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Mechatronics Engineering

Graduation Project

Study of Increasing Solar Domestic Hot Water System Efficiency

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Abstract

Solar domestic hot water systems are gaining acceptance worldwide including in Palestine. The system constitutes simple design and can be easily manufacturing.

In this project many tests were done to find the performance of the solar domestic hot water system and increase its efficiency by increasing the thermal performance of the flat-plate solar collector, and by dividing the commercial storage tank into multi storage tanks.

However, this project developed a new model system that is more efficient than the commercial one, because the period that needed to heat the 50 liter storage tank is less than the 200 liter, especially in the morning period. On other hand, the management and the control panel added some efficiency to the system by storing the hot water inside the tank and using it when the sun radiation is decreased.

Table of Contents

CHAPTER TWO

Solar Energy

CHAPTER THREE

Solar Domestic Hot Water System

CHAPTER FOUR

Experimental System Setup

CHAPTER FIVE

Experimental Result

CHAPTER SIX

Conclusion and Recommendation

REFERENCES

APPENDIX

List of Tables

List of Figures

List of Charts

NOMENCLATURES

Q_{in}	Amount of solar radiation received by the collector, in (W)
G_T	Is the intensity of solar radiation, (W/m^2).
A_c	Collector surface area of in (m^2).
Q_o	Rate of heat loss, (W).
U_L	Overall heat transfer coefficient, in (W/K).
T_c	The mean collector temperature, °C.
T_a	The ambient temperature, °C.
Q_u	Is the rate of useful energy extracted by the collector,(W)
$(mc)_c$	Thermal capacity of collector, (kJ/K.m^2)
η_c	The efficiency of collector.
$(\dot{m}c_p)_f$	The mass flow rate and heat capacity for the fluid,(kJ/K).
T_f	The fluid temperature °C.
T_t	Storage tank temperature °C.
$(mc)_t$	Thermal capacity for storage tank
η_t	Efficiency of storage tank
Q_t	Energy losses from the storage tank
t:	Time
T_{si}	Initial water temperature inside the storage tank, °C

T_{sf}	Final water temperature inside the storage tank after 48 hours °C
UA_s:	The product of the surface area and heat loss coefficient of the storage tank, W/K
M_s	Mass of water inside the storage tank (according to the tank)
C_p	Specific heat of water at constant pressure, (4.18 kJ/kg°C)
τ_{st}:	Time constant for storage tank

Chapter One

Project overview

Contents:

Chapter One

Project overview

1.1 Introduction

The sun is the source of the vast majority of the energy used on earth. Most of the energy used has undergone various transformations before it is finally utilized, but it is also possible to tap this source of solar energy as it arrives on the earth's surface, and it is the world's largest energy resource. Solar energy is a form of renewable energy, which is abundant in our environment more importantly.

The use of solar energy can reduce the use of fossil fuels as well as reducing harmful environmental emission resulting from the burning of fossil fuels.

The Solar Energy use is not something new; it has been used for several centuries ago for different functions. But it was replaced for crude oil in the Industrial Revolution.

Currently, due to high crude oil costs and its great negative environmental impact, it has been decided to return to the use of solar energy. If crude oil had not replaced the solar energy, surely that nowadays, the researchers would have more technology in renewable energy.

Solar energy can be utilized in many ways; the most common method is to convert sunlight into heat energy to produce hot water. This technology has been in use for long period of time and sufficient products are available commercially.

Experience in the recent years proved that most of the people consider solar energy as a profitable investment. Solar heating technology is the oldest and most developed branch of all renewable energy systems. Nowadays, solar collectors are very good in quality and efficiency. Some implementations operate with more than 80% efficiency. The developments of these solar devices are continuous and progressive. In order to improve the efficiency, powerful simulations of solar system operation are required. Computer aided software are available to help in designing these systems. The possibilities to predict the operation of the system in different circumstances facilitates reducing the cost and to enhance the productivity are real. A solar heating system can be divided into some basic subsystems like the solar collector, the water storage tank, the heat-exchanger, the solar pump and the control system. Research and development of ways to increase useful heat from these systems is being considered by many active research groups and companies, which also the main objective of this project.

1.2 Project's idea

The main idea of this project is how to increase the efficiency for the hot water solar collector system. The idea will be realized by considering two variables, the first is static which is the storage capacity, and the second is a dynamic one, which is managing the water that goes to the user by conveys the sun's energy. The indicator of efficiency will be based on compare the outlet temperature of the collector by using sensor with the optimal temperature that the researchers will get from calculations and design.

1.3 Project's objectives

This project aims to improve the benefits of the renewable energy to produce hot water by increasing the efficiency of the hot water solar collector.

The importance of this project can be summarized in the following points:

1. Developing a dynamic mathematical model for an active flat-plate solar collector with single glass cover working in parallel channel arrangement under transient conditions.
2. Propose a solution method to the derived model has the capability to compute the transient temperature distributions.
3. Building an experimental prototype for the purpose of producing hot water by solar collector.
4. Study the increasing of heat transfer between the flow water and the collector's tube.
5. Increasing the use of thermal solar energy as renewable energy and friendly for the environment.

1.4 Recognition of the need

Because of the most default hot water flat plate solar collector can only reach 45% of efficiency [4], so this project will develop the system to increase the efficiency of the hot water solar collector.

1.5 Literature review

Hot water solar collector and all related issues are well studied internationally. Some literature review like [1], [2], and [3] provide some studies about the hot water solar collector like optimal control of flow in solar collectors for maximum exergy extraction, robust control of solar plants with distributed collectors, and modeling and simulation of a solar absorption cooling system.

1. Optimal control of flow in solar collectors for maximum exergy extraction[1]

This article talks about which the control of temperature and flow rates in solar thermal engineering, is an important factor for performance increasing. The authors stated that, in many instances, energy-based performance measures can be misleading, and that exergy-based performance measures provide a more realistic evaluation of thermodynamic systems. Exergy analysis is a useful mean for understanding how we use energy to perform a specific task. For instance, analysis of exergy flows in solar-driven systems can lead to identification of inefficient parts and optimum operating conditions.

The article refers to optimal operation strategies for exergy gain maximization in open loop thermal solar energy collection systems. The water mass-flow rate in the collectors is the control parameter. The main contributions consist in improving the energy conversion model and the solar collector model. Also, an optimal control approach was adopted here instead of the variational approach used in previous work. Indirect optimal control methods are rather difficult to implement because explicit adjoined equations cannot be easily built for the realistic flat-plate solar collector model adopted in this project.

2. **Robust control of solar plants with distributed collectors [2]**

The design of a robust control scheme has been presented in this paper to control the outlet temperature of a solar collector field despite system uncertainties and disturbances. First, a nonlinear series feed-forward was used to compensate for the disturbances effect, and then a set of uncertain linear systems was obtained capturing the system dynamics in the form of an uncertain second-order system plus dead time. Afterwards, the Quantitative Feedback Theory (QFT) technique was used to design a robust control structure fulfilling different robust time-domain and system stability specifications, and resulting in a robust two degree of freedom (2DoF) scheme with a reference prefilter and a proportional-integral-derivative (PID) with fixed parameters.

A modified antireset-windup scheme plus a reference governor was used to face input saturation problem. The proposed control structure was tested through several real experiments showing promising results. The results obtained presented in this article will be useful to our project, but linearized system will be used.

3. **Modeling and simulation of a solar absorption cooling system for India [3]**

This article talks about that the hot water inlet temperature is found to affect the surface area of some of the system components. Increasing this temperature decreases the absorber and solution heat exchanger surface area, while the dimensions of the other components remain unchanged.

Although high reference temperature increases the system coefficient of performance and decreases the surface area of system components, lower reference temperature gives better results for the fraction of the total load met by non-purchased energy than high reference temperatures do. For this study, a 353 K reference temperature is the best choice. The obtained technical data will be used as indicator for project's results.

1.6 Project budget

The apparatus requirements are fluids (water), solar flat plate collector, storage tanks, sensors, valves, piping, and fittings.

The budget of the project also includes printing cost, local study, and survey. The following table shows the estimated cost of each one.

Table 1.1: Project budget

Description	DSR Grant (NIS)
Solar flat plate collector	400
Two storage tank	600
Four solenoid valves	800
Piping and fitting	550
Electronic elements	650
Total cost	**3000**

1.7 Project schedule

The time plan views the stages of establishing the project with its components, divided into two semesters as shown in the following tables.

