Charges which should be included in the electricity bill is:

Demand charge=3.43 per 100 tk.

VAT=5.24 per 100 tk.

Service charge = per month 6 tk.

Total other charge per month= 14.67 tk.

Total other charge per year= 176.04 tk.

According to the power development board of Bangladesh (PDB) per unit electricity charge is BDT is mentioned below:

Electricity charge:

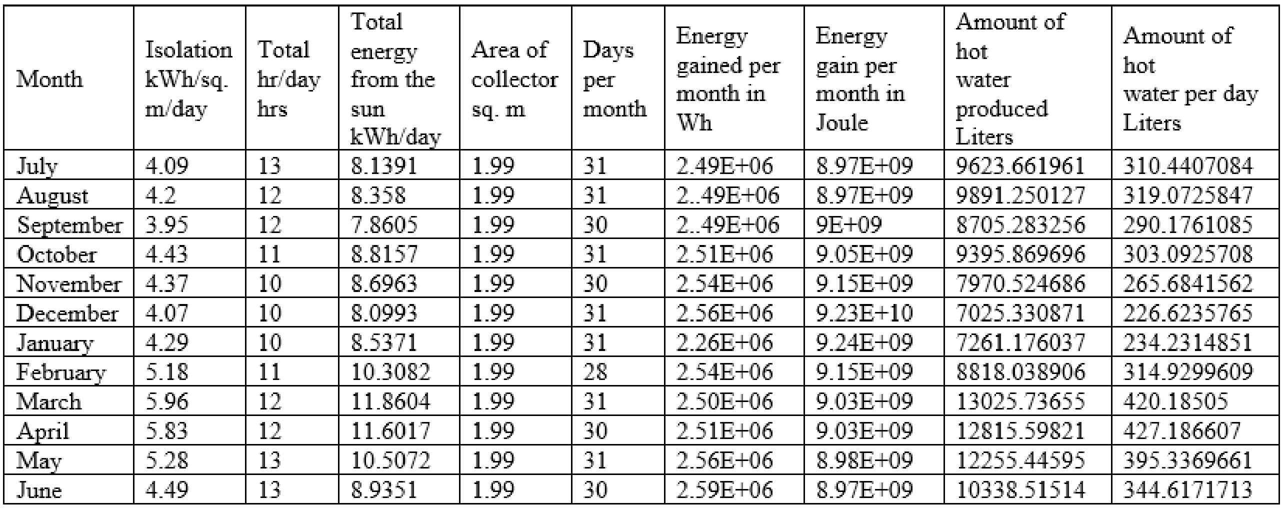
0 to 100 units = 2.60 tk.

101 to 400 units = 3.30 tk.

401 and above = 5.65 tk.

Therefore, per year cost = 8400 tk. + 176.67 tk. = 8567.67 tk.

From the above charge rate, we see our electric heater (guizer) per month charge is in the 101 to 400 units.



Month	Isolation kWh/sq. m/day	Total hr/day hrs	Total energy from the sun kWh/day	Area of collector sq. m	Days per month	Energy gained per month in Wh	Energy gain per month in Joule	Amount of hot water produced Liters	Amount of hot water per day Liters
July	4.09	13	8.1391	1.99	31	2.49E+06	8.97E+09	9623.661961	310.4407084
August	4.2	12	8.358	1.99	31	2..49E+06	8.97E+09	9891.250127	319.0725847
September	3.95	12	7.8605	1.99	30	2..49E+06	9E+09	8705.283256	290.1761085
October	4.43	11	8.8157	1.99	31	2.51E+06	9.05E+09	9395.869696	303.0925708
November	4.37	10	8.6963	1.99	30	2.54E+06	9.15E+09	7970.524686	265.6841562
December	4.07	10	8.0993	1.99	31	2.56E+06	9.23E+10	7025.330871	226.6235765
January	4.29	10	8.5371	1.99	31	2.26E+06	9.24E+09	7261.176037	234.2314851
February	5.18	11	10.3082	1.99	28	2.54E+06	9.15E+09	8818.038906	314.9299609
March	5.96	12	11.8604	1.99	31	2.50E+06	9.03E+09	13025.73655	420.18505
April	5.83	12	11.6017	1.99	30	2.51E+06	9.03E+09	12815.59821	427.186607
May	5.28	13	10.5072	1.99	31	2.56E+06	8.98E+09	12255.44595	395.3369661
June	4.49	13	8.9351	1.99	30	2.59E+06	8.97E+09	10338.51514	344.6171713

Table 3.1: Amount of hot water and energy collected by the SDHWS [4].

Therefore, we have calculated BDT 260 for first 100 units and then we have subtracted from BDT 700 and get BDT 440. For this BDT 440, the unit range has to be 101-400.

So units used per month by the guizer = 100 units + 133 units = 233 units = 233 kWh/month = 233 x 12 = 2769 kWh/year.

Amount of energy we get from the collectors per year (from the isolation data) = 3395.2584 kWh/year.

So, we can conclude that our collector is producing more hot water that the required amount.

Now, considering that the guizer and the controllers consume 20% of the electricity bill (approx.), the amount we are saving:

BDT 8,567.67 x 80% = 6,854.136 tk.

So, the payback would be in 1, 00,000/6854.136 = 14.6 years.

Our solar hot water system lifetime is 30years where the electric water heater lifetime is not more than 5 years. Hence, after 5 years a new electric water heater will bear more cost. The maintenance cost of electric heater is about BDT 1000 to 2000 whereas there is no requirement for maintenance of solar water heater [4].

3.5 Conclusion

The assembling cost, nearby atmosphere, customary building hones, and shifting measures of solace all are considered typically to do the protection. Both heat exchange and layer examination might be performed in extensive mechanical applications, however in family unit circumstances (machines and building protection), air snugness is the key in decreasing heat exchange because of air spillage (constrained or common convection).

CHAPTER 4

Modeling of Storage Tank

4.1 Introduction

As the prevalence of solar domestic hot water system expands, they are progressively being considered for use in multi-family private and little business applications (e.g., motels, eateries, laundromats, and so forth.). These bigger frameworks (e.g., 500 to 1500 L) ordinarily require bigger capacity vessels that are essentially more costly than standard private units and that must be built nearby, expanding establishment cost.

4.2 Stratification Model of Tank Introduction

The amount of heat ΔQ, that can be put away in a sensible heat stockpiling is straightforwardly corresponding to the specific heat C_p and mass m of the material and the temperature extend related with the procedure is ΔT and the vitality put away in a material experiencing a temperature change from T_1 to T_2, including a change of phase ΔH_f is given by,

$$\begin{aligned}\Delta Q &= C_p m(\Delta T)\\ &= m\left(\int_{T_1}^{T_f} C_{p_s}(\Delta T)dT + \int_{T_f}^{T_2} C_{p_l}(\Delta T)dT + \Delta H_f\right) \qquad (1)\end{aligned}$$

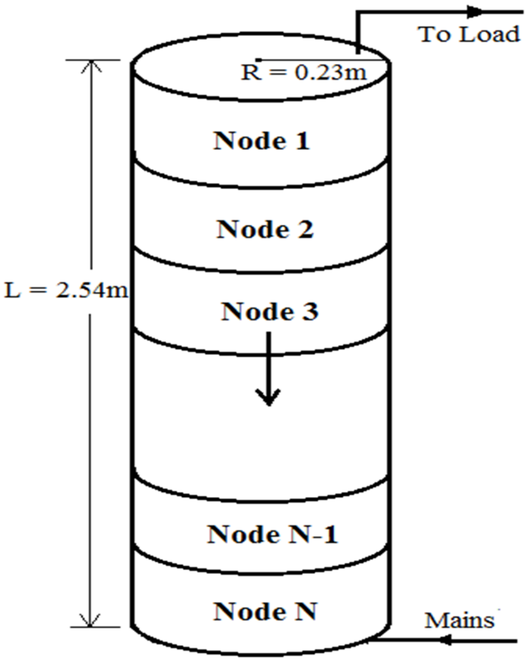
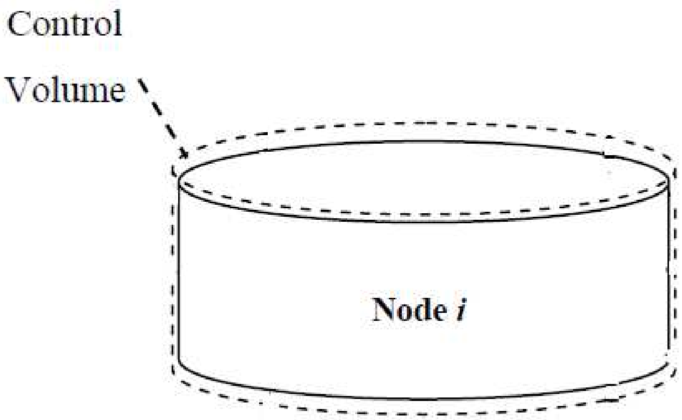


Fig. 4.1: Storage tank divided into sections for the purpose of modeling stratification.

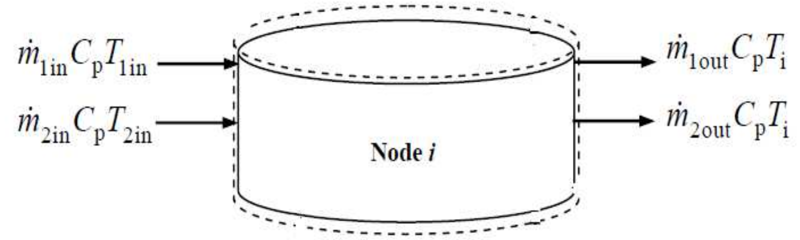
4.3 Procedures of Stratification

To appraise the temperature conveyance and the heat losses qualities of the vertical tank, the vitality and mass streams into and out of every capacity hub from adjoining hubs are evaluated in view of the hub temperatures that existed toward the start of the time step.



Control volume used to characterize the stream of mass into and out of hub i. where, 1 <i< N.

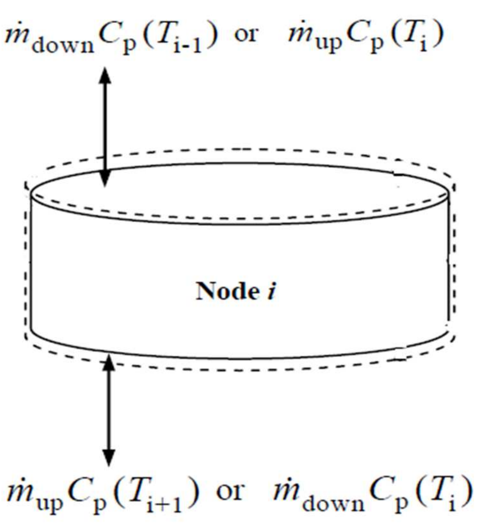
Mass stream rates of the incoming and outgoing water



$\dot{m}_{1\,in}$, $\dot{m}_{1\,out}$, $\dot{m}_{2\,in}$ and $\dot{m}_{2\,out}$ are the mass stream rates of the entering and leaving water 1 and 2,

T_i, $T_{1\,in}$, $T_{2\,in}$ and T_{env} are the temperatures hub i, the temperature of the entering water 1 and the entering water 2,

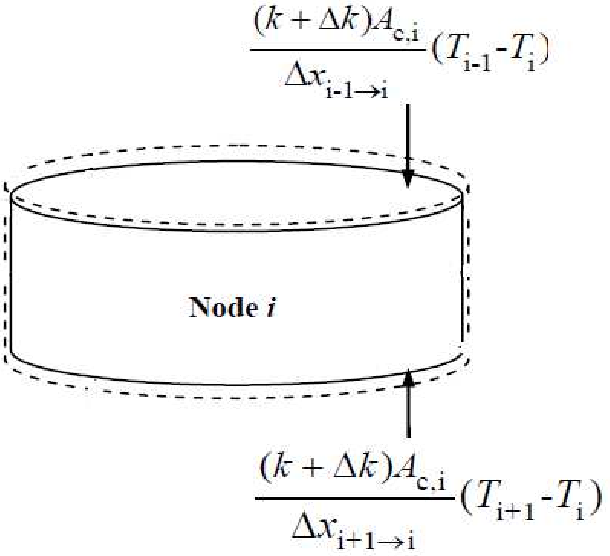
Water mass stream rates up and down the Tank



Where, $\dot{m}_{\mathrm{up}}$and $\dot{m}_{\mathrm{down}}$ are the dilute stream rates up and the tank, separately;

$\mathrm{T_{i+1}}$, $\mathrm{T_{i-1}}$and $\mathrm{T_i}$ are the temperatures situated at beneath or more hub i, and the temperature of the hub i, individually;

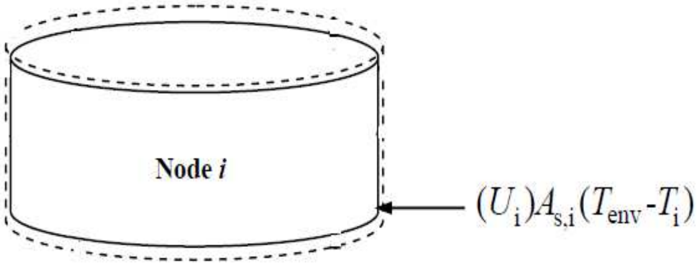
Water tank thermal conductivity and the de-stratification conductivity



Where, $\mathrm{A_{C,i}}$ is the cross-sectional range of hub i,

k and Δk are the tank water thermal conductivity and the de-stratification conductivity

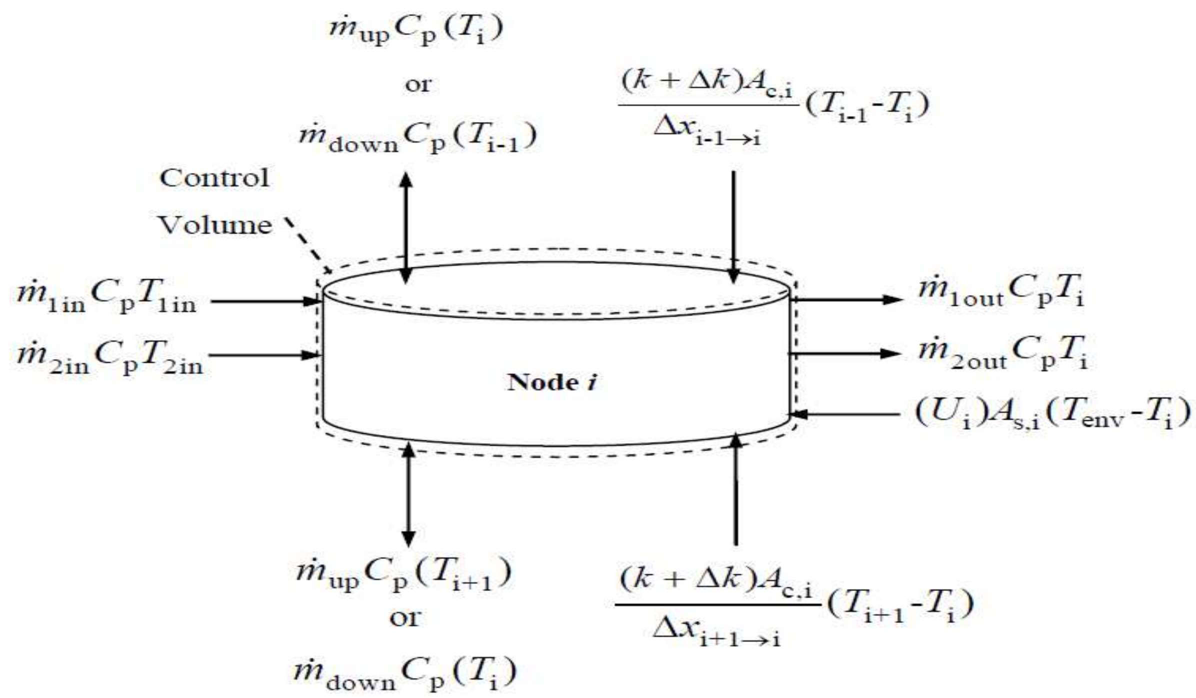
$\Delta \mathrm{x_{i+1\to i}}$ and $\Delta \mathrm{x_{i-1\to i}}$are the inside to focus separate between hub i and the hub underneath or more it, individually.



Where, $\mathrm{A_{S,i}}$ is the surface zone of hub i and $\mathrm{U_i}$ is the hub heat loss coefficient per unit range;

$\mathrm{T_i}$ and $\mathrm{T_{env}}$ are the temperatures of hub i and the temperature of the environment;

Control volume used to characterize the stream of mass into and out of hub i. where, 1 <i< N.