Table 1.2: Timing schedule of the First Semester

Process	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Collecting data and literature	■	■	■	■											
Analyzing of data				■	■	■									
Developing the model						■	■	■	■						
Process calculation and simulation									■	■	■	■			
Writing the documentation									■	■	■	■	■	■	
Develop scheme for the proposed system												■	■	■	■

Table 1.3: Timing schedule of the Second Semester

Process	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Full Designing															
Purchasing the Components															
System Implementation															
Solar heat thermal testing analysis															
Documentation															

1.8 Project layout

This chapter presented the general idea of the project and its importance in the field of application and specialization, in addition conduct the literature review of the previous studies about this project, this chapter also includes the time plan for all over the project, and the tools, equipment, and materials that are used in the project, and finally the total cost.

Chapter two presents an introduction about solar energy, the definition of solar energy with the advantages of it, the renewable and nonrenewable energy, radiation intensity, and the solar time.

Chapter three discusses the domestic hot water principles, the main system components, and the design for the solar flat plate, solar storage tank, and the control panel.

Chapter four shows the experimental setup for the project and the design for each component as build in the prototype, also derivate the analytical study for the system.

Chapter five discusses the experimental results and the tests that done on the system's components, and analysis the data for the efficiency.

Finally, chapter six presents the conclusion and recommendation for the project.

Chapter Two

Solar Energy

Contents:

Chapter Two

Solar Energy

2.1 Introduction

The sun produces an enormous amount of light. It generates 3.38×10^{26} watts of power in the form of light. In comparison, an incandescent lamp emits 60 to 100 watts of power. The temperature of the outer, visible part of the sun is 5500°C (9900°F). Light from the sun takes about eight minutes to reach earth. This light is still strong and useful enough when it reaches the earth.

The earth is about 150 million km from the sun and has a radius of about 6360 km. The total surface area of the earth is about 510 million km^2, of which only about 21% is land. The earth rotates around the sun in an elliptical orbit at a mean rate of about 30 km/s and at the same time revolves at a rate of 0.5 km/s. The earth's axis of rotation is tilted at 23.45° with respect to its orbit about the sun. This orientation is maintained by the earth in its orbital movement. This tilted position together with its daily rotation and yearly revolution accounts for the distribution of solar radiation over the earths and the change in day length[14].

2.2 Renewable and nonrenewable energy

Natural resources are grouped into two categories, renewable and nonrenewable. A renewable resource is the energy that does not change or vanishes with the time and still for ever so we can use it all the time.

The non-renewable energy can be change or vanish with the time so we cannot depend on it all the time so we must find other resources. According to the law of Conservation of Energy:

- Energy can only change from one form to another.
- Energy cannot be created or destroyed, and it can be found in various forms such as: solar radiation, wind energy, tide power, biomass, etc.

2.2.1 Renewable Energy

Renewable energy today provides about 9% of the world energy. However in many parts of the world these percentages are increasing significantly. Wind energy is the fastest growing energy resource in the world today. Some recent studies suggest that renewable could rise to a 30–40% share by 2050, assuming global policy efforts are made to address environmental issues, especially climate change.

Renewable energy resource can be categorized into the forms of radiant solar, wind, hydropower, and biomass and geothermal. Each of these forms has many uses. Renewable energy resources offer many advantages to the energy market. They can be used in many ways, offer minimal environmental problem, and can be harnessed with appropriate technology. They particularly offer hope to the developing countries whose economic growth rates are seriously hampered by high energy costs.

Every day, the earth receives many times more energy from the sun than that is consumed from all other resources. The primary reason for low use of solar energy is economics, especially when the cost of renewable energy generation is viewed in comparison with lower priced commercial fuels.

Renewable energy sources will be available long after our fossil fuels run out. They are economically and politically less risky than many conventional supplies, whose costs are much less predictable.

2.2.2 Non-renewable Energy

Non-renewable energy source come out of the ground as liquid, gases and solids. Right now crude oil is the naturally liquid commercial fossil fuel. Natural gas and propane are normally gases, and coal is a solid. Coal, petroleum, natural gas, and propane are all considered fossil fuels because they formed the buried remains of plants and animals that lived millions of years ago. Uranium are, a solid, is mined and converted to a fuel and is not a fossil fuel.

These energy sources are considered nonrenewable because they cannot be replenished in a short period of time. Renewable energy source can be replenished naturally in a short period of time.

2.3 Solar energy

The sun is a big ball of heat and light resulting from nuclear fusion at its core. Sunlight is the major type of solar energy that reaches the earth as heat and light. Solar energy is often called "alternative energy" to fossil fuel energy sources such as oil and coal.

Example of our use of solar heat energy is for water heating system as shown in the figure (2.1). A solar panel is used to collect heat. The heat is transferred to pipes inside the solar panel and water is heated as it passes through the pipes. The hot water, heated by the sun, can then be used for showers, cleaning, or heating your home.

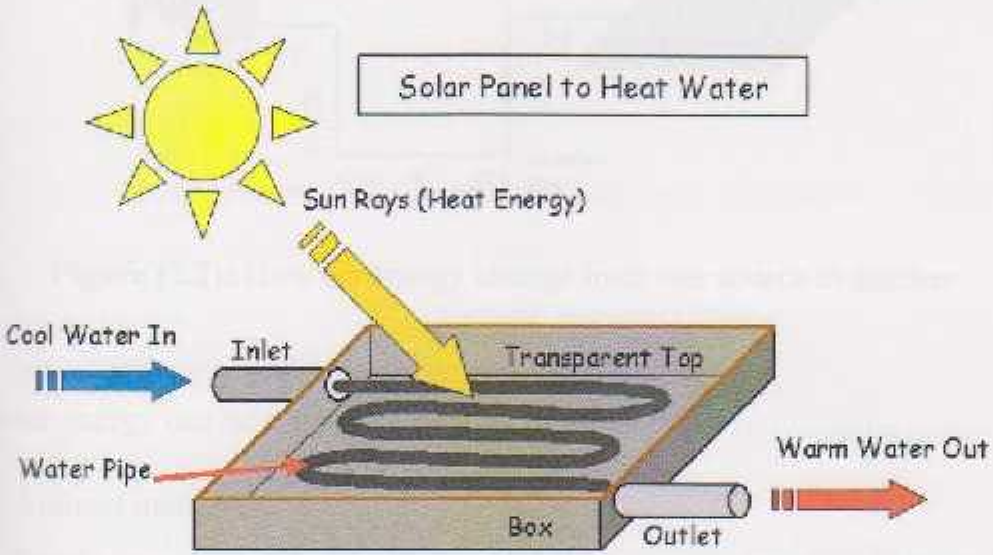


Figure (2.1): The principle operation of the sun collector

The researchers also use solar thermal energy through passive solar designs. Windows or skylights in your home can be designed to face the sun so that they heat into the house keeping you warmer in the winter.

The light energy from the sun can be transformed into electrical energy and used immediately or stored in batteries. Photovoltaic (PV) panels are the devices that convert light energy into electrical energy.

Solar Cell Circuit

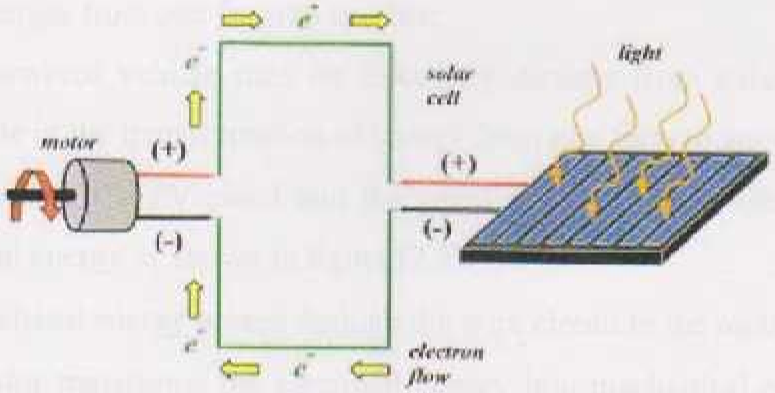


Figure (2.2): How the energy change from one source to another

The solar energy can be controlled by a lot of method:

1. The indirect method:

People can make indirect use of solar energy that has been naturally collected. The sun's energy, acting on the oceans and atmosphere, produces winds that for centuries have turned windmills and driven sailing ships. Modern windmills are strong, light, weather-resistance, aerodynamically designed machines that produce electricity when attached to generators.

2. The direct method:

People have devised two main types of artificial collectors to directly capture and utilize solar energy: flat plate collectors and concentration collectors. Both require large surface areas exposed to the sun since so little of the sun's energy reaches earth's surface. Even in areas that receive a lot of sunshine, a collector surface as big as a two-car garage floor is needed to gather the energy that one person typically uses during a single day.

3. Energy changes from one form to another:

Solar powered vehicle runs on electricity directly from solar energy as a simple example in the transformation of energy from one form to another.

- Sunlight hits the PV panel and the panel transforms the light energy into electrical energy as shown in figure (2.2).
- The electrical energy passes through the wire circuit to the motor.
- The motor transforms the electrical energy into mechanical energy to turn the drive shaft which turns the wheels.
- The wheels rotate on the ground to move the vehicle transforming mechanical energy into vehicle motion.

Solar vehicle ideal energy chain:

Light Energy >> Electrical Energy >> Mechanical Energy >> Kinetic Energy

Energy transformation is not perfect, the above case is ideal because not all systems are perfect and in reality there will be losses of energy from our system.

In a simplified view of this case some losses will be from:

- Friction of electrons passing through the wires; this is released as heat energy.
- Friction of the drive shaft or wheels in the ground; this is released as either heat or sound energy.

Even with these losses the law of conservation of energy still holds. The amount of energy into a system will always equal the amount of energy out of a system.

2.4 Solar time

Solar time is the time interval between two successive passages of the sun across the meridian of the observer.

Solar time will be different from watch time due to two main reasons:

1. The watch time is dependent on the standard meridian of the country or region and since there could there be difference between the local longitude (L_{lo}) and the standard meridian (L_{st}) and this is taken care of by the following expression:

$$\Delta = 4(L_{st} - L_{lo})$$ [5] ..... (2.1)

2. The rotational and angular velocities of the earth are not always constant. This correction is known as the equation of time (ET), this describes the position of the sun during each day of the year, and only the day of the year is needed as the input.

The values of the equation of time as a function of the day of the year (N) can be obtained approximately from the following equations:

$$ET = 9.87\sin(2\beta) - 7.53\cos(\beta) - 1.5\sin(\beta)$$ [5] ..... (2.2)

where β is:

$$\beta = (N - 81)360/364 \quad \text{..... (2.3)}$$

The solar time is the time specified in all sun-angle relationships and all calculations in solar energy are based on solar time only and to an observer at any location on the surface of the earth, the movement of the sun is symmetrical about solar noon.

Hour angle is the angular displacement of the sun east or west of the local meridian due to the rotation of earth on its axis at 15° per hour. At solar noon (the time when the sun is directly overhead) the hour angle is zero. In the morning it is negative, while in the afternoon, it's positive. The variation of the hour angle over a day at 15° per hour, the hour angle can, therefore, be calculated from the following equation:

$$\Omega = 15(t - 12) \text{ degree} \quad \text{..... (2.4)}$$

where, t is solar time in hours

Hour angle tells us how close we are to solar noon indicating the radiation, as the solar intensity is maximum at noon and hour angle is always with reference to a particular location or site. It does not depend on any other parameters (geographical or otherwise) such as GMT, latitude, etc.

2.5 Derived angles of the sun

Derived angles are used to define the sun's position in relation to the surface of the earth.

1. The Declination Angle(δ) :

The plane that includes the earth's equator is called the equatorial plane. If a line is drawn between the center of the earth and the sun, the angle between this line and the earth's equatorial plane is called the declination angle (δ), as depicted in figure (2.3). At the time of year when the northern part of the earth's rotational axis is inclined toward the sun, the earth's equatorial plane is inclined 23.45 degrees to the earth-sun line. At this time (about June 21), we observe that the noontime sun is at its highest point in the sky and the declination angle $\delta = +23.45$ degrees. We call this condition the summer solstice, and it marks the beginning of summer in the Northern Hemisphere.

As the earth continues its yearly orbit about the sun, a point is reached about 3 months later where a line from the earth to the sun lies on the equatorial plane. At this point an observer on the equator would observe that the sun was directly overhead at noontime. This condition is called an equinox since anywhere on the earth, the time during which the sun is visible (daytime) is exactly 12 hours and the time when it is not visible (nighttime) is 12 hours. There are two such conditions during a year; the autumnal equinox on about September 23, marking the start of the fall; and the vernal equinox on about March 22, marking the beginning of spring. At the equinoxes, the declination angle (δ) is zero

The variation of the solar declination throughout the year is shown in figure (2.3). The declination (δ) in degrees for any day of the year (N) can be calculated approximately by the equation

$$\delta = 23.45 sin\left\{\frac{360(284+N)}{365}\right\} degrees \qquad \text{..... (2.5)}$$

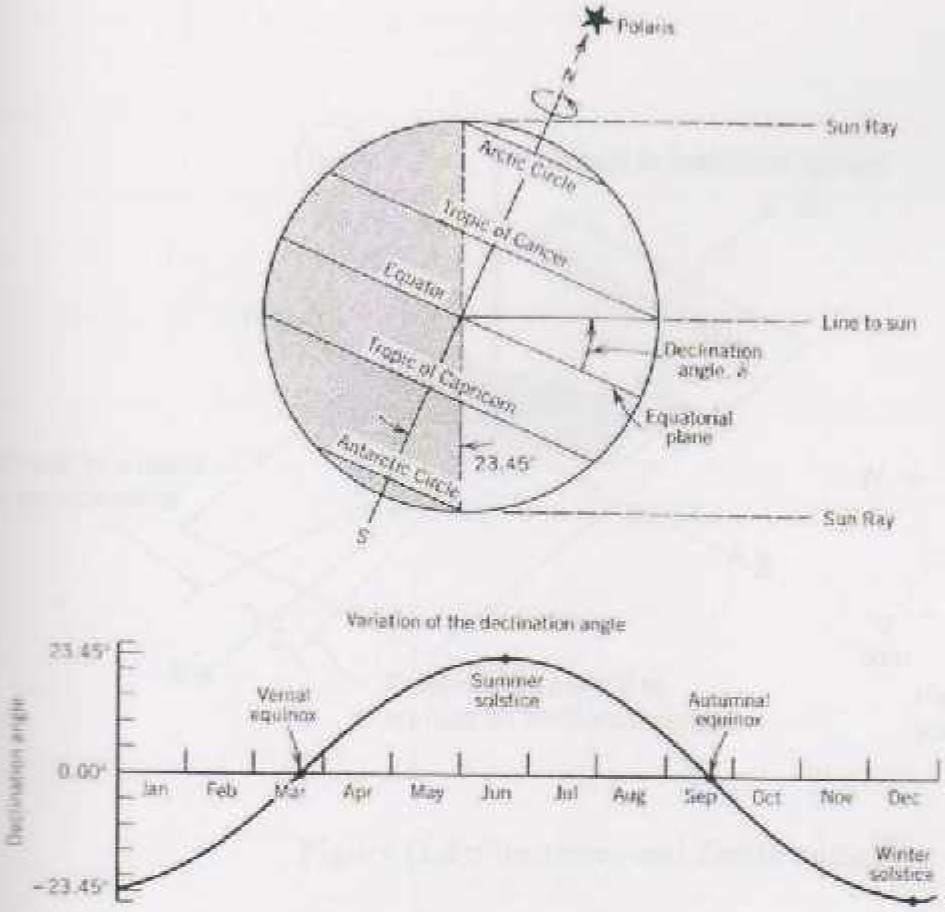


Figure (2.3): The declination angle (δ). The earth is shown in the summer solstice position when (δ) = +23.45 degrees. Note the definition of the tropics as the intersection of the earth-sun line with the surface of the earth at the solstices and the definition of the Arctic and Antarctic circles by extreme parallel sun rays[11].