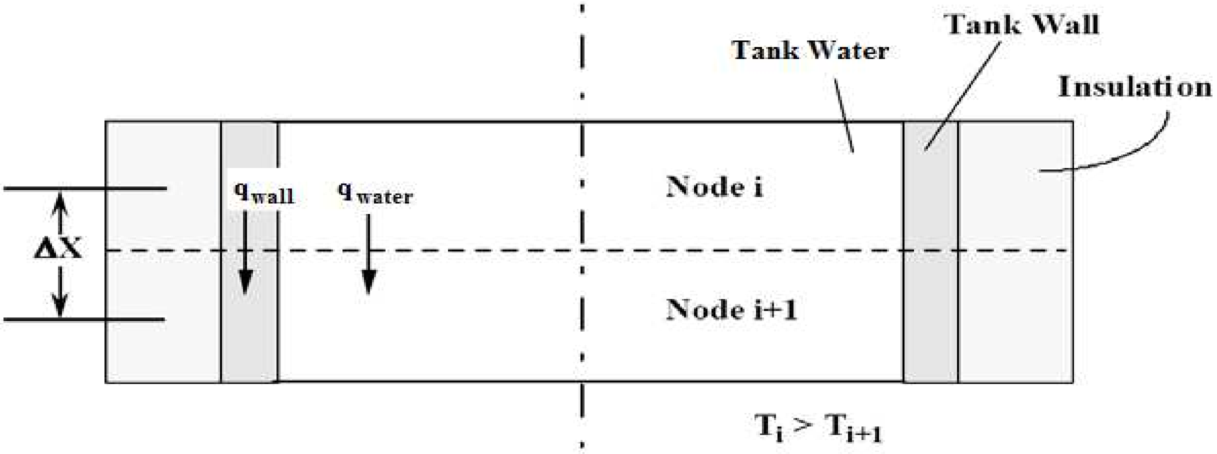
To comprehend for the temperature circulation in the capacity tank, an arrangement of N first-arrange, conventional differential conditions coming about because of every hub's vitality adjust (Newton, 1995) is gathered, e.g., a vitality adjust expounded on the ith tank hub is:

$$M_iC_P\frac{dT_i}{dT}=\frac{(k+\Delta k)A_{C,i}}{\Delta x_{i+1\to i}}(T_{i+1}-T_i)+\frac{(k+\Delta k)A_{C,i}}{\Delta x_{i-1\to i}}(T_{i-1}-T_i)+(U_i)A_{S,i}(T_{env}-T_i)$$
$$+\dot{m}_{down}C_P(T_{i-1})-\dot{m}_{up}C_P(T_i)-\dot{m}_{down}C_P(T_i)+\dot{m}_{up}C_P(T_{i+1})$$
$$+\dot{m}_{1\,in}C_P\left(T_{1\,in}\right)-\dot{m}_{1\,out}C_P(T_i)+\dot{m}_{2\,in}C_P\left(T_{2\,in}\right)-\dot{m}_{2\,out}C_P(T_i) \qquad (2)$$

Where, $\Delta x_{i+1\to i}$ and $\Delta x_{i-1\to i}$ are the the middle to-focus separate between hub i and the hub underneath or more it, individually.

k and Δk are the tank water thermal conductivity and the de-stratification conductivity.

Newton (1995) additionally talked about the impact of conduction between contiguous hubs and along the capacity divider on the exactness of 1-D models-



De-stratification between neighboring hubs because of divider conduction (Newton, 1995).

The heat stream from hub i to hub i+1 as:

$$q_{total} = q_{wall} + q_{water}$$

$$q_{total} = \frac{k_{wall}\,A_{C,\ wall}}{\Delta x}(T_i - T_{i+1}) + \frac{k_{water}A_{C,water}}{\Delta x}(T_i - T_{i+1}) \quad (3)$$

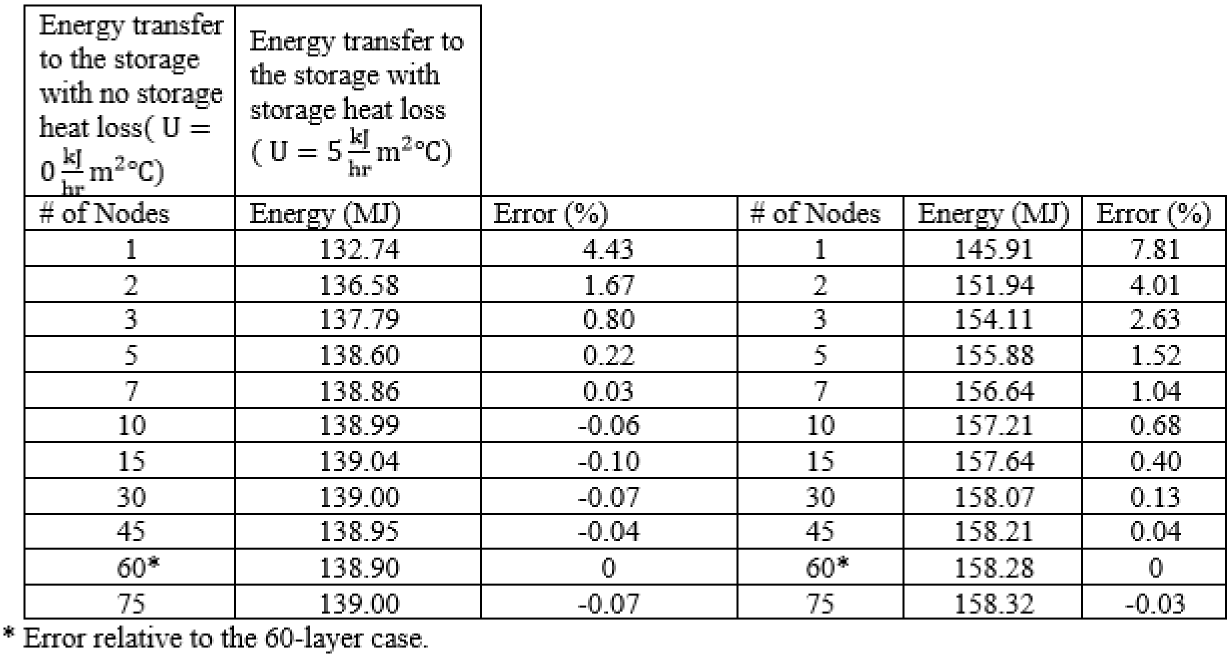
The equation can be rearranged to give:

$$q_{total} = \frac{(k_{water}+\Delta k)\,A_{C,water}}{\Delta x}(T_i - T_{i+1}) \quad (4)$$

Where Δk is an additional thermal conductivity term characterized as:

$$\Delta k = k_{wall}\frac{A_{C,\ wall}}{A_{C,water}}$$

Table 3.1. Vitality exchange to capacity versus number of hubs chose [9].



Energy transfer to the storage with no storage heat loss(U = $0\,\frac{kJ}{hr}\,m^2{}^\circ C$)	Energy transfer to the storage with storage heat loss (U = $5\,\frac{kJ}{hr}\,m^2{}^\circ C$)				
# of Nodes	Energy (MJ)	Error (%)	# of Nodes	Energy (MJ)	Error (%)
1	132.74	4.43	1	145.91	7.81
2	136.58	1.67	2	151.94	4.01
3	137.79	0.80	3	154.11	2.63
5	138.60	0.22	5	155.88	1.52
7	138.86	0.03	7	156.64	1.04
10	138.99	-0.06	10	157.21	0.68
15	139.04	-0.10	15	157.64	0.40
30	139.00	-0.07	30	158.07	0.13
45	138.95	-0.04	45	158.21	0.04
60*	138.90	0	60*	158.28	0
75	139.00	-0.07	75	158.32	-0.03

* Error relative to the 60-layer case.

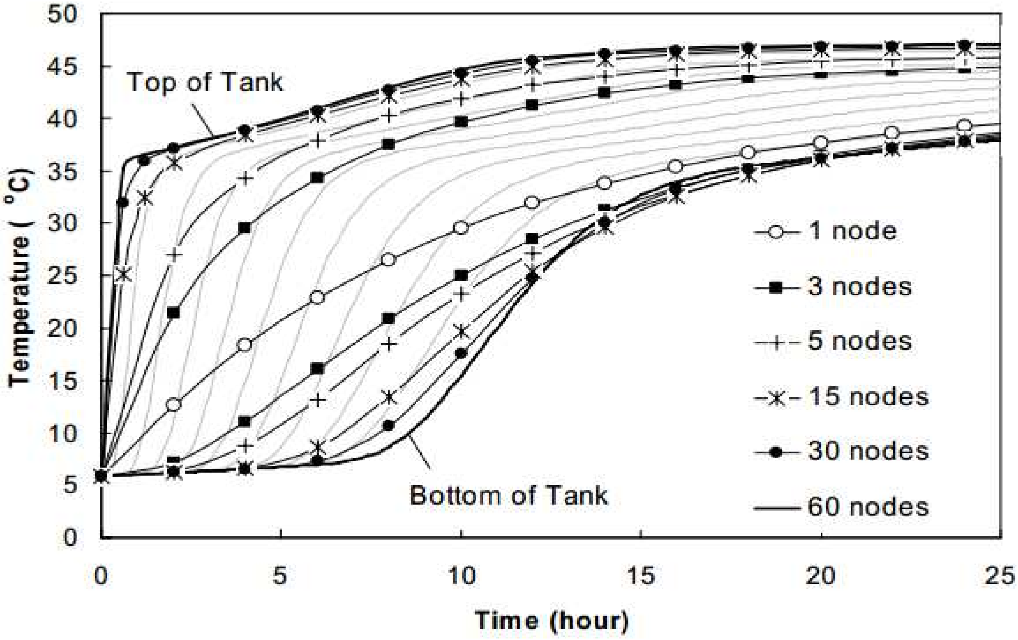


Fig. 4.2: Nodes sensitivity of storage model [9].

As a methods for examination, the best and base hub temperatures of the capacity tank (for all cases) are delineated in Figure 3.2 against the temperature profile acquired for an instance of 60 hubs. This figure unmistakably delineates the change in the temperature evaluates as the quantity of simulated layers increments [9].

4.4 The accuracy of the model:

The model depends on various suspicions being met:

(1) the stream of water inside the tank is one-dimensional;

(2) the temperature and density of the water in every hub is uniform and steady finished the time step;

(3) the water streams from every hub are considered completely blended before they enter a contiguous hub;

(4) the heat misfortune to the outside of the tank and conduction in the tank dividers are sufficiently low that a few dimensional temperature angles don't shape, advancing convection and de-stratification; and

(5) the water speeds entering and leaving the capacity tank are sufficiently low that they don't advance broad blending inside the capacity tanks.

For the impact of conduction between nearby hubs the straightforward approach depends on the accompanying suspicions being met:

(1) the divider and water are thought to be at a similar temperature in every hub

(2) the conductivity of the water and divider in every hub is uniform and consistent over the time step; and

(3) the thickness of the tank divider is considerably less than the span of the tank.

4.5 Series Combination of Storage Tank:

As a contrasting option to an expansive single tank, stockpiling frameworks comprising of interconnected single little tanks, Figure 3.2 have been examined. Built of little, pre-assembled, modest tanks, they might be effortlessly transported into a working for interconnection. Profoundly secluded, the various stockpiling tanks can be interconnected in an assortment of approaches to accomplish the coveted stream attributes and capacity limit. What's more, I have demonstrated that by interfacing singular stockpiling tanks in arrangement it is conceivable to accomplish elevated amounts of stratification in the capacity framework, lessening entropy generation and enhancing general framework execution. Whenever associated, these tanks shape a solitary unit that can be designed in an assortment of courses of action.

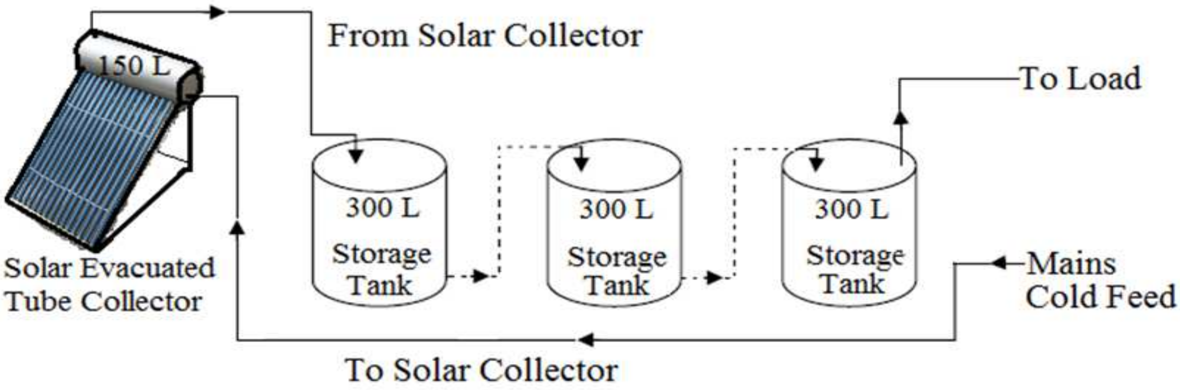


Fig. 4.3: A series connection of solar storage tanks plumbed in the series charge and discharge configuration.

4.6 Conclusion

With respect to private and little business applications, the notoriety of sun powered local high temp water frameworks increments. The scientific condition of aggregate sum of heat into hubs of the capacity tank has been demonstrated utilizing the heat stream condition between two adjoining hubs. Ordinarily require bigger capacity vessels that are altogether more costly than standard private units. The considered high temp water stockpiling tank of our sun oriented residential heated water framework is moderately more affordable.

CHAPTER 5

Solar Angles of Collector

5.1 Introduction

Where is the sun in the sky? From analyst point of view on Earth, the sun is continually changing its position in the sky. It is entirely clear that consistently the sun moves from the east toward the west amongst dawn and dusk. It additionally moves from north to south over the span of the year. To quantify the position of the sun each day at sun oriented twelve (or the season of day when the sun is the most noteworthy in the sky), it would be at an alternate point each day. The correct area of the sun in the sky relies upon where we live, the day of the year, and, obviously, the season of day. These impacts the outline choices are made when sun based emptied tube collector is introduced.

5.2 Angle of Incidence

All solar angles to execute the collector has been appeared by the Figure 4.1.

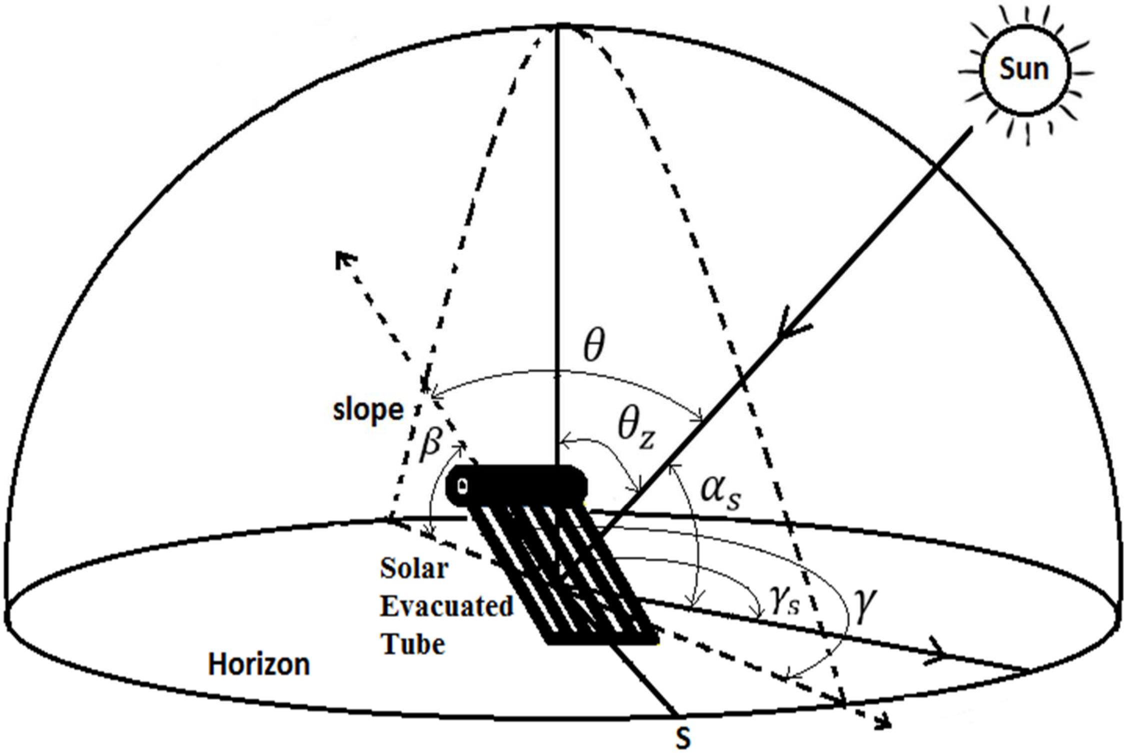


Fig. 5.1: All Angles of Solar Evacuated Tube Collector.

The point between the beam radiation on a surface and the ordinary to that surface that portrays the position of the sun in the sky.

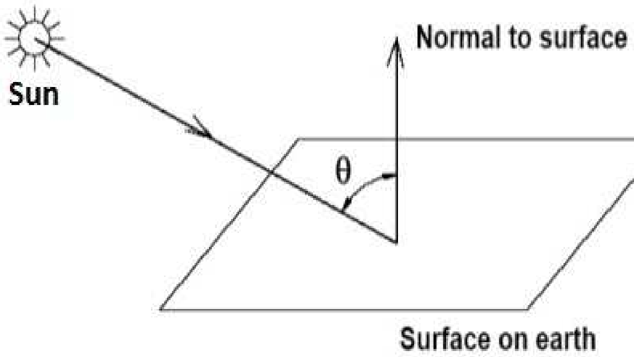


Fig. 5.2: Angle of incidence (θ).