2. Angle of Incidence (θ)

The solar incidence angle (θ) is the angle between the sun's rays and the normal on a surface. For a horizontal plane, the incidence angle (θ) and the zenith angle (θ) are the same. The angles shown in figure (2.4)

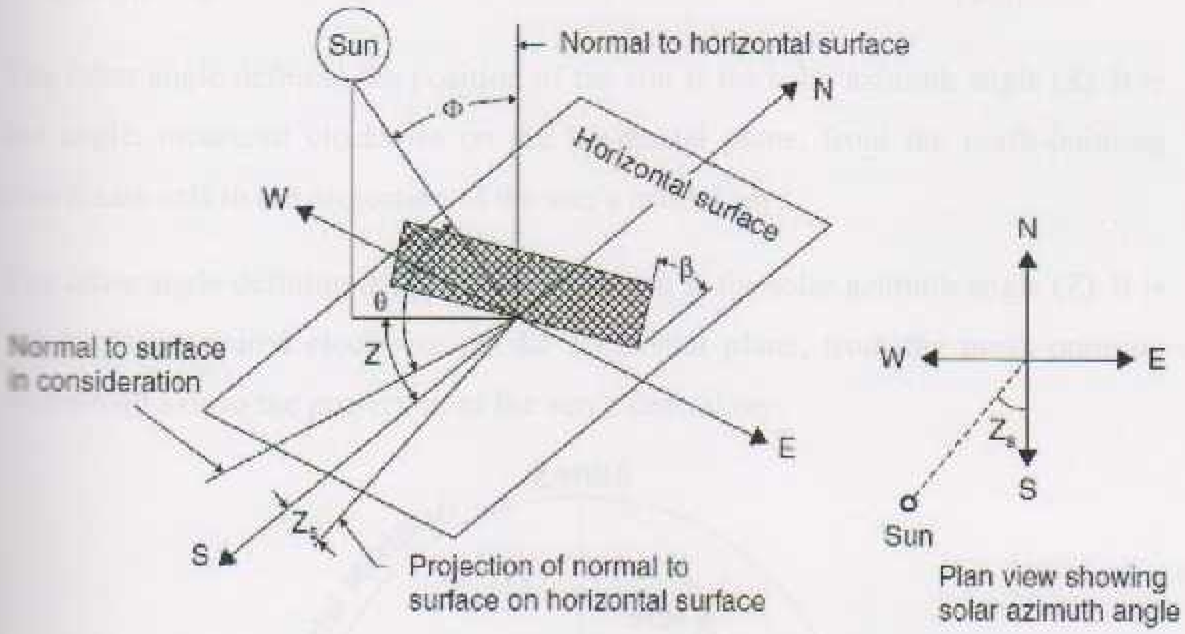


Figure (2.4): Incidence and Zenith angle[12]

Where

β =Surface tilt angle from the horizontal

Z_s = Surface azimuth angle, the angle between the normal to the surface from true south, westward is designated as positive.

3. Altitude angle (α)

The solar altitude angle (α) is defined as the angle between the central ray from the sun, and a horizontal plane containing the observer, as shown in figure (2.5). As an alternative, the sun's altitude may be described in terms of the solar zenith angle (ϕ) which is simply the complement of the solar altitude angle or

$$\alpha = 90 - \phi \qquad \text{..... (2.6)}$$

The other angle defining the position of the sun is the solar azimuth angle (Z). It is the angle, measured clockwise on the horizontal plane, from the north-pointing coordinate axis to the projection of the sun's central ray.

The other angle defining the position of the sun is the solar azimuth angle (Z). It is the angle, measured clockwise on the horizontal plane, from the north-pointing coordinate axis to the projection of the sun's central ray.

Figure (2.5): Earth surface coordinate system showing the solar azimuth angle (Z), the solar altitude angle (α) and the solar zenith angle (ϕ) [13].

4. Azimuth angle (Z)

Azimuth angle (Z) is the angle on the horizontal plane measured from south to the horizontal projection of the sun's rays and is shown in Figure (2.6). East of south is taken as negative and west of south as positive.

If a south-facing roof is unavailable, or the total solar array is larger than the area of a south-facing roof section, an east or west-facing surface is the next best option. Be aware that solar power output decreases proportionally with a horizontal angle, or "azimuth", greater than 15° from due south. The decrease in annual power output from latitude-tilted east or west-facing array may be as much as 15% or more in the lower latitudes or as much 25% or more in the higher latitudes of the United States.

A void directing your tilted solar panels northwest, north or northwest, north or northeast, as you'll get little power output.

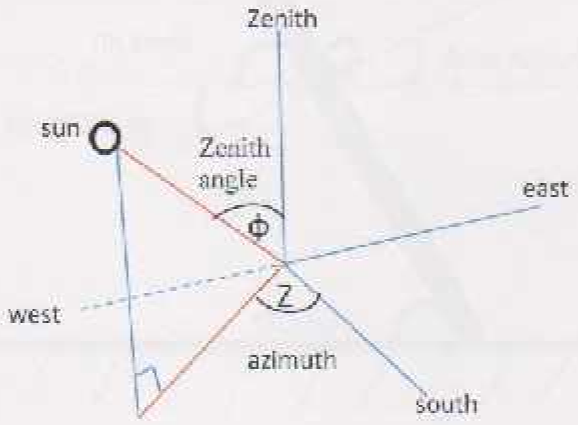


Figure (2.6): Azimuth angle[11]

5. Slope (β) or Tilt angle

Tilt angle is the angle the collector surface makes with the horizontal plane and is shown in figure (2.7).

To capture the maximum amount of solar radiation over a year, the solar array should be tilted at an angle approximately equal to a site's latitude, and facing within 15° of due south. To optimize winter performance, the solar array can be tilted 15° more than the latitude angle, and to optimize summer performance, 15° less than the latitude angle. At any given instant, the array will output maximum available power when pointed directly at the sun.

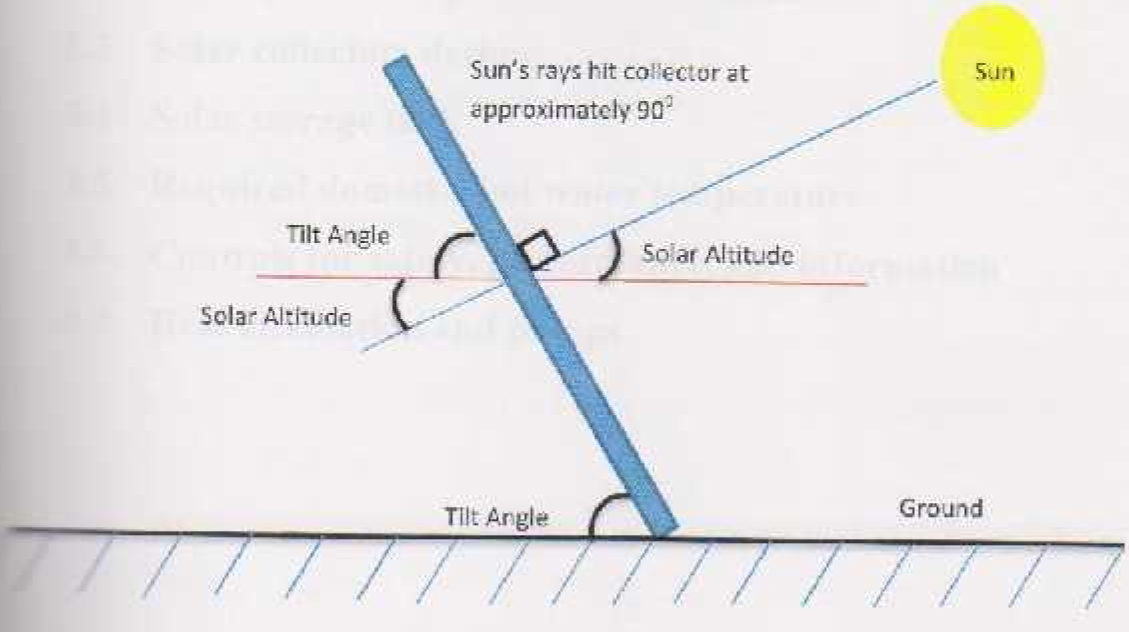


Figure (2.7): Collector tilt angle[13]

Chapter Three

Solar Domestic Hot Water System

Contents:

Chapter Three

Solar Domestic Hot Water System

3.1 Domestic hot water principles

In a solar domestic hot water system there are two circuits:

1. Primary circuit that collects the solar energy and transfers it to a water tank in which it is stored;
2. Secondary circuit that transfers the heat stored in the tank to the domestic hot water supply to be consumed at taps etc.

The primary and secondary circuits sometimes use the same water – simply moving it from the solar collector via pipes and tanks to the taps. This arrangement is called a 'direct' system. However, in most systems the primary and secondary circuits use different and transfer the heat from one liquid to the other via a heat exchanger as shown in figure (3.1.a).

Heat exchangers are normally constructed of a series of metal pipes or plates. This arrangement is called an 'indirect' system. There can be more than one heat exchanger. The water is circulated over and over again in a loop, but the heat moves in one direction only as shown in figure (3.1.b). Heat exchangers can be inside the storage tank, inside the collector or separate. The direction of higher temperature liquid leaving a solar collector is called the flow whereas the direction of lower temperature liquid returning to a heat generator is termed the return.

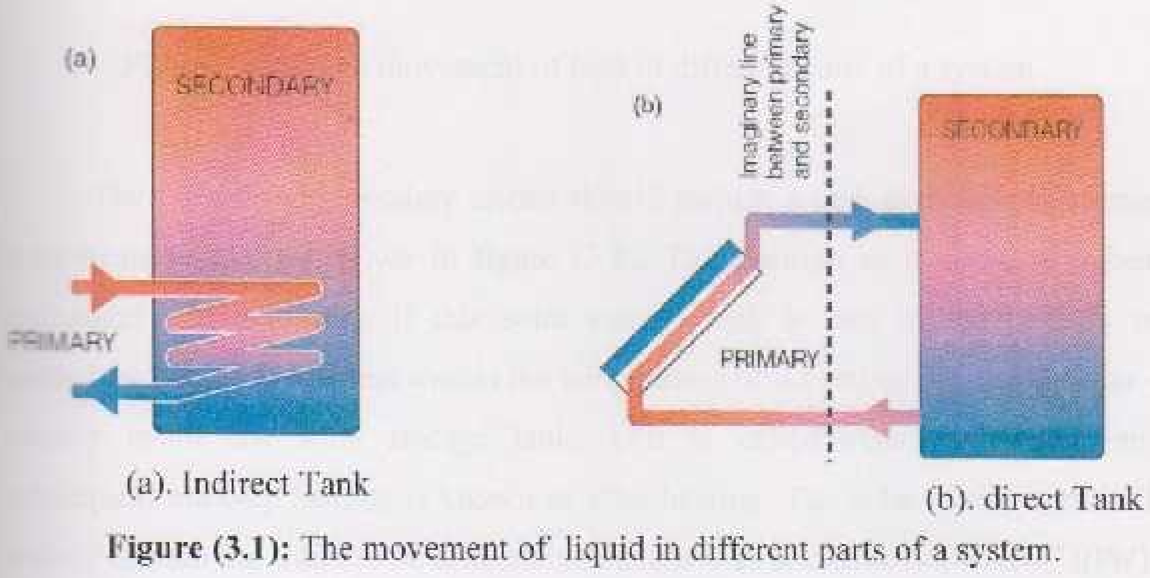
These terms are often confused but the trick is to consider where the source of heat is as this is where the heat starts to flow. In the same way, the hottest pipe leaving a gas or oil boiler is called the flow.

A solar water heating primary circuit consists of:

1. Collector to capture the solar radiation.
2. Heat transfer fluid to move heat to the secondary system.
3. Separate storage tank or a collector-integrated storage tank.
4. Heat exchanger (in some systems).
5. Pipework to circulate the fluid.

A solar water heating secondary circuit consists of:

1. Cold fresh water (drinking quality) source.
2. Pipe or heat exchanger to connect with primary circuit.
3. A back-up heat source (usually).
4. Discharge points (taps, showers etc.).



(a). Indirect Tank

(b). direct Tank

Figure (3.1): The movement of liquid in different parts of a system.

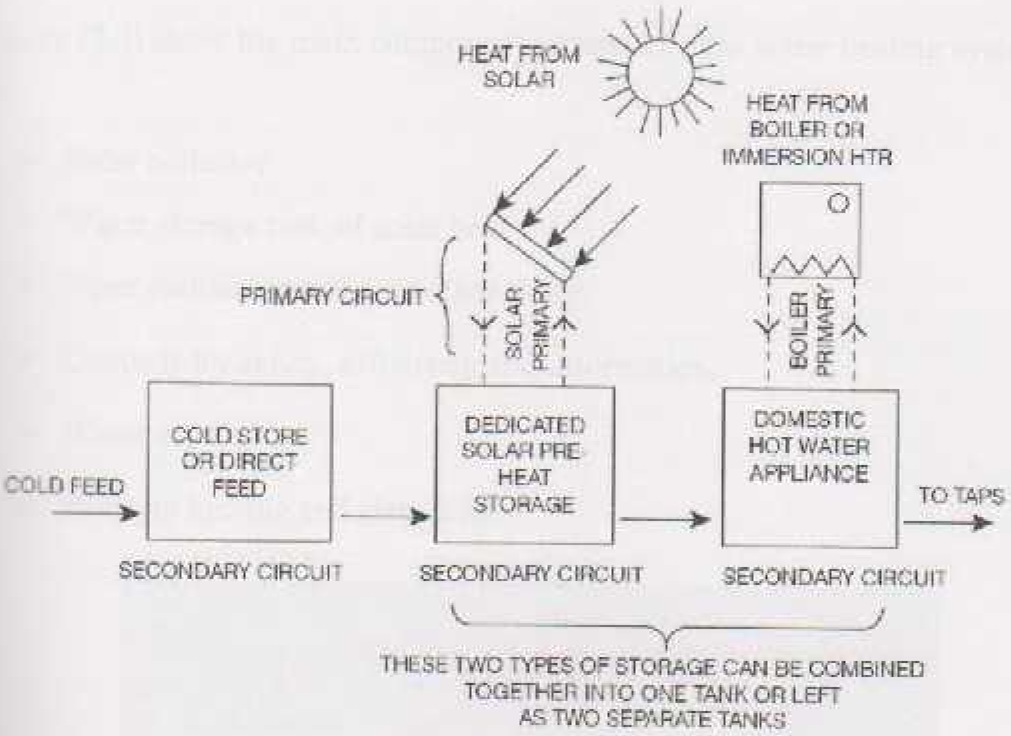


Figure (3.2): The movement of heat in different parts of a system.

The primary or secondary circuit should include a tank dedicated to storing solar-heated water as shown in figure (3.2). The position or absence of a heat exchanger will determine if this solar storage tank is part of the primary or secondary circuit. Solar heat warms the temperature of incoming fresh cold water – usually inside the solar storage tank. This is called solar preheating; any subsequent back-up heating is known as after-heating. The solar storage tank will mainly contain the water to be ultimately consumed as domestic hot water (DHW).

3.2 System components and functions

Figure (3.3) show the main component groups in solar water heating systems such as:

- Solar collector.
- Water storage tank of solar heat.
- Pipes containing water or other fluids.
- Controls for safety, efficiency and information.
- Water supply.
- Back-up heating and electricity.

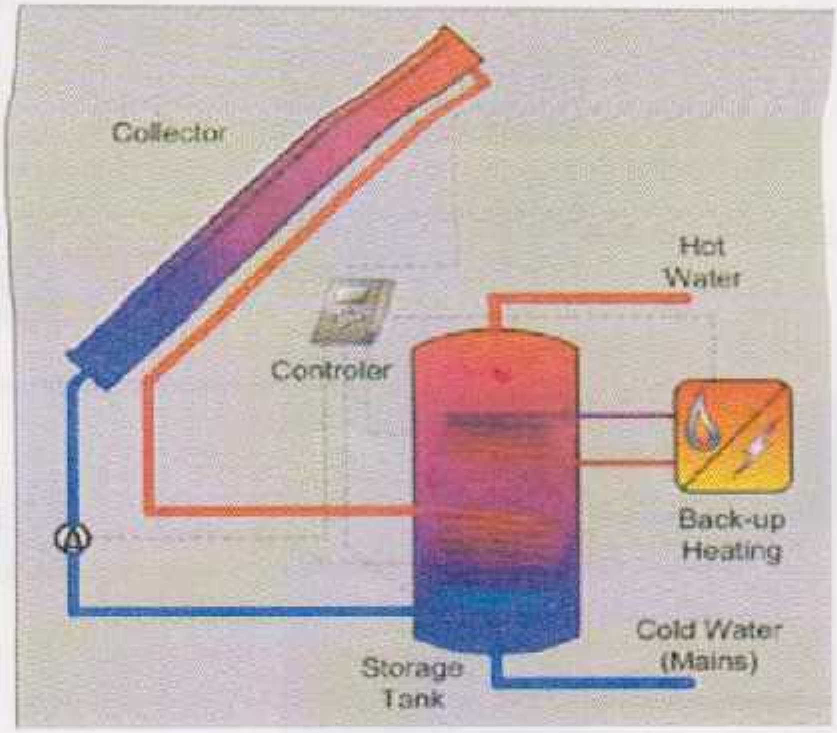


Figure (3.3): A schematic example of a solar (DHW), showing the characteristic component.

Collectors can take various shapes and forms, ranging from simple dark coloured surfaces to glazed panels, tubes or a combination involving mirrors and lenses. They are best fitted where no shading exists, but can work acceptably if shading is minor, intermittent or seasonal. A larger collector array (field) may be made up of smaller individual collectors.