The general condition of the incident angle (as indicated by Jhon A. Duffie, William A. Beckman) connection with other angle, for example, latitude, collector slope, surface azimuth angle, hour angle is [10]:

$$\cos\theta = \sin\delta \sin\emptyset \cos\beta - \sin\delta \cos\emptyset \sin\beta \cos\gamma + \cos\delta \cos\emptyset \cos\beta \cos\omega +$$
$$\cos\delta \sin\emptyset \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \qquad (5)$$

Where, $\theta =$ Incidence angle, $\delta =$ Decliniation angle, $\emptyset =$ Latitude of location, $\beta =$ Tilt angle, $\gamma =$ Surface azimuth angles, $\omega =$ Hour angle

When tilt angle $\beta = 0^0$, the surface is horizontal. In this condition, the angle of incidence noticeably equivalent to the zenith angle of the sun θ_z. Thus, we have

$$\cos\theta = \cos\theta_z = \cos\delta \cos\emptyset \cos\omega + \sin\delta \sin\emptyset \qquad (6)$$

At the point when tilt angle $\beta = 90^0$, in this position the surface is typical to the horizontal plane. Thus, we have

$$\cos\theta = \cos\delta \sin\varphi \cos\gamma \cos\omega - \sin\delta \cos\varphi \cos\gamma + \cos\delta \sin\gamma \sin\omega \qquad (7)$$

When surface facing south, that is $\gamma = 0^0$. For the inclined surface facing south the angle of incidence can be given as

$$\cos\theta = \cos\delta \cos(\emptyset - \beta) \cos\omega + \sin\delta \sin(\emptyset - \beta) \qquad (8)$$

When $\beta = 90^0$ and $\gamma = 0^0$. In this condition, the vertical surface is facing south. Hence, we have

$$\cos\theta = \cos\delta \sin\emptyset \cos\omega - \sin\delta \cos\emptyset \qquad (9)$$

5.3 Hour Angle

The angular displacement of the sun east or west of the local meridialn due to ratoiton of the earth on its axiz at 15 degree per hour; negative for AM hours, positive for PM hours. It is an angular measure of time –

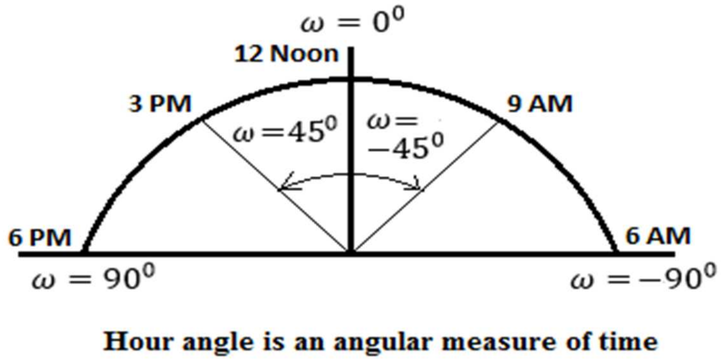


Fig. 5.3: Hour angle (ω).

At solar noon the hour angle meets zero and since the hour angle changes at 15° per hour. The hour angles can be given as follows,

$$\omega = [\text{Solar time} \; - 12] * 15^0$$

We know, $\cos\theta_z = \cos\delta\cos\emptyset\cos\omega + \sin\delta\sin\emptyset$ [when, $\beta = 0^0$]

The hour angle (ω) of the sunset or sunrise, we put $\theta_z = 90^0$ or $\alpha = 0^0$ in above equation which now becomes:

$$\cos\omega = -(\tan\emptyset * \tan\delta)$$

The hour angle (ω) for an inclined surface, is given by the relationship below:

$$\omega = \min[\omega, \cos^{-1}(-\tan(\emptyset - \beta) * \tan\delta)] \tag{10}$$

ω is the smaller value chosen between the ω and $\cos^{-1}(-\tan(\emptyset - \beta) * \tan\delta)$

5.4 Latitude of Location & Declination angles

Latitude, the angular location north or south of the equator, north positive; $-90^0 \leq \varphi \leq 90^0$.

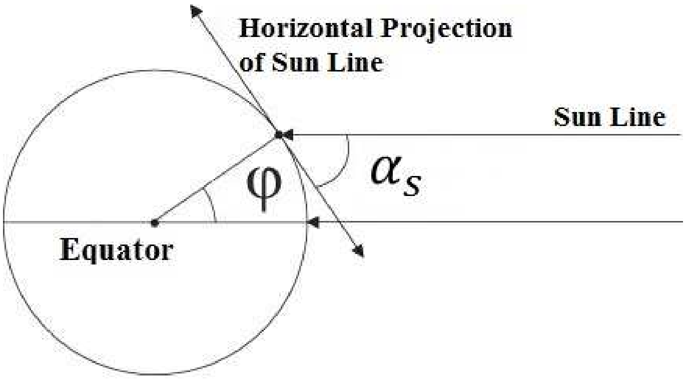


Fig. 5.4: Latitude of Location (φ).

Declination, the angular position of the sun at solar noon with respect to the plane of the equator, north positive; $-23.45^0 \leq \delta \leq 23.45^0$.

$$\text{Declination angle} = 23.45\ \sin\left[\frac{360(N+284)}{365}\right] \tag{11}$$

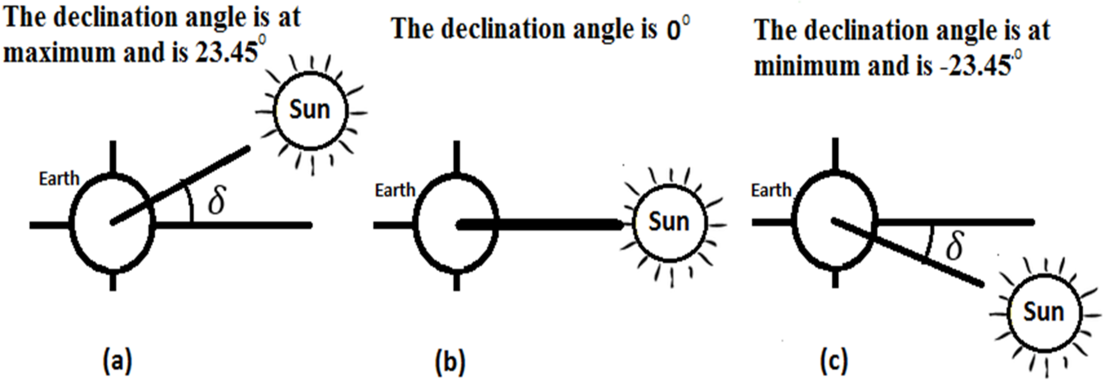


Fig. 5.5: Position of declination angle (δ).

5.5 Solar Azimuth and Surface Azimuth Angles

Solar azimuth angle is the angular displacement from south of the projection of beam radiation on the horizontal plane.

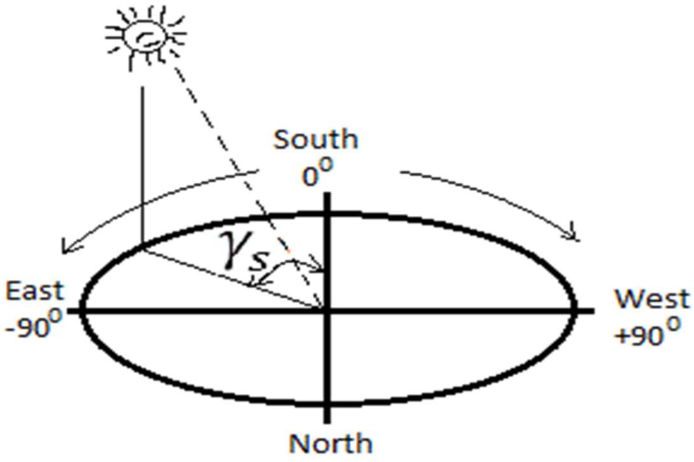


Fig. 5.6: Solar azimuth angle (γ_s).

Displacements east of south are negative and west of south are positive.

$$\cos(\gamma_s) = \left[\frac{\sin(\alpha_s)\sin(\emptyset)-\sin(\delta)}{\cos(\alpha_s)\cos(\emptyset)}\right][\mathrm{sgn}(\omega)] \qquad (12)$$

Where, γ_s= Solar azimuth angle, α_s= Altitude angle, $\emptyset$ = Latitude of location, δ = Declination angle, ω = Hour angle

Surface azimuth angle is the deviation of the projection on a hrizontal plane of the normal

to the surface from the local meridan, with zero due south, $-180^0 \leq \gamma \leq 180^0$.

East is negative, and west is positive.

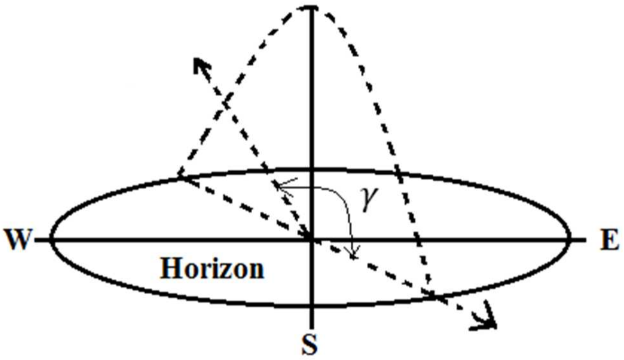


Fig. 5.7: Surface azimuth angle (γ).

5.6 Solar Altitude and Zenith Angles

The altitude angle is the angular height of the sun in the sky measured from the horizon.

The altitude is used to describe the heitht in meters ablovesea level.

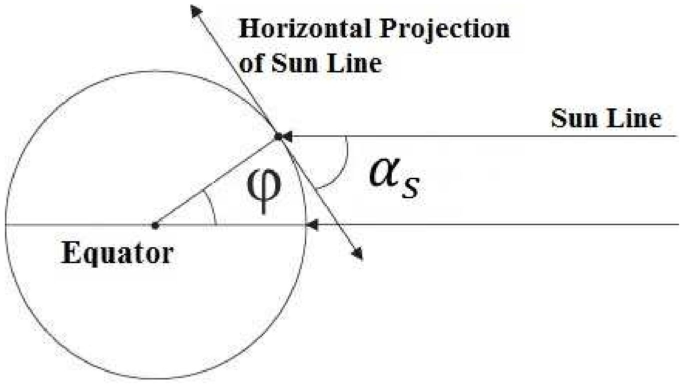


Fig. 5.8: Solar altitude angle (α_s)

The altitude angle varies throughout the day. It also depends on the latitude of a particular location the day of the year.

$\sin \alpha_s = \cos \delta \cos \emptyset \cos \omega + \sin \delta \sin \emptyset$ (13)

The zenith angle (θ_z) is the angle between the vartical and the line to the sun, that is, the anlge of incidence of beam readiation on a horizontal surface.

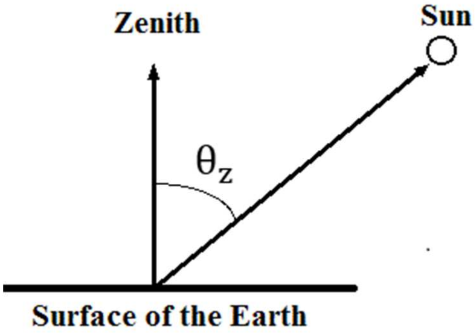


Fig. 5.9: zenith angle (θ_z)

The zenith angle (θ_z) is,

$\cos\theta_z = \cos\delta \cos\emptyset \cos\omega + \sin\emptyset \sin\delta$ (14)

The latitude, collector slope, surface azimuth angle, solar azimuth angle, hour angle, zenith angle, altitude angle are calculated using the equation (5).

And the values of those angles are directly related to the solar noon [11].

5.7 Bangladesh Latitude and Longitude Map

Bangladesh's latitude and longitude is 24° 00' N and 90° 00' E. The map of Bangladesh showing major towns, roads, airports with latitudes and longitudes plotted on it.

Fig. 5.10: Bangladesh Latitude Longitude Map [13]

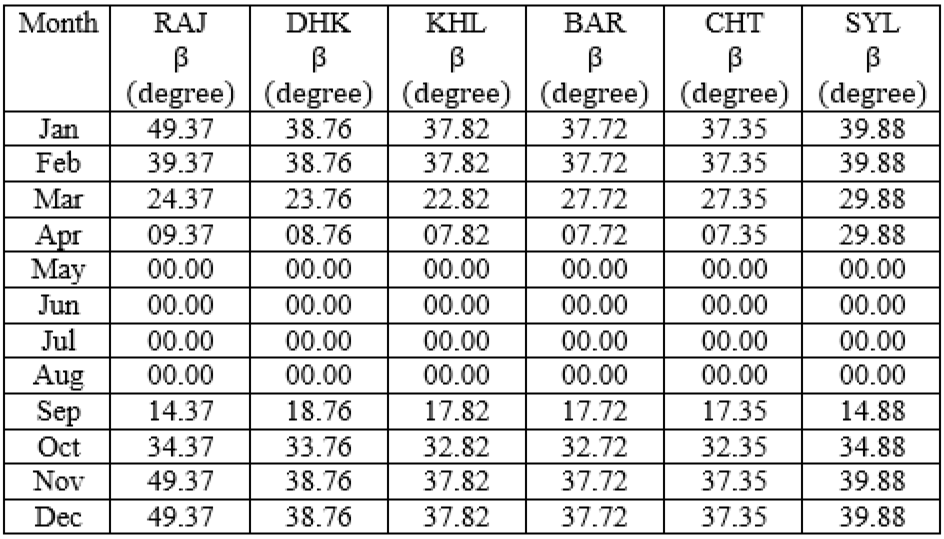
Latitude and Longitude values of different location in Bangladesh

Stations/Sites	Lat (degree)	Long (degree)
Barisal	22.75	90.33
Bogra	24.85	89.37
Chittagong	22.27	91.82
Cox's Bazar	21.43	91.93
Dhaka	23.77	90.38
Rajshahi	24.37	88.70
Rangamati	22.53	92.20
Rangpur	22.73	92.23
Satkhira	25.72	89.08
Sylhet	22.90	89.88

Table 5.1: Latitude and Longitude values of different location in Bangladesh. [26]

5.7.1 Tilt Angle Model

Monthly different tilt angles (β) with $\gamma = 0^0$ for each location in Bangladesh.



Month	RAJ β (degree)	DHK β (degree)	KHL β (degree)	BAR β (degree)	CHT β (degree)	SYL β (degree)
Jan	49.37	38.76	37.82	37.72	37.35	39.88
Feb	39.37	38.76	37.82	37.72	37.35	39.88
Mar	24.37	23.76	22.82	27.72	27.35	29.88
Apr	09.37	08.76	07.82	07.72	07.35	29.88
May	00.00	00.00	00.00	00.00	00.00	00.00
Jun	00.00	00.00	00.00	00.00	00.00	00.00
Jul	00.00	00.00	00.00	00.00	00.00	00.00
Aug	00.00	00.00	00.00	00.00	00.00	00.00
Sep	14.37	18.76	17.82	17.72	17.35	14.88
Oct	34.37	33.76	32.82	32.72	32.35	34.88
Nov	49.37	38.76	37.82	37.72	37.35	39.88
Dec	49.37	38.76	37.82	37.72	37.35	39.88

Table 5.2: Tilt angles for different location in Bangladesh [14].

Sunshine hours of Dhaka (for Latitude $\emptyset$ = 23.77 degree)

Hour angle,

$$\omega_s = \arccos\left(\frac{\cos 85 - \sin\emptyset - \sin\delta}{\cos\emptyset\cos\delta}\right) \tag{15}$$

Sunshine Hours, $N = \frac{\omega_s}{7.639}$

Month	Monthly average sunshine hours
Jan	09.73
Feb	10.03
Mar	10.09
Apr	11.60
May	12.15
Jun	12.41
Jul	12.29
Aug	11.82
Sep	11.18
Oct	10.47
Nov	09.86
Dec	09.56

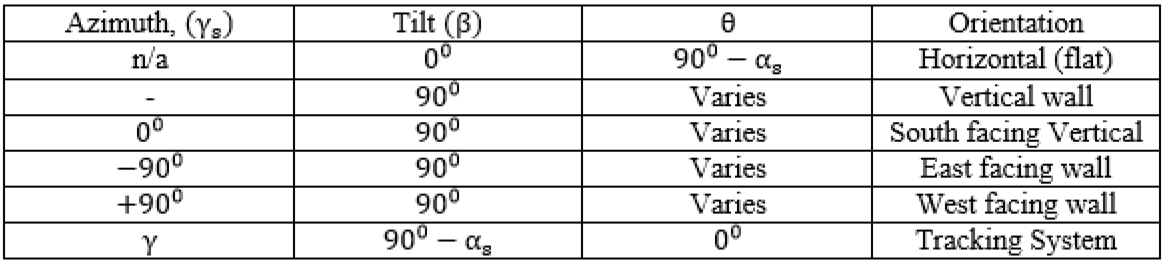
Table 5.3: Average Sunshine Hours of Months.