Because the collector gradually heats a store of water the solar heat can be used at times when solar irradiation is low or non-present. Figure (3.4) shows the solar irradiation has been converted into heat, the heated liquid moves into the storage tank and then on to other locations by either water or water containing chemical additives such as antifreeze. All pipes and ducts usually require insulating to help retain heat.

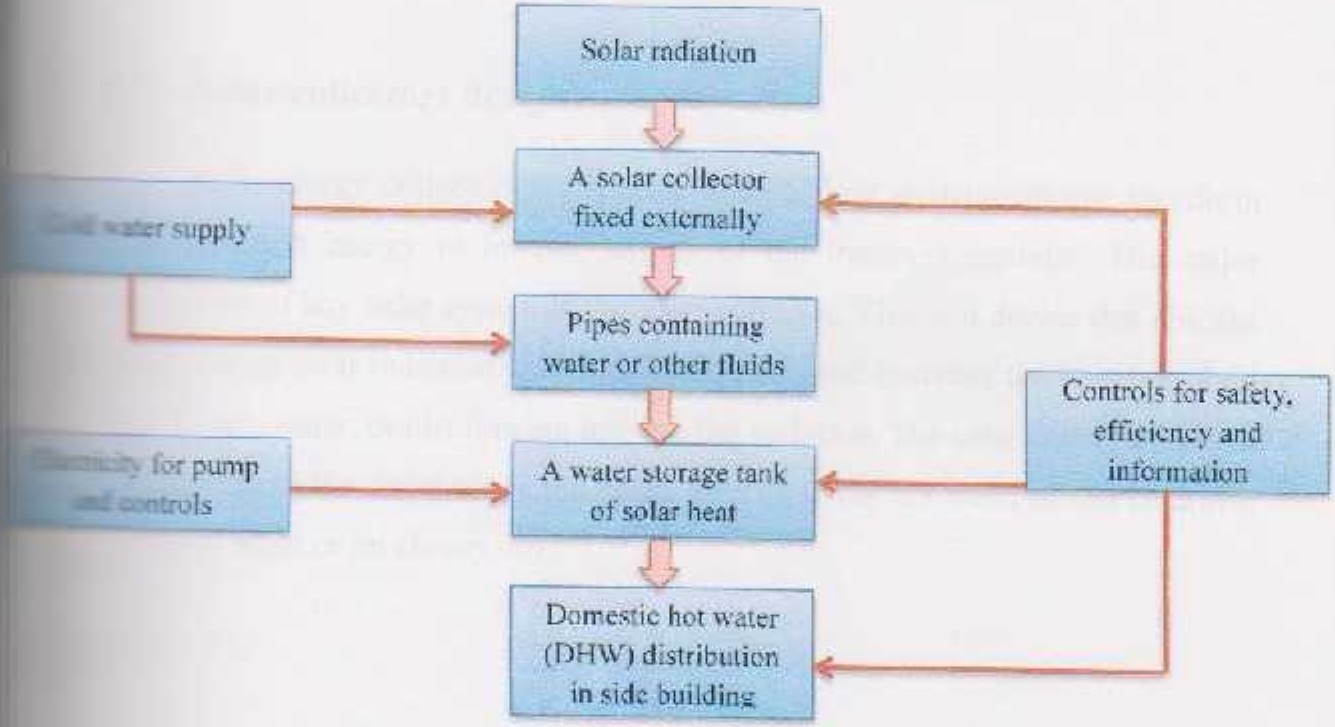


Figure (3.4): A complete solar water heating system is made up of a sequence of functional groups.

The heat generated by the sun's radiation can cause solid and liquid materials to reach high temperatures well over 100°C (212°F). Such temperatures cause expansion and so pressure can build up. A liquid can become a gas (e.g. water to steam), and its volume can increase a thousand-fold. Correctly designed equipment will be designed to withstand this, but safety controls are also needed to ensure the physical limits of materials are not exceeded and that the risk of scalding and explosion is reduced. Controls can be a combination of mechanical (passive) or electrical. They can also improve the solar collector efficiency by altering pumped circulation fluid rates and changing the order of heating extra storage tanks. Controls can also provide an indication of correct functioning and provide extra performance information.

3.3 Solar collectors design

Solar energy collectors are special kinds of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device that absorbs the incoming solar radiation, converts it into heat, and transfers the heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy collected is carried from the circulating fluid either directly to the hot water or can be drawn for use at night or on cloudy days.

3.3.1 General construction

Figure (3.5) shows how heat from the sun is collected by the absorber and is carried away by the fluid flowing through the tubes attached to the absorber. Since these collectors are located outside and normally in a cooler environment, the heated absorber can lose heat to its surroundings. To reduce this heat loss, a cover is placed over the absorber and the sides and back of the absorber are insulated. The cover must allow solar radiation to penetrate and, since glass is typically used, some of this radiation will be reflected and radiated out to the atmosphere. The following sections will provide a brief overview and details of the solar collector parts.

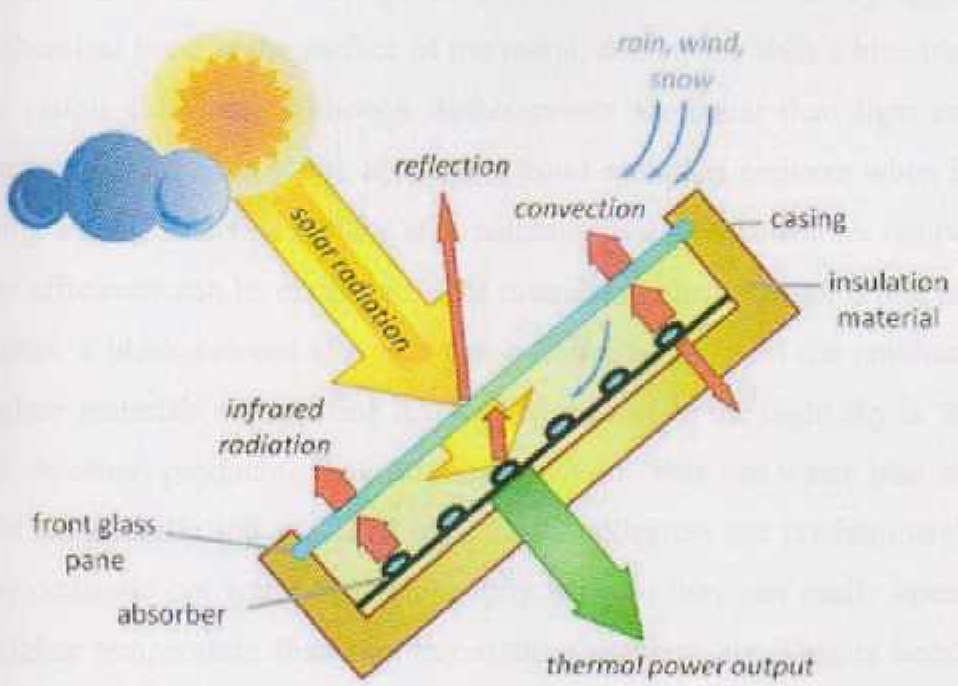


Figure (3.5): A schematic of a flat plate collector (FPC) showing the heat gain and loss mechanisms that play a role in determining the thermal efficiency of a collector

3.3.1.1 Absorber

The part of the collector that receives the solar radiation is called the absorber. This is dark-colored, often black, since lighter colors tend to reflect rather than absorb. Special coatings on the absorber surface assist the collector's efficiency by reducing 're-emittance' – the amount of radiation that is lost from the absorber as it gets hot – just like when you hold your hand over a car on a sunny day, you can feel the heat 'bouncing off' the surface and being lost to the air. These special coatings are called 'selective' coatings. Black paint is a cheap option for creating a darkened absorber surface; however, this can also result in high re-radiated losses and can lose adherence over time and peel away from the absorber if it becomes hot. Selective coatings are preferable. These are factory-applied and form a chemical bond at the surface of the metal, sometimes with a blue/black hue with no visible thickness. Although darker colors are better than light colors at absorbing radiation, dark colors also make good radiation emitters when hot. By combining a dark, selective surface and maintaining a lower absorber temperature, collector efficiency can be optimized. One interesting phenomenon is that on clear, dark nights, a black-colored absorber can become colder than the ambient air or other lighter materials surrounding it. This happens when the night sky is 'blacker' than the absorber, producing a net loss of radiation. This can waste heat should a pump be accidentally left switched on. Glazed collectors are predominately used for solar domestic hot water (DHW) heating because they can easily operate at a much higher temperature than the surrounding ambient air. This is because the front of the absorber is covered with a transparent sheet that reduces air movements and consequent heat loss. This cover, often made of glass or plastic, allows most of the solar radiation to pass straight through but also reduces the amount of re-emittance heat loss from the absorber. In colder climates, the temperature of DHW that is to be heated is significantly higher than the ambient air so only glazed collectors can be used. In some very hot climates, glazing may not be needed. Glass covers have the advantage of durability and ease of recycling, but tend to be heavy and can sometimes crack when impacted. Plastic covers have the advantage of lower weight, but can suffer from thermal and ultraviolet degradation in the long term; the cover becomes discolored and causes reduced solar radiation transmission.

3.3.1.2 Housing

The housing of a collector must provide the necessary mechanical strength to protect the absorber and the insulation to minimize heat loss to the environment. It must withstand wind and snow loads that occur in the area where the collector is installed. It also must be tight enough against rain penetration. These features need to be ensured over the entire lifetime of the system (20 to 25 years). Housings are typically made from aluminum sheet stock or extruded sections, galvanized and painted steel, molded or extruded plastic parts, or composite wood products.

3.3.1.3 Insulation

Insulation is added behind the absorber plate and on the sides of the collector to reduce thermal heat losses. The insulation must use a minimum of binders because it is intended for high temperatures (up to about 400 °F [204 °C] for flat plate collector stagnation); otherwise, the binders will outgas and form a film on the underside of the collector glazing blocking solar radiation. Common insulating materials include, for example, mineral fiber, ceramic fiber, glass fiberglass, and plastic foams. Sometimes polyurethane foam is used, though its resistance to temperature and moisture is limited so it should not be allowed to contact the absorber plate inside the collector. The insulation provides low heat conductivity, some mechanical strength, and temperature and fire resistance.

3.3. 2 Types of solar thermal energy collectors

Figure (3.6) shows the four different types of solar hot water collectors. The type of collector chosen for a certain application depends mainly on the required operating temperature and the given ambient temperature range. Due to the design and simplicity of design each type has a maximum temperature that they are best suited to provide:

- Unglazed EPDM collector - below 90 °F (32 °C) [7]
- Flat plate - below 160 °F (71 °C) [7]
- Evacuated tube - up to 350 °F (177 °C) [7]
- Parabolic trough - up to 570 °F (299 °C). [7]

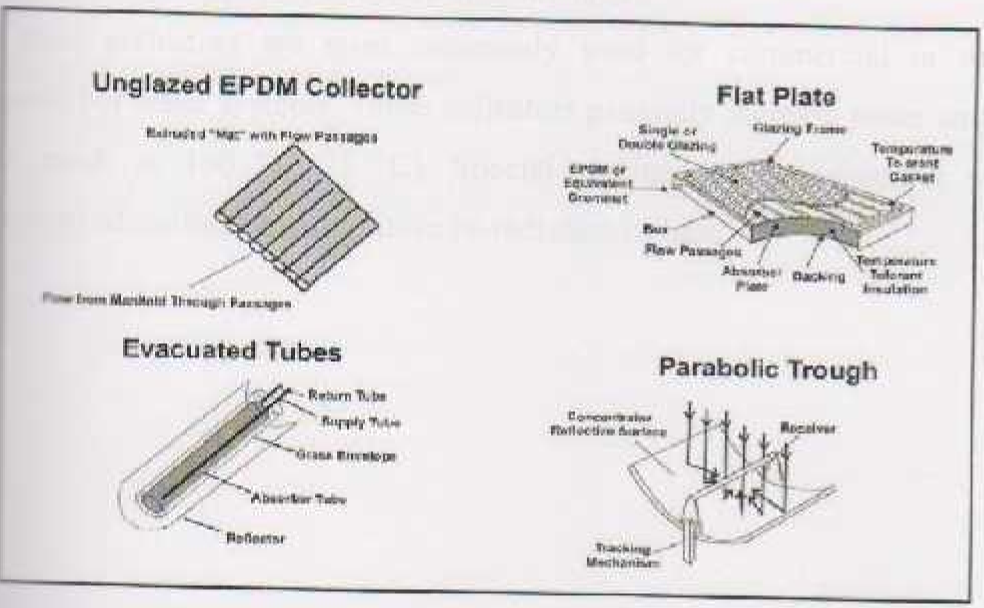


Figure (3.6): Types of solar thermal energy collectors.

3.3.2.1 Glazed flat plate

Flat plate collectors (FPC) are essentially insulated boxes that have a flat dark plate absorber that is covered by a transparent cover figure (3.7). The solar energy heats the absorber and heat is carried away by a heat transfer fluid that flows through riser tubes that are connected to the absorber. The riser tubes are attached to the absorber in a parallel pattern or they meander from one side to the other.

The cover (usually a sheet of glass) is held in place by a frame above the absorber. The frame also seals the collector at the sides and at the back. It must provide mechanical strength and rain tightness, and must be designed to enable simple roof- and facade attachment or even integration into these building elements. The back and sides of the collector are insulated. Flat plate collectors are usually installed in stationary systems, i.e., they do not rotate to follow the path of the sun. The advantages of flat plate collectors are their simple, robust, low-maintenance design, and their large and effective aperture area.

Flat plate collectors are most commonly used for commercial or residential domestic hot water systems. These collectors generally increase water temperature to as much as 160 °F (71 °C). Special coatings on the absorber maximize absorption of sunlight and minimize re-radiation of heat.

Figure (3.7): Flat plate collector with selective coating on the absorber. The parallel lines indicate where the riser tubes are connected to the absorber by ultrasonic welding.

3.3.2.2 Evacuated tube

Evacuated tube collectors figure (3.8) can be designed to increase water/steam temperatures to as high as 350 °F (177 °C)[7]. They may use a variety of configurations, but they generally encase both the absorber surface and the tubes of heat transfer fluid in a vacuum sealed tubular glass for highly efficient insulation. Evacuated tube collectors are the most efficient collector type for cold climates with low level diffuse sunlight. There are three types of evacuated tube collectors: (1) direct flow, (2) heat pipe, and (3) Sydney tube type.

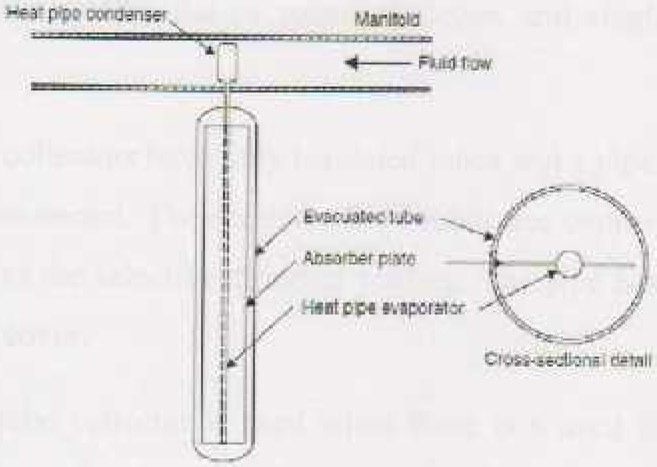


Figure (3.8): Evacuated-tube collector.

The direct flow type has the heat transfer fluid flowing through copper tubes attached to an absorber plate mounted inside the evacuated tube. The heat pipe type uses a heat pipe attached to the absorber plate. The heat pipe transfers the heating energy to the condensing section of the heat pipe where the collector fluid is warmed. This occurs in the header where the evacuated tubes are connected.

The last type has an evacuated tube called a Sydney tube that encapsulates a heat conductor sheet (absorber) with heat transfer fluid carrying tubes. The Sydney tube slides over the absorber section and locks into the collectors header forming a tight seal. Within the Sydney tube the space between inner and outer glass tube is evacuated. The selective coating is sputtered onto the outside of the inner glass tube. A heat conductor/transfer sheet is located inside the inner glass tube that conducts the heat from the glass into the U-form tubes carrying the heat transfer fluid. The Sydney tube type collector's performance can be enhanced through the use of a compound parabolic concentrator located behind each tube. This device will reflect the solar radiation that passes between each evacuated tube back to the underside of the cylindrical absorber in the collector tubes. There are various other construction methods like flat or round absorber, and single- or double-walled glass.

Evacuated tube collectors have only insulated tubes and a pipe header to which the evacuated are connected. The collector fluid tubes use copper and typically black chrome is used as the selective absorber coating. The pipe header is insulated and has a protective cover.

The evacuated tube collector is used when there is a need for hotter water than would be necessary for domestic hot water heating. Hotter water is needed for applications that have cooling in the summer as a requirement and in some cases where building heating is a major need. Solar assisted cooling uses an absorption or adsorption chiller, which requires hot water temperatures in the range of 130 to 350 °F (55 to 180 °C).