Optimum Tilt Angle Model of Dhaka (for Latitude $\emptyset$ = 23.77 degree)

Month	Monthly average Declination Angle	Monthly average Solar Beam Radiation (kWh/m^2 -day)
Jan	-20.847	2.980
Feb	-13.325	3.180
Mar	-02.389	3.823
Apr	09.493	4.040
May	18.806	4.821
Jun	23.077	3.942
Jul	21.101	3.937
Aug	13.296	3.712
Sep	01.994	2.896
Oct	-09.849	3.167
Nov	-19.051	2.596
Dec	-23.096	2.852

Table 5.4: Monthly average Declination angle(δ).

The solar evacuated tube collector is south facing vertical in the Solar Domestic Hot Water System.



Azimuth, (γ_s)	Tilt (β)	θ	Orientation
n/a	0^0	$90^0 - \alpha_s$	Horizontal (flat)
-	90^0	Varies	Vertical wall
0^0	90^0	Varies	South facing Vertical
-90^0	90^0	Varies	East facing wall
$+90^0$	90^0	Varies	West facing wall
γ	$90^0 - \alpha_s$	0^0	Tracking System

Table 5.5: Angle Orientation from the Azimuth and the Tilt angle

The angle between the horizontal plane and the solar evacuated tube collector is called the tilt angle.

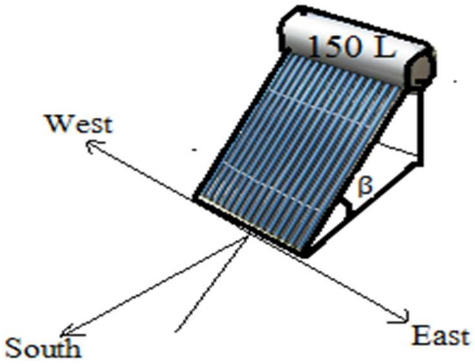


Fig 5.11: Tilt angle of the collector (β).

Optimum Tilt angle of Dhaka (for Latitude ∅ = 23.77 degree)

Optimum tilt angle, $\beta_{\mathrm{opt}} = \frac{\sum_{i=1}^{12} H_{b_i} \tan(\emptyset - \delta_i)}{\sum_{i=1}^{12} H_{b_i}}$

$$= 23.569 \text{ degree} \tag{16}$$

From equation (16), when the surface facing south $\gamma = 0^0$, for normal incidence of the direct sun beam to a tilted collector, i.e. $\theta = 0^0$, during the solar noon, $\omega = 0^0$, of a day of the year. We have,

$\cos\theta = \cos[(\emptyset - \beta) - \delta]$

or, $\theta = (\emptyset - \beta) - \delta$

Set $\theta = 0$, So we have, $\beta = \emptyset - \delta$ (17)

Case study on the tilt angle (β), the tilt surface is south facing of a northern latitude of 23.77^0 at February 15.

The value of N for Julian day at February 15 is,

N = 31+15 = 46

We know, the Declination angle,

$\delta = 23.45 \sin[\frac{360(N+284)}{365}]$

At February 15,The Declination angle,

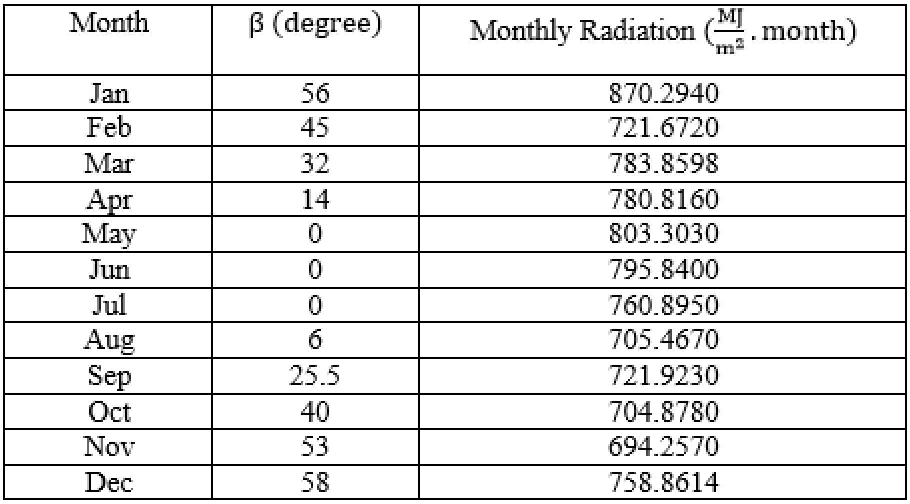
$\delta = 23.45 \sin[\frac{360(46+284)}{365}] = -13.3^0$

From equation (17) for normal incidence of the direct sun beam to a tilted collector, i.e. $\theta = 0^0$, during the solar noon, $\omega = 0^0$, of a day of the year. So, we have,

$\beta = \emptyset - \delta = 23.77^0 - (-13.3^0) = 37.07^0$

5.7.2 Tilt Angle of Collector at New Delhi

Tilt angle (β) for every long stretch of the year for a south-bound solar collector at New Delhi-



Month	β (degree)	Monthly Radiation ($\frac{MJ}{m^2}$. month)
Jan	56	870.2940
Feb	45	721.6720
Mar	32	783.8598
Apr	14	780.8160
May	0	803.3030
Jun	0	795.8400
Jul	0	760.8950
Aug	6	705.4670
Sep	25.5	721.9230
Oct	40	704.8780
Nov	53	694.2570
Dec	58	758.8614

Table 5.6: Tilt Angle (β) for Each Month of the Year at New Delhi [15].

5.7.3 Fixed Tilt Angles in United States

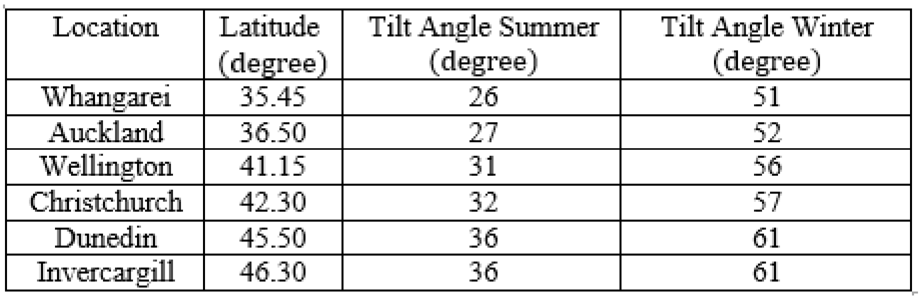
Monthly Fixed tilt angles (β) with $\gamma = 0^0$ for each location in United States.

Month	Fixed Tilt Angle β (degree)				
	0^0	$(\emptyset - 15)^0$	$\emptyset^0$	$(\emptyset - 15)^0$	90^0
Jan	0	47.15	62.15	77.15	90
Feb	0	47.15	62.15	77.15	90
Mar	0	47.15	62.15	77.15	90
Apr	0	47.15	62.15	77.15	90
May	0	47.15	62.15	77.15	90
Jun	0	47.15	62.15	77.15	90
Jul	0	47.15	62.15	77.15	90
Aug	0	47.15	62.15	77.15	90
Sep	0	47.15	62.15	77.15	90
Oct	0	47.15	62.15	77.15	90
Nov	0	47.15	62.15	77.15	90
Dec	0	47.15	62.15	77.15	90

Table 5.7: Monthly Fixed tilt angles (β) in United States [16].

5.7.4 Tilt Angle for Solar Collector in New Zealand

Tilt angles (β) with $\gamma = 0^0$ for each New Zealand.



Location	Latitude (degree)	Tilt Angle Summer (degree)	Tilt Angle Winter (degree)
Whangarei	35.45	26	51
Auckland	36.50	27	52
Wellington	41.15	31	56
Christchurch	42.30	32	57
Dunedin	45.50	36	61
Invercargill	46.30	36	61

Table 5.8: Tilt Angle (β) for Solar Collector in New Zealand [17].

5.7.5 Optimal Tilt Angle for Different Countries

Optimal Tilt angle of the year for different countries.

Country	**City**	**Latitude (° N)**	**Optimal Tilt Angle (°)**
Egypt	Luxor	25.69	28.1
Morocco	Smara	26.73	28.3
Egypt	Sharm Sheikkh	27.86	30.1
Morocco	Agadir	30.41	32.2
Libya	Syrte	31.20	31.3
Egypt	Alexandria	31.20	31.3
Palestine	Gaza	31.41	32.2
Libya	Tripoli	32.90	34.1
Syria	Damascus	33.51	33.1
Algeria	Mecheria	33.55	35.3
Lebanon	Beirut	33.88	31.9
Cyprus	Nicosia	35.16	34.1
Morocco	Larache	35.18	34.9
Greece	Heraklion	35.32	32.5
Syria	Latakia	35.52	35.1
Tunisia	Tunis	35.41	37.2
Malta	Valetta	35.89	35.6
Tunisia	Bizerte	37.27	37.0
Spain	Seville	37.38	36.5
Turkey	Isparta	37.76	36.9
Italy	Marsala	37.80	37.4

Table 5.9: Optimal Tilt angle of different countries [18].

5.8 Conclusion

In any case, the most normally acknowledged tradition for breaking down sun powered radiation for heat vitality applications, is clockwise from due north, so east is 90°, south is 180° and west is 270°. This is the definition utilized by National Renewable Energy Laboratory in their sunlight based position number crunchers [19] and is additionally the tradition utilized as a part of the equations displayed here. Characterizing azimuthal edges in respect to due north, take counter clockwise edges as negative [20].

CHAPTER 6

Modeling of Collector

6.1 Introduction

A collector is a heat gadget for catching sun based radiation. A sun based emptied tube collector gathers heat by engrossing daylight. Sun based radiation is vitality as electromagnetic radiation from the infrared (long) to the bright (short) wavelengths. The amount of sun based vitality striking the world's surface (sun oriented steady) midpoints around 1,000 watts for every square meter under clear skies, contingent on climate conditions, area and introduction.

6.2 Mathematical Model of Collector

From heat balance equation, the useful thermal power and the loss from the absorber is equal to the amount of thermal power into the absorber.

$$Q_{useful} + Q_{loss} = Q_{beam} + Q_{diffuse} + Q_{reflect}$$
$$\Rightarrow Q_{useful} = Q_{beam} + Q_{diffuse} + Q_{reflect} - Q_{loss} \qquad (18)$$

Q_{beam} is thermal power from the direct beam radiation (W). The radiation received from the sun without having been scattered by the atmosphere.

$$Q_{beam} = \int_{-\pi}^{\pi} A_{abs}(K_{\theta,b} F_R\, G_{beam} \alpha\tau) VF\, d\emptyset \qquad (19)$$

Where,
A_{abs} = Area of the absorber tube (m^2).
The tube absorber area as seen from the top is, $A_{abs} = L_{abs} * R_{abs}$ (m^2).
$K_{\theta,b}$ = Incident angle modifier constant (a dimensionless number).
F_R = Heat removal factor from the absorber (a dimensionless number)
G_{beam} = Direct beam solar radiation (W/m^2).
$\alpha\tau$ = Absorptance transmittance product for efficiency= 0.0368
VF = View factor of the absorber tubes from the sky

$$VF = \int_{-\pi}^{\pi} \frac{(1+\cos\omega)}{2d\omega} = 0.5 \qquad (20)$$

If shadowing is accounted for, this factor will still be reduced.

$Q_{diffuse}$ is thermal power from the diffuse radiation (W). The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

$$Q_{diffuse} = \int_{-\pi}^{\pi} A_{abs}(K_{\theta,d} F_R\, G_{diffuse} \alpha\tau) VF\, d\emptyset \tag{21}$$

$Q_{reflected}$ is thermal power from the reflected radiation (W). As we have the beam & diffuse radiation into the all glass evacuated tube of surface of the absorber area also we get some thermal power from the reflector with the reflectance of surface.

$$Q_{reflect} = \int_{-\pi}^{\pi} A_{abs}(K_{\theta,r} F_R\, G_{reflect} \alpha\tau) VF\, d\emptyset \tag{22}$$

Where,
$K_{\theta,d}$ = Incident angle modifier for the diffuse radiation = $(1 + \cos\beta)/2$
$G_{diffuse}$ = Diffuse solar radiation (W/m^2).
$K_{\theta,r}$ = Incident angle modifier = $(1 - \cos\beta)/2$
$G_{reflect}$ =Reflected solar radiation (Watt per sq. m) = $\rho_r(G_{diffuse} + G_{beam})$
ρ_r = Reflectance of surface (a dimensionless number)
t_m = Mean water temperature
U_L = Average heat loss coefficient, $W/(m^2 \cdot {}^{o}C)$

The losses due to convection are Q_{loss} act as thermal power loss (W). Convection is the transfer of heat from one place to another by the movement of water. Convection is usually the dominant form of heat transfer in water.

$$Q_{loss} = \int_{-\pi}^{\pi} A_{abs} U_L (t_m - t_a)\, d\emptyset \tag{23}$$

And

$$U_L = \frac{C_{pw} m (t_1 - t_3)}{A_{abs}(t_m - t_a)\Delta t} \quad t_m = \frac{(t_1 + t_2 + t_3)}{3} \quad t_a = \frac{(t_{a1} + t_{a2} + t_{a3})}{3} \tag{24}$$

Where,
U_L = Average heat loss coefficient, $W/(m^2\,{}^{o}C)$
t_m = Average water temperature (${}^{o}C$)
t_a = Average ambient temperature, (${}^{o}C$)
Δt = Total testing time from water temperature t_1 to t_3, (s)
m = Mass of water inside the all-glass evacuated solar collector tube, kg
C_{pw} = Specific heat of water ($J/kg \cdot {}^{o}C$),
A_{abs} = Absorber surface area, m^2
t_{a1}, t_{a2}, t_{a3} = Corresponding ambient temperature recorded at the same time, (${}^{o}C$).
t_1, t_2, t_3 = Three average water temperature (${}^{o}C$).

The incident radiation on the collector surface is equivalent to the entirety of useful heat and a few distinctive misfortune terms, as is apparent from the energy balance of the absorber of a sunlight based thermal collector-

Total Solar Radiation = Useful thermal power + Total loss

$$A_{abs}I_{rad} = Q_{useful} + Q_{loss-opt} + Q_{loss,\ thermal}$$

$$\text{Or, } A_{abs}I_{rad} = Q_{useful} + Q_{loss-opt} + Q_{loss,\, convective} + Q_{loss,\, conductive} + Q_{loss,\ radiative} \tag{25}$$

$$Q_{useful} = C_{pw}m(T_{out} - T_{in}) = C_{pw}m(\Delta T) \tag{26}$$

From equation (25) we can get outlet temperature of the collector. Using equation (25) and equation (26) we have,

$$\text{Efficiency} = \frac{Q_{useful}}{A_{abs}I_{rad}} = \frac{C_{pw}m(\Delta T)}{I_{rad}A_{abs}} \tag{27}$$

The efficiency of all glass evacuated tube solar collector has been modeled which shows the unsteady state efficiency of the collector [21, 22, 23].

6.3 Heat Transfer Process of Collector

The outer glass tube is used to decrease the heat loss from the inner tube. Absorber is heated by the various type of radiation (e.g. Beam or direct radiation, diffuse radiation, reflected radiation etc.). There are some losses due to convection, conductive, radiative and optical. So, the heat transfers and water flow process in solar collector tube is a complicated process which includes forced convection, nature convection and heat conduction [24].

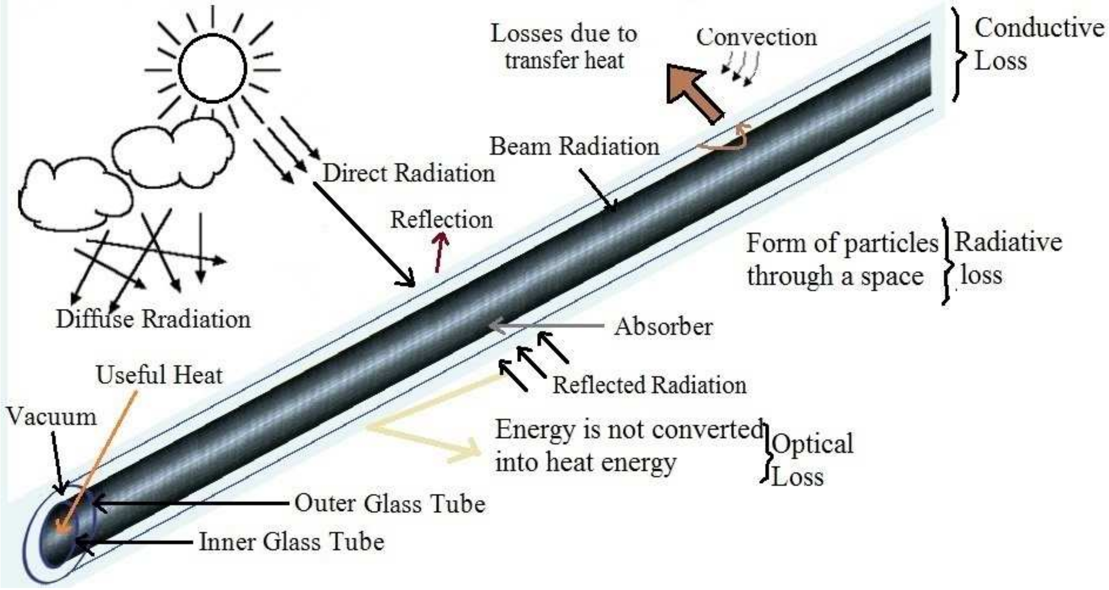


Fig. 6.1: Effect of radiation on the all glass evacuated tube collector.

6.4 Absorption Process

All glass solar evacuated tube collector is a borosilicate glass tube. It has three layers and the two layers with a similar hub vacuum zed between them, can achieve 5×10-2Pa and Coated with AL\N\AL specific engrossing covering material. The glass tube has high engrossing productivity in light of the fact that the vacuum attractive control sputtering specific absorptive covering on the heat gathering plates has a high retention. Coefficient is over 93%, and the emanation coefficient is around 6%. The tube can continue effect of condition, with high heat proficiency during the time [25].

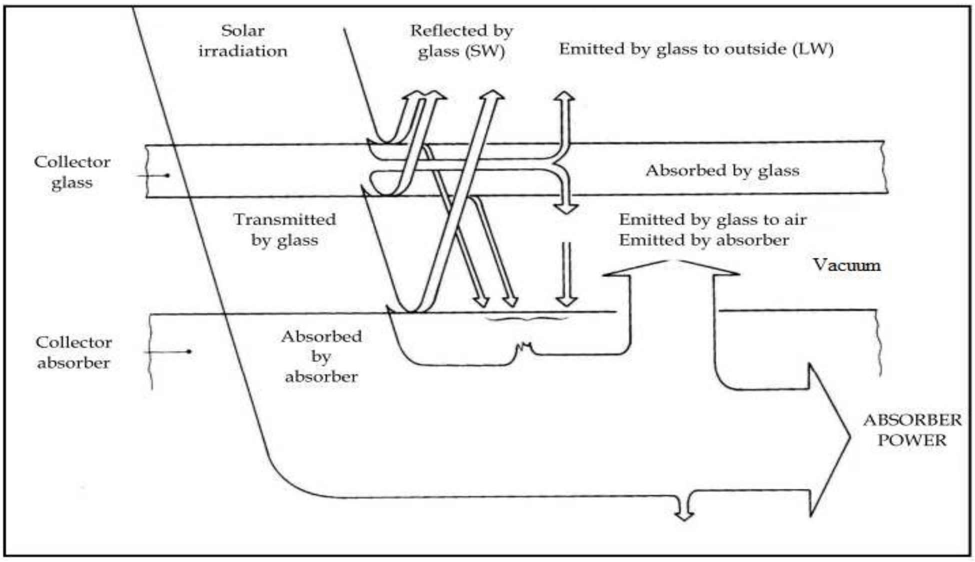


Fig. 6.2: Absorption Process

Case Study for the useful thermal power assuming 100L water if the temperature of water at the outlet of the all-glass solar evacuated tube collector 150^0F and atmospheric 90^0F and for the efficiency we considering 1.99m^2 surface area (only for 15 tubes) where the solar radiation $9.2 * 10^6 \text{J/m}^2$-day.

For 150^0F, $°\text{C} = (150 - 32) * \frac{5}{9} = 65°\text{C} = \text{T}_\text{out}$

For 90^0F, $°\text{C} = (90 - 32) * \frac{5}{9} = 32°\text{C} = \text{T}_\text{a}$

$$\Delta\text{t} = (\text{T}_\text{out} - \text{T}_\text{a}) = (65 - 32) = 33°\text{C}$$

Useful Thermal power,

$$\text{Q}_\text{useful} = \text{m} * \text{C}_\text{pw} * \Delta\text{t} = 100 * 4.2 * 10^3 * 0.000278 * 33 = \frac{3853.08\ \text{Wh}}{\text{day}} * 10^{-3}$$
$$= 3.85\ \text{kWh/day}$$

Efficiency of Collector (η)

$$\text{I}_\text{rad} = 9.2 * 10^6 * 10^{-3} * 0.000278 = 2.56\ \text{kWh/(m}^2\text{day)}$$

$$\text{Input power} = \text{A}_\text{abs} * \text{I}_\text{rad} = 1.99\text{m}^2 * 2.56\text{kWh/(m}^2\text{day)}$$
$$= 5.08\ \text{kWh/day}$$

$$\text{Efficiency}, \eta = \frac{Q_{useful}}{A_{abs} * I_{rad}} * 100 = \frac{3.85}{5.08} * 100 = 75\%$$

6.5 Experimental view of the System

Micro-controller is the heart of the project which controls electromechanically operated valves of the system in the case of a two-port valve the flow is switched on or off. The controller gets the signal from the temperature sensors and from the water level detector to control the flow of water into the inlet and the outlet of the valves [2].

(a) (b)

Fig. 6.3: (a) Initial control experiment of SDHWS, (b) electromagnetic valves.

Initial experiment and after finalizing the experiment for controlling the whole system has been shown in the figure 6.3 and figure 6.4.

(a) (b)

Fig. 6.4: (a) After finalizing control experiment, (b) Solar tank along with evacuated tube.

6.6 Conclusion

To enhance the execution of all-glass emptied tube gatherer, an appropriate protection has assumed control over the water radiator framework. Likewise, a contextual investigation has suffocated for all-glass evacuated tube collector. Test comes about demonstrate the effectiveness of sunlight based water heater and the heat exchange model of water heater framework is legitimate. In view of the model, the connection between the water tank normal temperature and tube width (water mass stream) is contemplated. This work can give some data and outlines to all-glass evacuated tube collector.

CHAPTER 7

Simulation of SDHWS

7.1 Introduction

In this part, a simulation from the foundation hypothesis, particulars and examination related with the multi-tank heat capacity under scrutiny have been reported. The simulation of the exploratory depiction has been clarified for heat exchange rates and temperature of the water, and additionally the points of interest from the test device and methodology used to assess its execution.

7.2 Modeling of SDHWS

A Transient System Simulation Program (TRNSYS) has been utilized as mimic of SDHWS. TRNSYS is a to a great degree adaptable graphically based programming condition used to reenact the conduct of transient frameworks. While most by far of recreations are centered around surveying the execution of thermal and electrical vitality frameworks, TRNSYS can similarly well be utilized to demonstrate other dynamic frameworks, for example, activity stream, or natural procedures. TRNSYS peruses and forms the info document, iteratively illuminates the framework, decides merging, and plots framework factors. It gives utilities that decide thermophysical properties, rearrange networks, perform straight relapses, and interject outside information documents. TNSYS is very expensive, so the built-in data of Asia has been considered and simulated in the simulation program because there is no specific data of Dhaka in the demo version.

Online plotter has been used to show the simulation. To get the simulation of SDHWDS the plotter has been shown to get the result of the irradiation, the temperature of hot water at the user end and outlet temperature of water of the solar evacuated tube collector. The input of the components except weather data is same as the SDHWS implemented BRACU project.

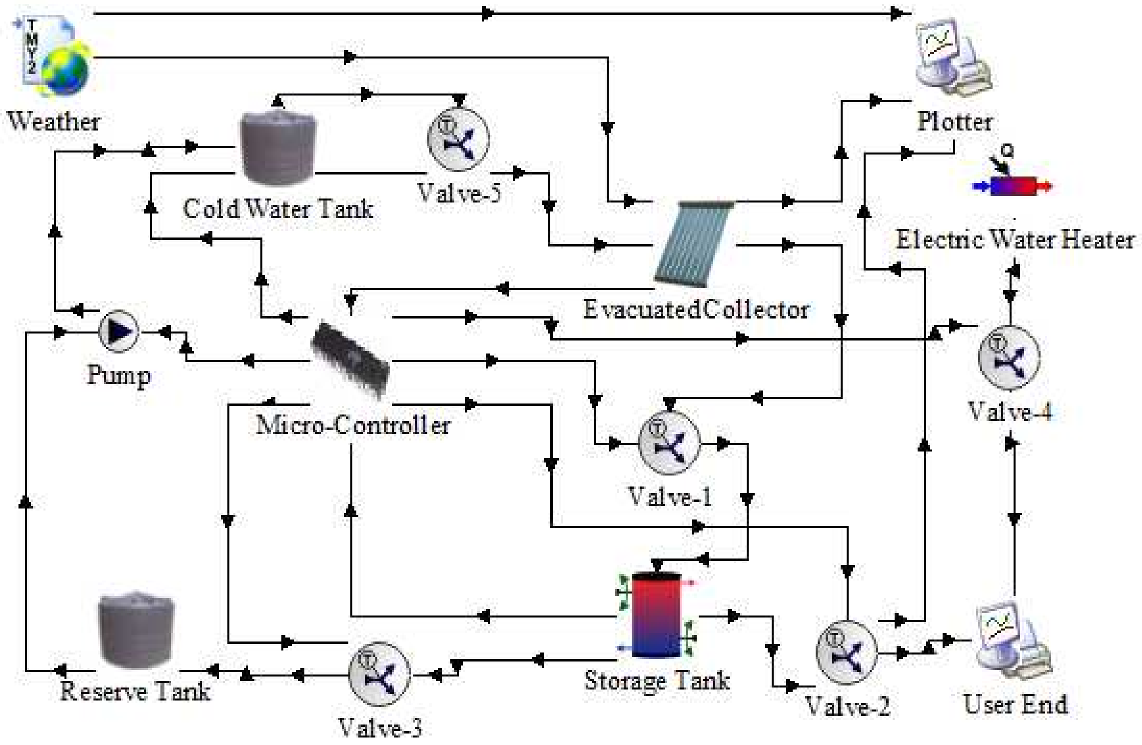
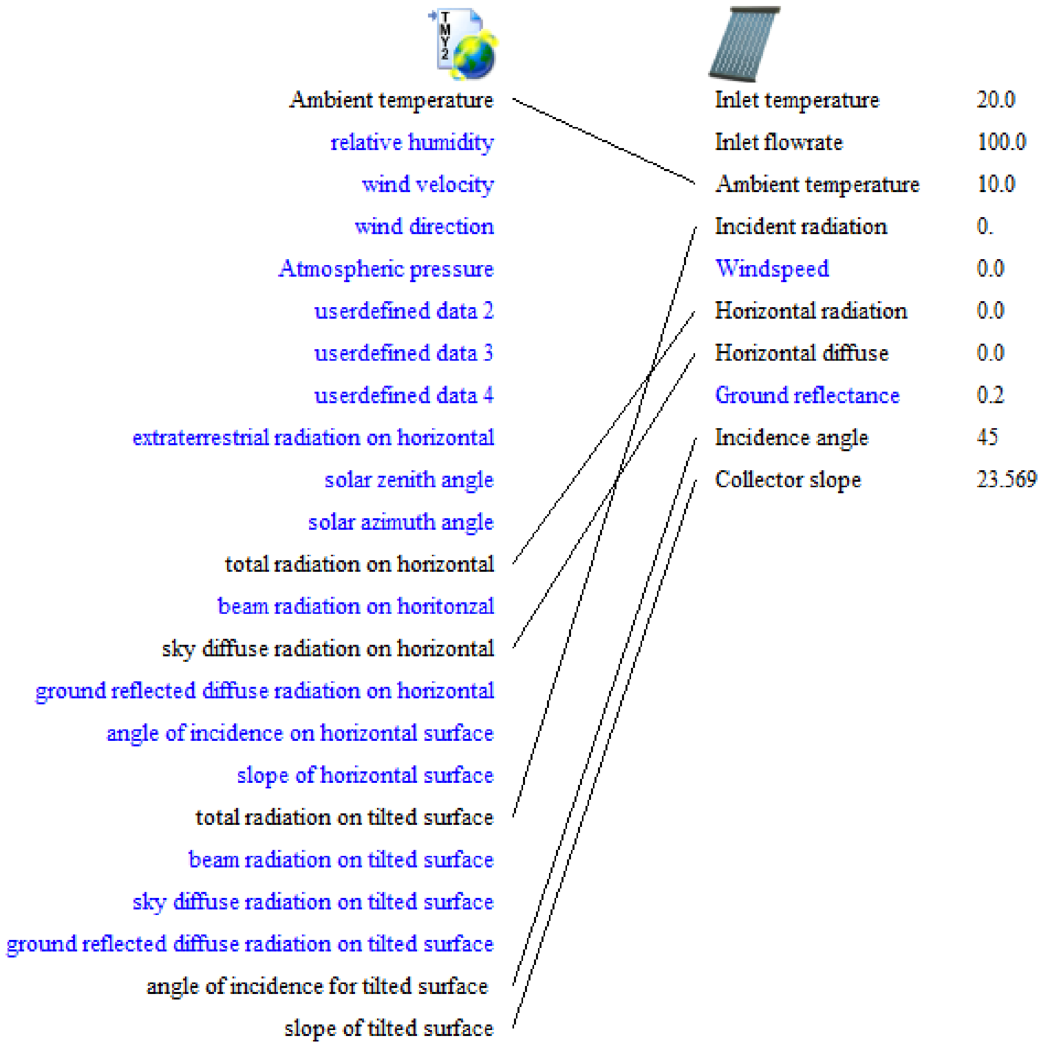


Fig. 7.1: Simulation block diagram of SDHWS.

7.3 Connections of Weather

Bangladesh has a tropical storm atmosphere portrayed by wide occasional varieties in precipitation, high temperatures, and high moistness. Provincial climatic contrasts in this level are minor. Three seasons are for the most part perceived: a sweltering, moist summer from March to June; a sweltering, damp and blustery rainstorm season from June to November; and a heat-sweltering, dry winter from December to February. All in all, most extreme summer temperatures go in the vicinity of 38 °C and 41 °C (100.4 °F and 105.8 °F). April is the hottest month in many parts of the country. January is the coolest month, when the normal temperature for the greater part of the nation is 16 °C – 20 °C (61 °F – 68 °F) during the day and around 10 °C (50 °F) during the evening.

The connection between weather component and collector component is necessary to get the proper simulation. It is a connection of similar unit of the component.



Inlet temperature	20.0
Inlet flowrate	100.0
Ambient temperature	10.0
Incident radiation	0.
Windspeed	0.0
Horizontal radiation	0.0
Horizontal diffuse	0.0
Ground reflectance	0.2
Incidence angle	45
Collector slope	23.569

Fig. 7.2: Connection of the weather to the solar evacuated tube collector in TRNSYS.

7.4 Results

The illustration of figure 7.3 and figure 7.4 exhibits the solar radiation and temperature of the water into hot tank and into storage tank. Solar radiation increases or decreases with the angular position of the sun at solar noon (declination angle) of the day. Heat transfer rates (Global Horizontal Radiation (GHI) kJ/hm2) in pink line, outlet temperature of the collector (temperature of hot water (°C) of hot water storage tank) in red line and the temperature of the water at the user end (temperature of water (°C) of storage tank temperature) in blue line have been shown in TRNSYS simulation results.

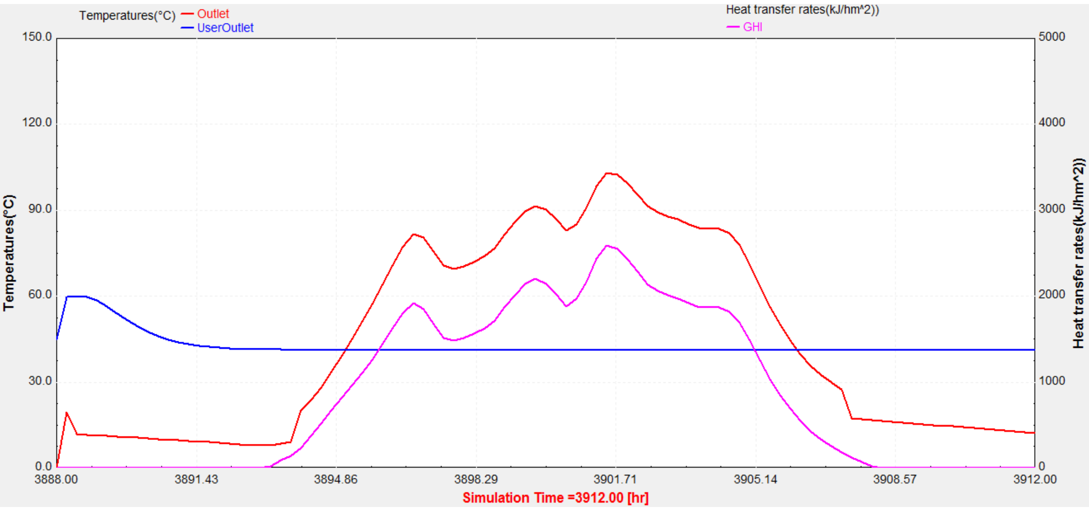


Fig. 7.3: Simulation of June 10, 2016.

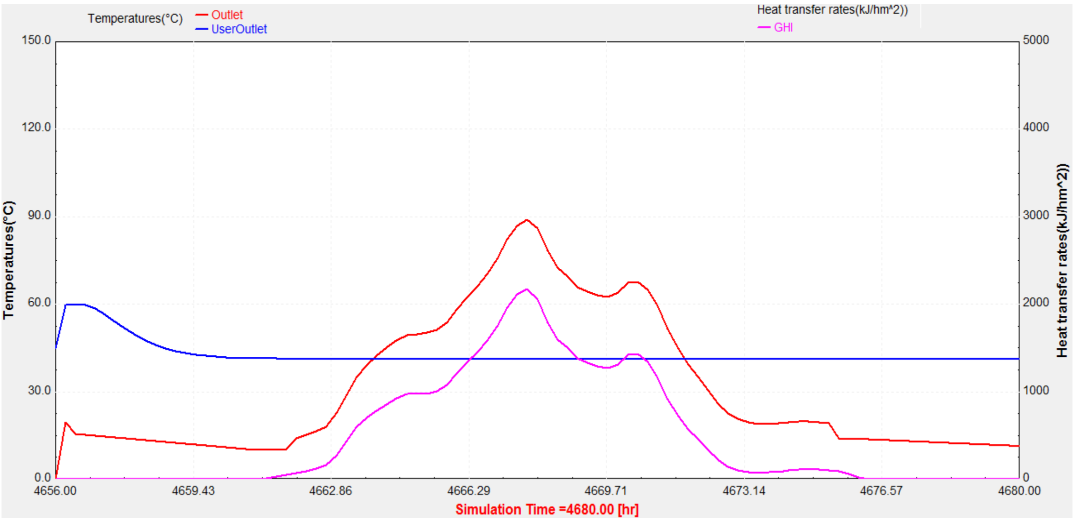


Fig. 7.4: Simulation of July 12, 2016.

There some limitation,

1. Red line (temperature of the outlet (°C) of collector) starts from zero. For Bangladesh it will start from above room temperature of the water.
2. At the beginning of the blue line (temperature of the water (°C) at the user end) follows the red line and also shows the constant temperature. For our project it will not constant.

7.5 Conclusion

This section demonstrates the reenactment of a household sun powered water heating establishment. The aftereffects of simulation performed on regular routine for a close planetary system (authority with surface of 1.99 m2 and a capacity tank of 300 liters) which gives high temp water. The installation comprises in a sun powered cleared tube gatherer, a high temp water tank, a water stockpiling tank, a wellspring of helper framework. We investigate all the more precisely the impact of the thermosyphone-stream rate and thus the stratification level of the tank on the water heating framework exhibitions. The enthusiasm of this examination dwells in the approach used to show the tank and in the investigation of the quantity of the hubs utilized on the picked up vitality.

CHAPTER 8

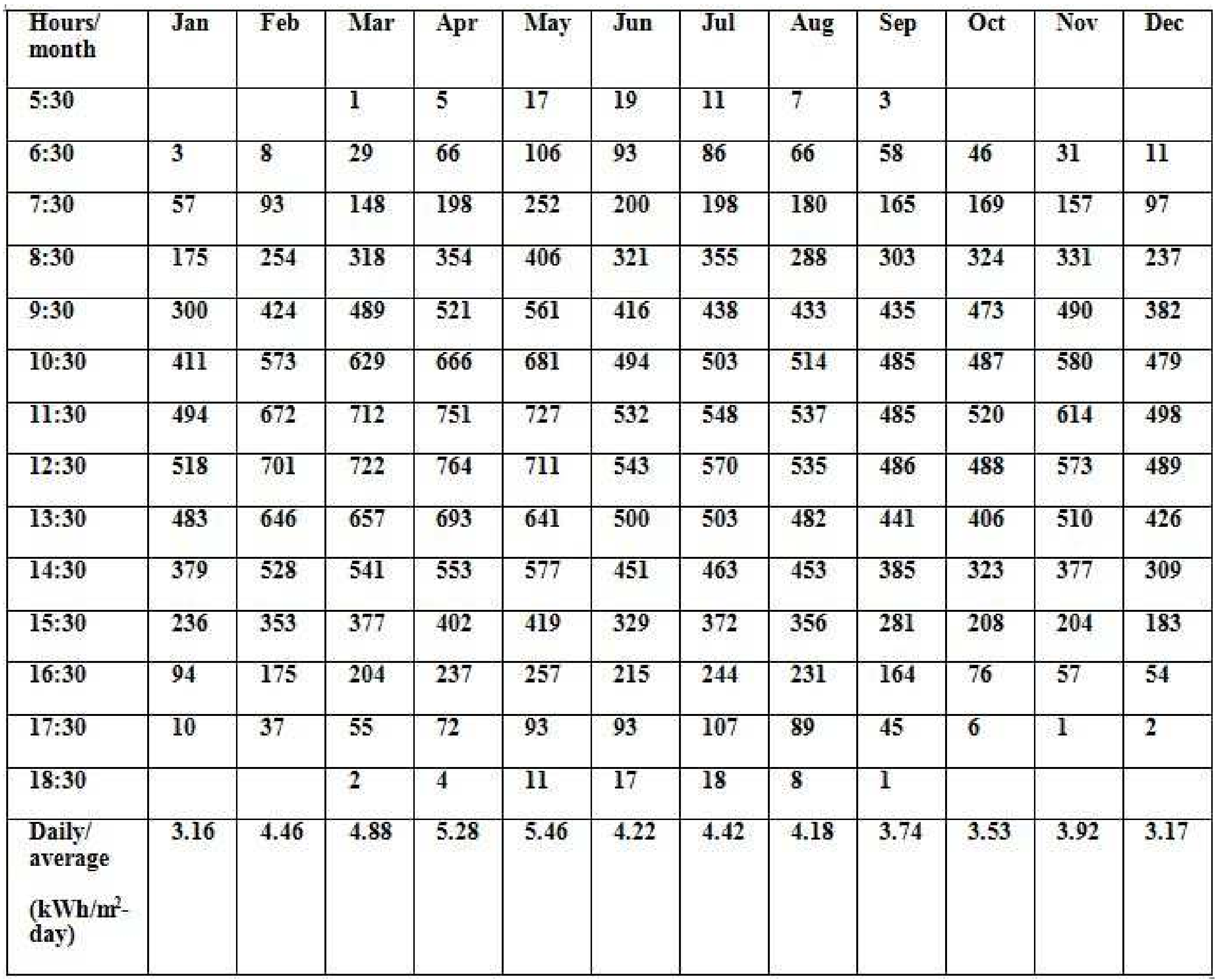
Discussion of Results

8.1 Introduction

Bangladesh Council of Scientific and Industrial Research (BCSIR) measured Global Horizontal Irradiance at Dhaka and Bandarban for about a year just utilizing programmed information recording framework. Bangladesh Meteorological Department (BMD) has begun Estimation of Global Horizontal Irradiance (GHI) estimation utilizing Eppley Precision Pyranometer for 7 stations over the nation. Programmed recording information have been masterminded under SWERA program utilizing universal subsidizing [26].

8.2 Data acquisition

In this chapter, the key features of the thermal storage are discussed in reference to the experi−mentally derived test results.



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 8.1: Monthly average GHI of Dhaka [26].

8.3 Model of Solar Radiation

Angstrom developed a equation between the solar radiation and sunshine duaration as;

$$\frac{\overline{\mathrm{H}}}{\overline{\mathrm{H}}_0} = \mathrm{a} + \mathrm{b}\,\frac{\overline{\mathrm{n}}}{\overline{\mathrm{N}}} \qquad (28)$$

$\frac{\overline{\mathrm{H}}}{\overline{\mathrm{H}}_0}$ is the ratio of monthly avearged daily GHI to monthly averaged daily extraterrestrial radiation on a horizontal surface.

$\frac{\overline{\mathrm{n}}}{\overline{\mathrm{N}}}$ is the ratio of monthly averaged sunshine hours and a, b are correlation coefficients.

The relative sunshine duration and state of the sky are related as follows:

$$\frac{\mathrm{n}}{\mathrm{N}'} = \frac{\mathrm{an}_1+\mathrm{bn}_2+\mathrm{cn}_3}{\mathrm{n}_{123}} \qquad (29)$$

Where,
$\mathrm{n}_1$is the number of clear days,
n_2 is the number of mixed days,
n_3 is the number of overcast days in a month.
$\mathrm{n}_{123} = \mathrm{n}_1 + \mathrm{n}_2 + \mathrm{n}_3$ under consideration; a, b, c are climatological parameters,
N′ is the period when the Campbell Stokes sunshine recoder remains sensitive over the day.

$$\mathrm{N}' = \frac{\arccos\left(\frac{\cos 85 - \sin\delta\,\sin\emptyset}{\cos\delta\,\cos\emptyset}\right)}{7.639} \qquad (30)$$

$\emptyset$ is the latitude of the station and δ is the declination [26].

8.4 Result Analysis

Solar radiation in a day depends on the sunshine hour of the day. The illustration of figure 9 exhibits the radiation increases or decreases with the angular position of the sun at solar noon (declination angle) of the day. Hot water storage tank temperature and storage tank temperature increase gradually with increasing the radiation and also decrease gradually with decreasing the radiation until new water (cold water) comes into the hot water storage tank.

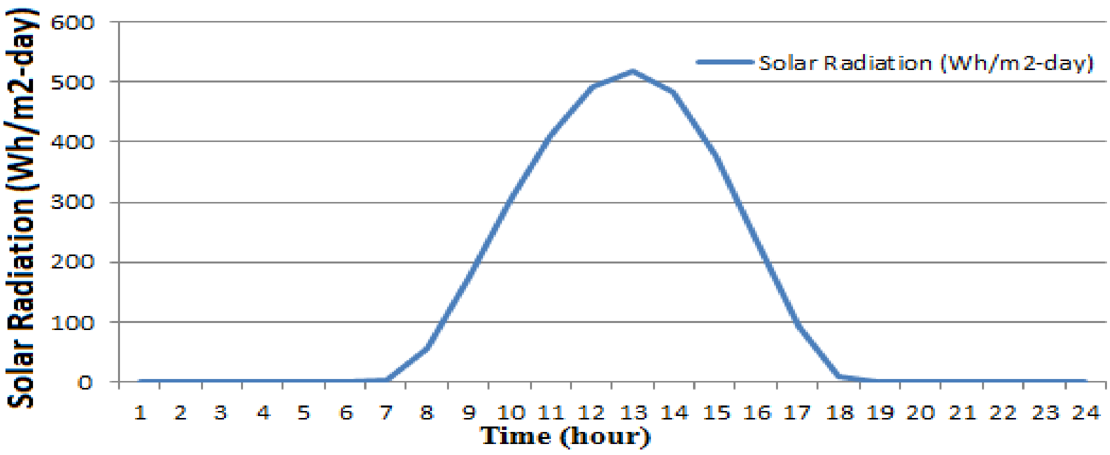


Fig. 8.1: Representing the solar radiation.

The illustration of figure 10 exhibits the Hot water storage tank temperature increases when the sunshine hours start in a day until all the water gets hot enough. After hot water passing through the outlet of the tank to the storage tank the cold water comes again into the hot water tank and the curve of hot water tank temperature gradually decrease in some time even though there have much radiation at solar noon. The simulation of the day is shown by considering the multiple same processes after collecting the hot water.

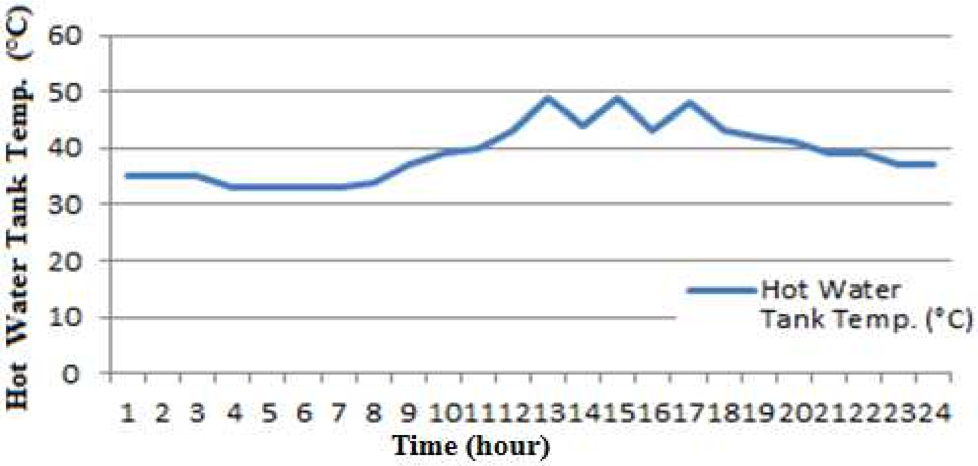


Fig. 8.2: Representing the Hot Water Tank temperature.

The illustration of figure 11 exhibits the initial temperature of the storage tank cannot be same as room temperature because it is properly insulated. When the hot water comes into the storage tank, the water temperature increases and the curve slightly shifts.

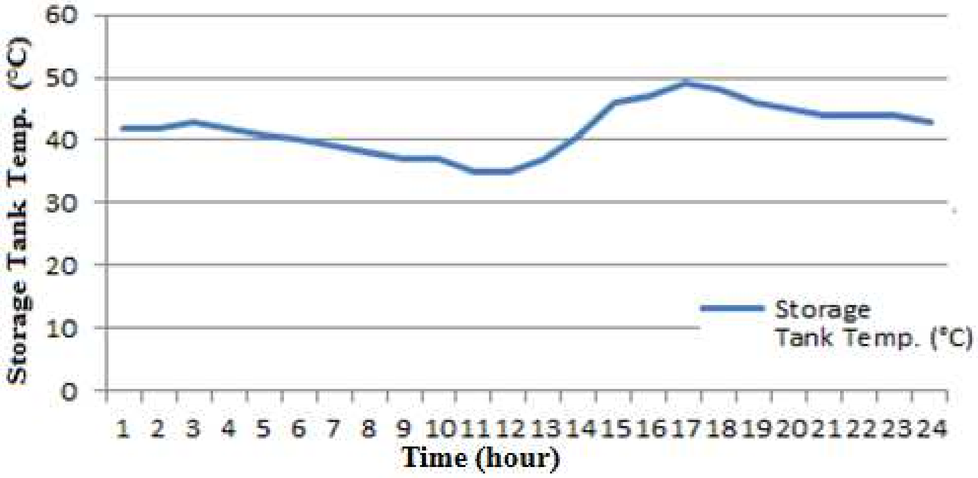


Fig. 8.3: Representing the Storage Tank temperature.

8.5 Conclusion

The simulation has been done using the SDHWS model. The hot water storage tank temperature and storage tank temperature are depending on solar radiation in a day, the radiation increases or decreases with the angular position of the sun at solar noon (declination angle) of the day. Hot water storage tank temperature is decreasing when new water (cold water) comes into the hot water storage tank and this hot water comes into the storage tank. So the water temperature increases of the storage tank. The simulation of the day is shown by considering the multiple same processes.

CHAPTER 9

Conclusion

9.1 Summary

A mathematical modeling of the prototype design is formulated and highlighted for the solar powered heating system that has been constructed by building up of multi-storage tanks which are connected with each other in series formation. Furthermore, during the analysis of the developed model, the actual position of the evacuated tube collector and the optimum solar inclination angle is also considered based on any various geographical locations of the system in Dhaka and its corresponding latitude and longitudinal angles. This paper also presents the calculated efficiency of the solar evacuated tube collector based on the developed model by taking into account of different possible types of heat losses (such as, optical, convectional heat loss, conductive loss and energy loss due to radiation to the outside atmosphere) that are likely to occur in order to make sure the calculated performance results of the solar heating system from the developed model is accurate, precise and reliable. The performance analysis of the solar heating water system is presented along with consideration case study of different solar inclination angles and efficiency of the system for obtaining the results of different parameters that are included and depended factors of the produced model. These parameters include, solar irradiance, temperature of hot water tank storage tank temperature. Analysis of the variation in the results of these parameters throughout the time (day/month/year) is of topmost priority to achieve higher accuracy in the performance analysis assessment of the developed model for the system.

In addition, an international conference publication has been done which is entitled “Mathematical Modeling of Solar Domestic Hot Water System (SDHWS) with thermal storage tank” [27].

9.2 Future Work

The concentration of this examination was to explore the exactness of the numerical model to foresee the execution of the multi-tank stockpiling and sun powered authority under a scope of test conditions. In spite of the fact that this work surveyed the stratification capability of a multi-tank thermal capacity unit and created a preparatory appraisal of the possibility of the multi-tank in a commonplace establishment, some of extra investigations have added to the operation of an inventive, medium limit, multi-tank thermal capacity through testing and reproduction, and to decide the key outline and operational components that influence the thermal stratification and framework execution of the unit.

A test was displayed to the operation of the heat move circle backward thermosyphone operation, and specifically, it is helpful to decide the temperature dispersion in the course circle with the goal that the thickness and net weight head can be precisely decided. In that capacity, it would be exceptionally significant to this work to explore the temperature conveyance in the characteristic convection heat trade circle so as to enhance the exactness of the model. Improvement of another, strong TRNSYS model ought to be finished that has the capacity to demonstrate positive and turn around thermosyphone streams. It would be of incredible advantage to stretch out research center testing to cover longer periods that incorporate climate and load inconstancy. This ought to incorporate the investigation of evening time standby heat losses and their impact on the operation and stratification level of the thermal energy storage (TES). The potential for expanded thermal misfortunes from the TES because of switch thermo directing on top of it and natural convection heat exchanger (NCHE) needs additionally examine. At last, it would be of extraordinary advantage to screen the execution of a multi-tank TES in a reasonable field establishment.

References

[1] Ferdous, J., Rahman Swjo, R., Hasan, R., & Azad, A. (2016). ‘Automation, heat loss reduction and optimum positioning of solar hot water system with storage tank in Bangladesh’, BRAC University Journal, XI(2), pp. 27–36.

[2] Rahman, M. Asifur, Sayem, A. Asif-uz-zaman ‘Alternative solar hot water system with multi storage tank’, Thesis, B.Sc in Electrical & Electronic Engineering, BRAC University, 2010.

[3] Hasan, M. R., Arifin, K., Rahman, A., & Azad, A. (2011). “Design, implementation and performance of a controller for uninterruptible solar hot water system”, Paper presented at the 2011 IEEE 18th International Conference on Industrial Engineering and Engineering Management, IE and EM 2011, (PART 1) pp. 584-588.

[4] M. K. Arefin, M. R. Hasan and A. Azad “Characteristics and Cost Analysis of an Automatic Solar Hot Water System in Bangladesh”, 2nd International Conference on Environmental Science and Technology IPCBEE vol.6, IACSIT Press, Singapore 2011.

[5] L. Mongibelloa, N. Biancob , M. Caliano, A. Lucad , “Transient analysis of a solar domestic hot water system using two different solvers”, Energy Procedia 81(2015) 89 – 99.

[6] I. G. Kelechi, A.damu M.urtala Zungeru, O. E. Ayobami, H. Habibu, A. F. Olugbenga “Design and Modelling of a Solar Water Heating System”, Industrial Engineering Letters, ISSN 2224-6096 (Paper), Vol.4, No.12, 2014.

[7] R. Yua, D. Yanb, Y. Gao “Investigation and modelling of the centralized solar domestic hot water system in residential buildings”, Procedia Engineering, 146 (2016), pp. 424 – 430.

[8] A. Verma, V. Kumar “Solar Water Heating System”, Vol.3 Issue.1, January 2015, pp. 53-63.

[9] Cynthia Ann, ‘Evaluation of a Stratified Multi-Tank Tehermal Storage for Solar Heating Applications’, Thesis, Doctor of Philosophy, Queen’s University, Kingston, Ontario, Canada, June, 2009.

[10] Duffie, J.A & Beckman, W.A. Solar Energy Renewable and the Environment. CRC Press 2010.

[11] John A. Duffie, "Solar Engineering of Thermal Processes" in Culinary & Hospitality Industry Publications Services, New York:John Wiley & Sons, pp. 20-22, 1991.

[12] Tian Qi, "Thermal Performance of the U-type Evacuated Glass Tubular Solar Collector", Building Energy & Environment, vol. 26, no. 3, pp. 51-54, 2007.

[13] Mapsofworld.com of different themes & projections for any Continent & Discover Countries: https://www.mapsofworld.com/. [Accessed: 17 - Sep - 2015].

[14] M. Rahman, S. Shareef, R. Rahman, & M. Choudhury, “Computation of solar radiation tilt factor and optimum tilt angle for Bangladesh”, Indian Journal of Radio & Space Physics, Vol. 29, February 2000, pp. 37-40.

[15] M. Jamil Ahmad, G. N. Tiwari “Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation”, The Open Renewable Energy Journal, 2:19-24, 2009.

[16] National Renewable Energy Laboratory (NREL), U.S. Department of Energy by the Midwest Research Institute, Technical Report NREL/TP-5000-62942, March 2016.

[17] BRANZ, a directory of New Zealand building and construction industry information. The authority on sustainable building: http://www.level.org.nz. BRANZ 2007, [Accessed: 15 – Sep – 2015].

[18] H. Darhmooui, D. Lahjouji “Latitude Based Model for Tilt Angle Optimization for Solar Collectors in the Mediterranean Region”, The Mediterranean Green Energy Forum 2013, MCEF-13, Energy Procedia 42(2013), pp. 426 – 435.

[19] Reda, I. Andreas, A. “Solar Position Algorithm for Solar Radiation Application”, Solar Energy, Elsevier, 75(5): 577-589; 2004

[20] Landsat Data Dictionary, https://lta.cr.usgs.gov/landsat_dictionary.html#sun_azimuth. [Accessed: 21 – Sep – 2015].

[21] Gao, Yan & An, Yujiao & Li, Deying & Chen, “Yanhong. (2010). Simulation Study of Influence of Inertia of Water on the Thermal Performance of All-glass Evacuated Tube Solar Collector”, Asia-Pacific Power and Energy Engineering Conference, APPEEC. 10.1109/APPEEC.2010.5449079.

[22] Yan, S., R. Tian, S. Hou, and L. Zhang, L., “Analysis on unsteady state efficiency of glass evacuated solar collector with an inserted heat pipe”, Journal of Engineering Thermophysics, vol 29(2). pp. 323.

[23] Weiqiang Kong, Zhifeng Wang, Xing Li, Xin Li, Ning Xiao, “Theoretical analysis and experimental verification of a new dynamic test method for solar collectors”, Solar Energy, vol 86, issue 1, 2012, pp 398-406.

[24] Luo Nanchun, "Analysis and Computation on the Heat Performance of All-glass Evacuated Tube Solar Collector", Joiurnal of Shan Dong Institute of Architecture and Engineering, vol. 13, no. 1, pp. 16-19, 1998.

[25] Sun Zhifeng, Zheng Ruicheng, "Studies on Test Methods for The Thermal Performance of Solar Collectors under Quasi-dynamic Conditions", Acta Energiae Solaris Sinica, vol. 28, no. 11, pp. 1195-1199, 2007.

[26] SWERA-Bangladesh report, ‘Solar and Wind Energy Resource Assessment (SWERA)-Bangladesh Resnewable Energy Research Centre’, February 2017.

[27] M. N. Islam and A.K.M. A. M. Azad, "Mathematical Modeling of Solar Domestic Hot Water System (SDHWS) with thermal storage tank", 4th International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, 2017, pp. 691-696.

Appendices

Appendix A

A.1 Code for the Weather

```
*****************************************************************************

   subroutine sloped_surfaces

! ****************************************************************************

! CALCULATE BEAM RADIATION, TOTAL RADIATION AND INCIDENCE ANGLE FOR EACH is-th PLANE

axslp=r%slopes(ip)*rdconv

axazm=r%axes(ip)*rdconv

sinasl=sin(axslp)

ip = ip+1

cosasl=cos(axslp); cosasl=sign(amax1(abs(cosasl),1.e-06),cosasl)

tanasl = sinasl/cosasl

alf = sazm - axazm; alf = sign(amax1(abs(alf),1.e-06),alf)

! KEEP THE DIFFERENCE OF SOLAR AZIMUTH AND AXIS AZIMUTH BETWEEN 180 AND -180 DEGREES

   if(abs(alf)>pi) alf = alf - sign((2.*pi),alf)

costtp = cosasl*coszen + sinasl*sinzen*cos(alf)

costtp = sign(amax1(abs(costtp),1.e-06),costtp)


tracking_mode: Select case (r%trackmode)

    case (1) ! FIXED SURFACE

      slope = axslp; azm = axazm


    case (2) ! SINGLE-AXIS TRACKER

      aux=abs(amod(axslp*dgconv,180.))
```

```
if(aux>0.1.and.aux.le.179.9) then
      slope = axslp; azm = sazm ! VERTICAL AXIS
     else
azm = axazm + .5*sign(pi,alf)
tanslp = tanzen*cos(sazm - azm); slope = atan(tanslp)
      if(slope<0.) slope = pi + slope
endif

    case (3) ! SLOPED AXIS
tangam = sinzen*sin(alf)/sinasl/costtp
     gam = atan(tangam); if(gam<.0.and.alf>0.) gam = pi+gam
     if(gam>.0.and.alf<0.) gam = gam-pi
tanslp = tanasl/cos(gam); slope = atan(tanslp)
     if(slope<0.) slope = pi+slope; azm = gam + axazm
     if(abs(azm)>pi) azm = azm - sign((2.*pi),azm)

    case (4) ! TWO-AXIS TRACKER
azm = sazm; slope = zenith
   end select tracking_mode

cosslp = cos(slope); sinslp = sin(slope)
costt = min(1.,cosslp*coszen+sinslp*sinzen*cos(sazm-azm))
   theta = acos(costt)*dgconv; slope = slope*dgconv

! BEAM AND GROUND REFLECTED RADIATION INDEPENDENT OF TILTED SURFACE MODEL
rb = amax1(costt,0.)/coszen; hbeam = hb*rb
hgrf  =hhor*r%rho*.5*(1.-cosslp)
```

```
tilted_surface_skymode: select case (r%skymode)
        case (1)                !ISOTROPIC SKY MODEL FOR TILTED SURFACE DIFFUSE
hdiff = hd*.5*(1.+cosslp)


        case (2)                        !HAY MODEL FOR TILTED SURFACE DIFFUSE
ai = hb/hextra; hdiff = hd*(.5*(1.-ai)*(1.+cosslp)+ai*rb)


        case (3)                                !REINDL TILTED SURFACE MODEL
ai = hb/hextra
f  =sqrt(hb/hhor); scube = (sin(slope*0.5*rdconv))**3
hdiff = hd*(0.5*(1.-ai)*(1.+cosslp)*(1.+f*scube)+ai*rb)


        case (4)            !PEREZ POINT SOURCE MODEL (SANDIA REPORT OCT, 1988)
hdn = hb/coszen
          if ( hd< 0.00001 ) then
            eps = 99999.
          else
epsiln = ( hd + hdn ) / hd
            eps = ( epsiln+1.041*zenith**3 )/( 1.+1.041*zenith**3 )
endif
skyb = hd/hextra
          if (eps>0.0 )nbin = 1; if (eps>1.065) nbin = 2
          if (eps>1.23) nbin = 3; if (eps>1.5  )nbin = 4
          if (eps>1.95) nbin = 5; if (eps>2.8  )nbin = 6
          if (eps>4.5 )nbin = 7; if (eps>6.2  ) nbin = 8
```

```
         p1=p11(nbin)+p12(nbin)*skyb+p13(nbin)*zenith;p1=max(p1,.0)
         p2=p21(nbin)+p22(nbin)*skyb+p23(nbin)*zenith
         a1=max(costt,0.); b1=amax1(cos(85.0*rdconv),coszen)

         if (hb> 0.) then
hdiff = hd*(0.5*(1.-p1)*(1.+cosslp)+p1*a1/b1+p2*sinslp)
         else        !DIFFUSE ASSUMED ISOTROPIC IF BEAM NOT POSITIVE
hdiff = hd*0.5*(1.+cosslp)
endif
hdiff = max(hdiff,0.)

      end select tilted_surface_skymode

      end subroutine sloped_surfaces
! ******************************************************************************

******************************************************************************
      subroutine suncalc
! ******************************************************************************
!CALCULATE SUN POSITION
sazm = 0.
coszen=cc*coshr+ss; coszen=sign(amax1(abs(coszen),1.e-06),coszen)
      zenith=acos(coszen); sinzen=sin(zenith); tanzen=sinzen/coszen
      if (abs(sinzen) .ge. 1e-06) then
sinazm=cosdec*sinhr/sinzen
sinazm=sign(amin1(abs(sinazm),1.),sinazm); sazm = asin(sinazm)
!DETERMINE WETHER THE SOLAR AZIMUTH IS GREATER THAN 90 DEGREES BY
```

```
!COMPARING THE HOUR ANGLE WITH THE HOUR ANGLE AT WHICH THE SOLAR
!AZIMUTH IS +/- 90 DEGREES
cwew = tandec/r%tanlat; cwew=sign(amin1(abs(cwew),1.),cwew)
wew = pi; if(r%latit*(decl-r%latit).le.0.) wew = acos(cwew)
     if((abs(w)-abs(wew))*r%latit*(decl-r%latit).le.0.) sazm = sign(pi,sazm) - sazm
!DON'T ALLOW THE SOLAR AZIMUTH TO BE GREATER THAN 180 DEGREES.
     if(abs(sazm) > pi) sazm = sazm - sign((2.*pi),sazm)
endif
    end subroutine suncalc
! ***********************************************************************
    end subroutine rad_proc
! ***********************************************************************
```

A.2 Code for Solar Evacuated Tube Collector

```
C   ***********************************************************************
C   INCIDENCE ANGLE MODIFIER SECTION
C   ***********************************************************************
C   SET THE IAM TO ZERO IF THERE IS NO INCIDENT SOLAR
    IF(GT.LE.0.) THEN
      XKAT=0.
      GOTO 100

    ENDIF
C   IF THE ZENITH ANGLE IS GREATER THAN 90, SET THE IAM TO 0. AND HEAD TO THE
C   THERMAL CALCULATIONS
    IF(THETAZ.GE.90.) THEN
      XKAT=0.
```

```
       GO TO 100
     ENDIF

C    DETERMINE THE TRANSVERSE INCIDENCE ANGLE
     TANTT=DSIN(THETAZ*RDCONV)*DSIN(DABS(SURFAZM-SOLAZM)*RDCONV)
    .     /DCOS(THETA*RDCONV)
     THETAT=DABS(DATAN(TANTT)/RDCONV)

C    DETERMINE THE LONGITUDINAL INCIDENCE ANGLE
     TANALF=DTAN(THETAZ*RDCONV)*DCOS((SURFAZM-SOLAZM)*RDCONV)
     THETAL=DABS(DATAN(TANALF)/RDCONV-SLOPE)

C    USE THE DATA SUBROUTINE TO INTERPOLATE TO FIND THE IAM FOR BEAM RADIATION
X(1)=THETAL
NXJ(1)=NXDATAL
X(2)=THETAT
NXJ(2)=NXDATAT
     CALL DYNAMICDATA(LUDATA1,2,NXJ,1,X,Y,INFO,*821)
     CALL LINKCK('TYPE71','DYNAMICDATA  ',1,99)
  XKATB=Y(1)

C    DETERMINE MODIFIER FOR DIFFUSE, ONCE DURING SIMULATION
     IF(OUT(7).GT.0.) GO TO 85

C    DIVIDE THE SKY INTO 'NDELT' BY 'NDELT' CHUNKS AND DO EACH PIECE SEPARATELY
     XKATD2=0.
     DDELT=PI/2./DBLE(NDELT)
```

```
C    LOOP THROUGH THE CHUNKS IN ONE DIRECTION AND CALCULATE THE SOLAR AZIMUTH
C    ANGLE
    DO 84 I=1,NDELT
      XKATD1=0.
      SOLAZM=DBLE(I-1)*DDELT+DDELT/2.

C      LOOP THROUGH THE CHUNKS IN THE OTHER DIRECTION AND CALCULATE THE
TRANSVERSE
C      AND LONGITUDINAL ANGLES
      DO 83 J=1,NDELT
        THETA=DBLE(J-1)*DDELT+DDELT/2.
        SINTT=DSIN(THETA)
        COSTT=DCOS(THETA)
        TANTT=SINTT/COSTT
        THETAT=DATAN(TANTT*DSIN(SOLAZM))/RDCONV
        THETAL=DATAN(TANTT*DCOS(SOLAZM))/RDCONV

C        USE THE DATA SUBROUTINE TO FIND THE DIFFUSE IAM FOR THIS CHUNK
X(1)=THETAL
NXJ(1)=NXDATAL
X(2)=THETAT
NXJ(2)=NXDATAT
        CALL DYNAMICDATA(LUDATA1,2,NXJ,1,X,Y,INFO,*831)
        CALL LINKCK('TYPE71','DYNAMICDATA  ',1,99)
    XKATD=Y(1)
```

```
      XKATD1=XKATD1+XKATD*COSTT*SINTT*DDELT
    XKATD2=XKATD2+XKATD1*DDELT

C    CALCULATE THE DIFFUSE IAM AND STORE IT IN THE OUT ARRAY FOR FUTURE TIMESTEPS
      XKATD=4.*XKATD2/PI
OUT(7)=XKATD

C    RETRIEVE THE DIFFUSE IAM FROM STORAGE AND CALCULATE THE OVERALL IAM
    XKATD=OUT(7)
      XKAT=(XKATB*(GT-GDT)+XKATD*GDT)/GT

C    ************************************************************************
C    THERMAL PERFORMANCE SECTION
C    ************************************************************************
  CONTINUE

C    INITIALIZE THE OUTLET TEMPERATURE
      TOUT1=0.

    CONTINUE

C    SECOND ORDER FLAT PLATE CALCULATIONS
C       EFF = A - B(DT)/I - C(DT^2)/I -or -
C       EFF = A - (B+C*DT)*DT/I
C       THEREFORE, FRUL' = (FRUL+FRTWO*DT)

C    MODIFY FRULP BASED ON THE EFFICIENCY MODE (FUNCTION OF INLET,AVERAGE,OUTLET)
```

```
    GO TO (116,117,118) ,EMODE

C    MODIFY EFFICIENCY PARAMETERS TO BE BASED ON (TI-TAMB)/GT
  FRULP=PAR(7)+PAR(8)*(TIN-TAMB)
    FRATIO=1.
    GO TO 119

C    MODIFY EFFICIENCY PARAMETERS TO BE BASED ON (TI-TAMB)/GT FROM (TAVE-TAMB)/GT
  FRULP=PAR(7)+PAR(8)*((TIN+TOUT1)/2-TAMB)
IF(GTEST.LE.0.) THEN
      FRATIO=1.
    ELSE
      FRATIO=1./(1.+FRULP/GTEST/CP_FLUID/2.)
    ENDIF
    GO TO 119

C    MODIFY EFFICIENCY PARAMETERS TO BE BASED ON (TI-TAMB)/GT FROM (TOUT-TAMB)/GT
  FRULP=PAR(7)+PAR(8)*(TOUT1-TAMB)
IF(GTEST.LE.0.) THEN
      FRATIO=1.
    ELSE
      FRATIO=1./(1.+FRULP/GTEST/CP_FLUID)
    ENDIF

  CONTINUE
    FRTAN=FRATIO*PAR(6)
    FRUL=FRATIO*PAR(7)
```

```
     FRTWO=FRATIO*PAR(8)
     FRULP=FRATIO*FRULP

IF(FLWC.LE.0.) THEN
C      NO FLOW THEN TWO CASE TO SOLVE - FRTWO=0., LINEAR THEN SOLVE LINEAR EQN
C                              - FRTWO NONZERO - SOLVE QUADRATIC EQN
IF(FRTWO.EQ.0.) THEN
          QU=0.
          TOUT=GT*FRTAN*XKAT/FRUL+TAMB
          EFFIC=0.
        ELSE
          QU=0.
          AAA=FRTWO
          BBB=FRUL-2.*FRTWO*TAMB
          CCC=FRTWO*TAMB*TAMB-FRUL*TAMB-FRTAN*GT*XKAT
          TOUT=(-BBB+(BBB*BBB-4.0*AAA*CCC)**0.5)/(2.0*AAA)
          EFFIC=0.
        ENDIF

     ELSE
C      CALCULATE EFFECTS OF NUMBER OF COLLECTORS IN SERIES AND PERFORMANCE AT
C      OFF-RATED FLOW RATES ON THERMAL PERFORMANCE
        IF((GTEST.LE.0.).OR.(AREA.LE.0.)) THEN
          RATIO=1.
        ELSE
          FTEST=FRULP/GTEST/CP_FLUID
          IF(FTEST.GE.1) THEN
```

```
     FPUL=FRULP
    ELSE
     FPUL=-GTEST*CP_FLUID*DLOG(1.-FRULP/GTEST/CP_FLUID)
    ENDIF

    RTEST=GTEST*CP_FLUID*(1.-DEXP(-FPUL/GTEST/CP_FLUID))
    R1=XNS*FLWC*CP_FLUID/AREA*(1.-DEXP(-FPUL*AREA/XNS/FLWC/
  1     CP_FLUID))/RTEST
    XK=R1*AREA*FRULP/FLWC/CP_FLUID/XNS
    R2=(1.-(1.-XK)**XNS)/XNS/XK
    R3=1.
    RATIO=R1*R2*R3
   ENDIF

C   CALCULATE THE USEFUL ENERGY GAIN AND COLLECTOR OUTLET TEMPERATURE
   QU=RATIO*AREA*(FRTAN*XKAT*GT-FRULP*(TIN-TAMB))
   TOUT=QU/FLWC/CP_FLUID+TIN
   IF((AREA.LE.0.).OR.(GT.LE.0.)) THEN
    EFFIC=0.
   ELSE
    EFFIC=QU/GT/AREA
   ENDIF
  ENDIF

C  CHECK FOR CONVERGENCE OF TOUT IF EFFICIENCY CURVE IS BASED UPON TAVE OR TOUT
 IF((DABS(TOUT-TOUT1).GT.CONV).AND.(EMODE.GT.1)) THEN
   TOUT1=TOUT
```

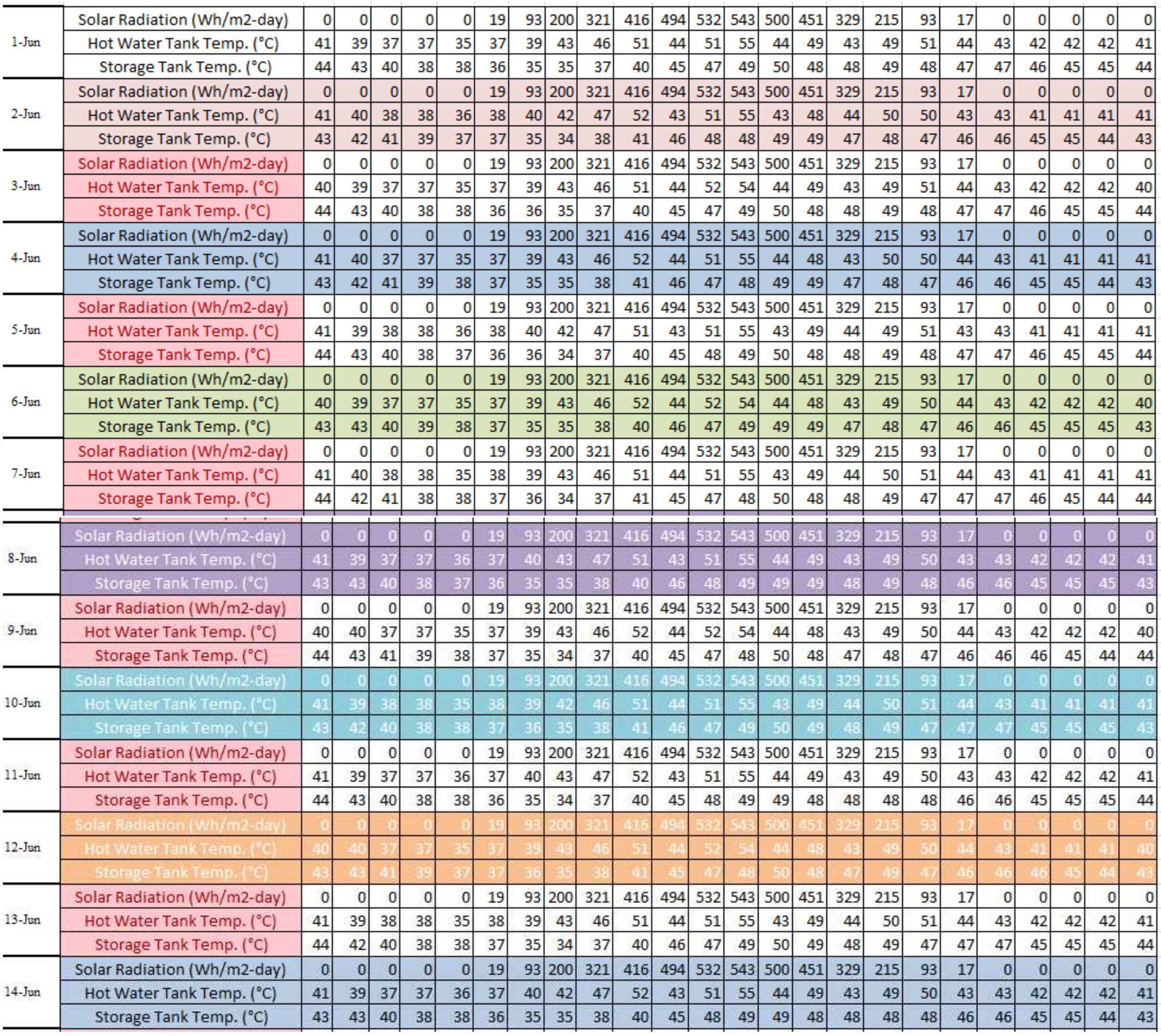
```
      GO TO 110
    ELSE
      GO TO 300
    ENDIF

C--------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT
300   OUT(1)=TOUT
OUT(2)=FLWC
OUT(3)=QU
OUT(4)=EFFIC

    RETURN 1
    END
C--------------------------------------------------------------------------------------------------------------
```

Appendix B

B.1 Sample data set for Solar Radiation, Temperature of Water into Hot Water Tank and Storage Tank

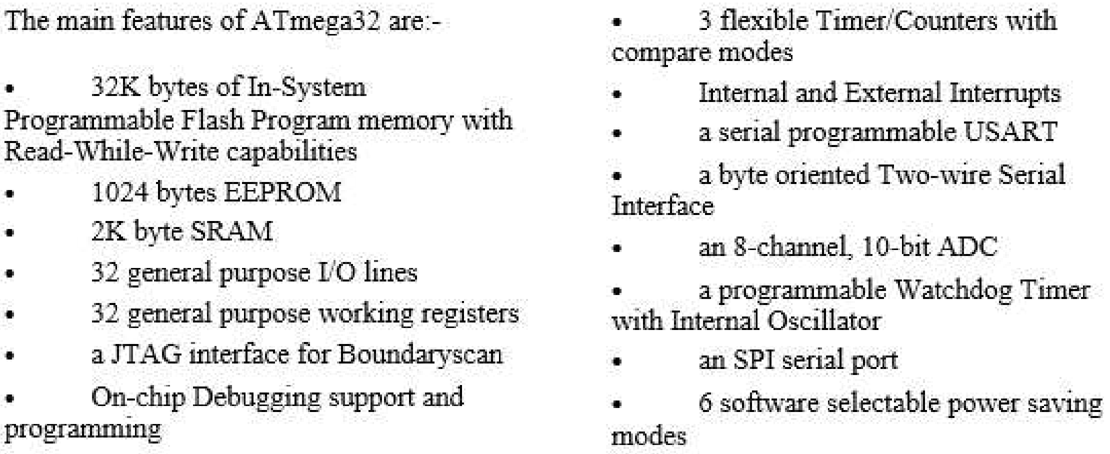


1-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	35	37	39	43	46	51	44	51	55	44	49	43	49	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	44	43	40	38	38	36	35	35	37	40	45	47	49	50	48	48	49	48	47	47	46	45	45	44
2-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	40	38	38	36	38	40	42	47	52	43	51	55	43	48	44	50	50	43	43	41	41	41	41
	Storage Tank Temp. (°C)	43	42	41	39	37	37	35	34	38	41	46	48	48	49	49	47	48	47	46	46	45	45	44	43
3-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	39	37	37	35	37	39	43	46	51	44	52	54	44	49	43	49	51	44	43	42	42	42	40
	Storage Tank Temp. (°C)	44	43	40	38	38	36	36	35	37	40	45	47	49	50	48	48	49	48	47	47	46	45	45	44
4-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	40	37	37	35	37	39	43	46	52	44	51	55	44	48	43	50	50	44	43	41	41	41	41
	Storage Tank Temp. (°C)	43	42	41	39	38	37	35	35	38	41	46	47	48	49	49	47	48	47	46	46	45	45	44	43
5-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	36	38	40	42	47	51	43	51	55	43	49	44	49	51	43	43	41	41	41	41
	Storage Tank Temp. (°C)	44	43	40	38	37	36	36	34	37	40	45	48	49	50	48	48	49	48	47	47	46	45	45	44
6-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	39	37	37	35	37	39	43	46	52	44	52	54	44	48	43	49	50	44	43	42	42	42	40
	Storage Tank Temp. (°C)	43	43	40	39	38	37	35	35	38	40	46	47	49	49	49	47	48	47	46	46	45	45	45	43
7-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	40	38	38	35	38	39	43	46	51	44	51	55	43	49	44	50	51	44	43	41	41	41	41
	Storage Tank Temp. (°C)	44	42	41	38	38	37	36	34	37	41	45	47	48	50	48	48	49	47	47	47	46	45	44	44
8-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	43	47	51	43	51	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	43	43	40	38	37	36	35	35	38	40	46	48	49	49	49	48	49	48	46	46	45	45	45	43
9-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	52	44	52	54	44	48	43	49	50	44	43	42	42	42	40
	Storage Tank Temp. (°C)	44	43	41	39	38	37	35	34	37	40	45	47	48	50	48	47	48	47	46	46	46	45	44	44
10-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	42	46	51	44	51	55	43	49	44	50	51	44	43	41	41	41	41
	Storage Tank Temp. (°C)	43	42	40	38	38	37	36	35	38	41	46	47	49	50	49	48	49	47	47	47	45	45	45	43
11-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	43	47	52	43	51	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	44	43	40	38	38	36	35	34	37	40	45	48	49	49	48	48	48	48	46	46	45	45	45	44
12-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	51	44	52	54	44	48	43	49	50	44	43	41	41	41	40
	Storage Tank Temp. (°C)	43	43	41	39	37	37	36	35	38	41	45	47	48	50	48	47	49	47	46	46	46	45	44	43
13-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	51	44	51	55	43	49	44	50	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	44	42	40	38	38	37	35	34	37	40	46	47	49	50	49	48	49	47	47	47	45	45	45	44
14-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	42	47	52	43	51	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	43	43	40	38	38	36	35	35	38	40	45	48	49	49	48	48	48	48	46	46	45	45	44	43

15-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	51	44	52	54	44	48	43	49	50	44	43	41	41	41	40
	Storage Tank Temp. (°C)	44	43	41	39	37	37	36	34	37	41	46	47	48	50	48	47	49	47	46	46	46	45	45	44
16-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	52	44	51	55	43	49	44	50	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	44	42	40	39	38	37	35	35	38	40	45	48	49	50	49	48	48	47	47	47	45	45	45	44
17-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	42	47	51	43	51	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	43	43	40	38	38	36	35	34	37	40	45	47	48	49	48	48	49	48	46	46	46	45	44	43
18-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	52	44	52	54	44	48	43	49	50	44	43	41	41	41	40
	Storage Tank Temp. (°C)	44	43	41	39	37	37	36	35	38	41	46	47	49	50	48	47	49	47	46	46	45	45	45	44
19-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	51	44	51	55	43	49	44	50	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	43	42	40	38	38	37	35	34	37	40	45	48	49	50	49	48	48	47	47	47	45	45	45	43
20-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	42	47	51	43	52	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	44	43	40	38	38	36	35	35	38	41	46	47	48	49	48	48	49	48	46	46	46	45	44	44
21-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	52	44	51	54	44	48	43	49	50	44	43	41	41	41	40
	Storage Tank Temp. (°C)	44	43	41	39	37	37	36	34	37	40	45	47	49	50	48	47	48	47	46	46	45	45	45	44
22-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	51	44	51	55	43	49	44	50	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	43	42	40	38	38	37	35	35	38	40	45	48	49	50	49	48	49	47	47	47	46	45	45	43
23-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	42	47	51	43	52	55	44	49	43	49	50	43	43	42	42	42	41
	Storage Tank Temp. (°C)	44	43	40	38	38	36	35	34	37	41	46	47	48	49	48	48	49	48	46	46	45	45	44	44
24-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	52	44	51	54	44	48	43	49	50	44	43	41	41	41	40
	Storage Tank Temp. (°C)	43	43	41	39	37	37	36	35	38	40	45	47	49	50	48	47	48	47	47	47	45	45	45	43
25-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	51	44	51	55	43	49	44	50	51	44	43	42	42	42	41
	Storage Tank Temp. (°C)	44	42	40	38	38	37	35	34	37	41	46	48	49	49	49	48	49	47	46	46	46	45	45	44
26-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	40	42	47	51	43	52	55	44	49	43	49	50	43	43	41	41	41	41
	Storage Tank Temp. (°C)	43	43	40	38	38	36	35	35	38	40	45	47	48	50	48	48	49	48	46	46	45	45	44	43
27-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	37	37	35	37	39	43	46	52	44	51	54	44	48	43	49	50	44	43	42	42	42	40
	Storage Tank Temp. (°C)	44	43	41	39	37	37	36	34	37	41	45	47	49	50	48	47	48	47	47	47	46	45	45	44
28-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	38	38	35	38	39	43	46	51	44	52	55	43	49	44	50	51	43	43	42	42	42	41
	Storage Tank Temp. (°C)	43	42	40	38	38	36	35	35	38	40	46	48	49	49	49	48	49	47	46	46	45	45	44	43
29-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	41	39	37	37	36	37	39	42	47	52	43	51	55	44	49	43	49	50	44	43	41	41	41	41
	Storage Tank Temp. (°C)	44	43	40	38	38	37	35	34	37	41	45	47	48	50	48	48	49	48	47	47	45	45	45	44
30-Jun	Solar Radiation (Wh/m2-day)	0	0	0	0	0	19	93	200	321	416	494	532	543	500	451	329	215	93	17	0	0	0	0	0
	Hot Water Tank Temp. (°C)	40	40	38	38	35	38	40	43	46	51	44	51	54	43	48	43	49	50	44	43	42	42	42	40
	Storage Tank Temp. (°C)	44	42	41	39	37	36	36	35	38	40	46	48	49	49	48	47	48	47	46		46	45	44	44

Appendix C

C.1 Main Features of AVR ATmega32 Microcontroller



The main features of ATmega32 are:-

- 32K bytes of In-System Programmable Flash Program memory with Read-While-Write capabilities
- 1024 bytes EEPROM
- 2K byte SRAM
- 32 general purpose I/O lines
- 32 general purpose working registers
- a JTAG interface for Boundaryscan
- On-chip Debugging support and programming
- 3 flexible Timer/Counters with compare modes
- Internal and External Interrupts
- a serial programmable USART
- a byte oriented Two-wire Serial Interface
- an 8-channel, 10-bit ADC
- a programmable Watchdog Timer with Internal Oscillator
- an SPI serial port
- 6 software selectable power saving modes