An evacuated tube type collector may also be chosen as an alternative for a flat plate collector in areas where winter time freezing occurs. In this case, water would be used as the heat transfer fluid in the collector and warm water would be pumped into the outside piping and collector when freezing of those components is threatened. This would require a small amount of heated water due to the insulating quality of the evacuated tubes. As a result, the cost and inferior heat transfer characteristics of a water glycol mixture are avoided. Also the a hotter water could be produced in the collector providing a lower heat transfer fluid flow thereby reducing distribution pipe and storage tank sizes. Also, the heat exchanger between the collector and the storage tank could be avoided thus reducing the required leaving collector temperature. As a total system, the evacuated tube collector could have a total cost competitive with a flat plate collector system. The use of evacuated tube type collectors obviates most of the stagnation concerns associated with an anti-freeze heat transfer fluid.

3.3. 3 Solar hot water collector efficiency

The efficiency of the solar collector is directly related to heat losses from the surface of the collector. Heat losses are predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Efficiency decreases when either the ambient temperature falls or when the collector temperature increases. This decrease in efficiency can be mitigated by increasing the insulation of the unit by sealing the unit in glass (for flat collectors), or providing a vacuum seal (for evacuated tube collectors). Figure (3.9) shows efficiency curves of these collectors.

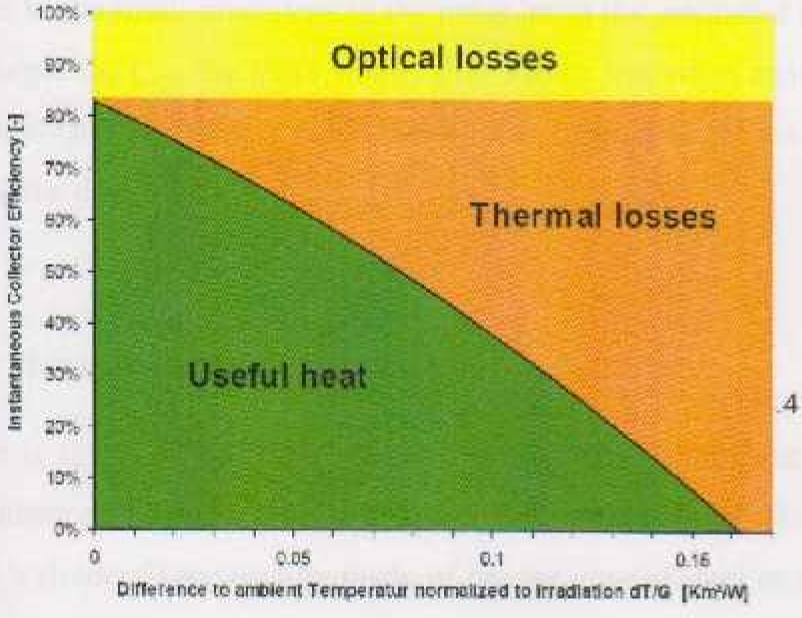


Figure (3.9): Typical solar collector efficiency curve with losses and useful heat indicated.

When comparing collector efficiencies, it is important to assume the same type of area (net vs. gross), and the same irradiation level.

The thermal performance of solar hot water collectors is characterized by:

- The power curve as shown in figure (3.9), parameter: η_0.
- Incidence Angle Modifier (IAM) because of the optical efficiency of the collector.
- Thermal capacity (C_{eff}), which is the measure of thermal response to heating and cooling.
- The quantity of heat input into the collector to heat it by -457.87 °F (1 °K). This information would be available from the collector manufacturer. This value is used in the solar collector simulation computer programs as it relates to the small time steps in the program to the estimated heat removed. The larger the C_{eff}, the more energy that will be lost when switching off and on the solar heat transfer pump, which can happen as the weather changes during the day.

3.4 Solar storage tank

Water is the most common medium used to store solar heat because it is cheap, abundant and has an excellent capacity to contain heat. Hot water tanks (also called 'cylinders') are usually made of copper, coated steel or stainless steel. However, they can also be made from glass-fiber, polymers or even concrete. In most countries the construction of water tanks in buildings is regulated by codes. Normally tanks should be insulated to reduce heat loss, using materials such as mineral wool and expanded foam. Some solar tanks only work with indirect circuits and so contain water that is continually recirculates. These can be made cheaply with mild steel. The warmer the climate the more likely the solar storage tank will be located outside, and in some cases it will be integral with the collector. The solar tank may not be the only hot water tank connected to the water system, since back-up heating equipment can also use tanks. Some tanks will be heated by solar alone, but some will also have other internal heat sources (electrical resistance immersion elements, heat exchanger coils). These dual heated, twin-coil or bivalent tanks have to be designed so that interference from one heat source by the other is avoided. In these tanks the return pipe to the collector is best connected as low as possible in the tank and as close as possible to the fresh cold water feed (if present) in order to reduce the risk of losing heat from other heat sources back out to the solar collector.

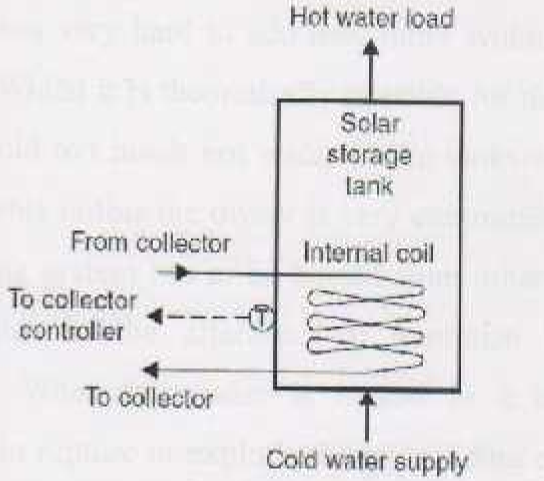


Figure (3.10): Pressurized storage with internal heat exchanger

The most important consideration for solar tanks is the volume of cool water available to be heated by the solar collector at the start of the day. This should be large enough to hold the heat produced on a hot sunny day without the temperature rising above safety limits. As DHW is used up it is replaced by fresh cold water, allowing more heat to be added. This means that the more people who use hot water during the daytime, the smaller the tank volume can be. If people are normally absent during the day, a larger tank is required. A tank that is too small gets hot too quickly and wastes the available solar energy. This makes the solar collector less efficient. Solar tanks are available in volumes of between 50 and 500 liters (13 and 130 gallons). Diameters range from 300 to 600mm (12–24 inches), heights from 900 to 2000mm (35–79 inches), in either vertical or horizontal formats. Several tanks can be linked together to create the necessary total volume.

Attempting to use a tank that can be heated completely from other heat sources runs a high risk of poor solar contribution. This is because if the water is already hot, it becomes very hard to add heat more without causing overheating or high heat losses. Whilst it is theoretically possible for the owner to adjust switches and timers to avoid too much hot water in the tanks at the start of the day, this can prove unreliable unless the owner is very committed. If a tank that is connected to a solar heating system has to be heated from other non-solar sources, then this is best done late in the afternoon to minimize the negative effect on solar contribution. When hot water is heated in a tank its expansion can cause components to rupture or explode. Local building codes often require extra safety components to either absorb the hot water expansion or allow it to discharge to waste. The extra volume of expansion of heated water is not normally allowed to go back into the cold water supply pipe, as this could cause contamination of drinking water. If this pipe is fitted to the tank, contamination is prevented by spring-loaded one-way valves or a separate tank of cold water that is filled by a float valve. A key difference between hot water tanks is whether they are designed to operate using a pipe open to the atmosphere or kept sealed and under a higher pressure. A solar tank will have purpose-made locations for attaching temperature sensors. It is useful to have at least two sensors, one near the top and one near the bottom of the tank. These sensor locations have small 'pockets' or tubes built into the side of the tank. They are left open at one end to insert the sensor. Alternatively, the tank will have open threaded holes that can be fitted with special sensor pockets. If sensor locations are not used, they can be blocked off. Tanks can corrode and eventually the metal will fail and leak depending on the water quality. Special metals, chemicals or coatings are sometimes added to inhibit corrosion. If local water is a problem, local plumbers and plumbing shops can give advice. Alternatively, a water sample can be tested at specialist laboratories and the results discussed with tank manufacturers. Some manufacturers will not guarantee their tanks unless the water quality is within specified limits. If lime scale is a problem, it is very likely to form when heated in a solar tank. The most reliable way to reduce its effect is to be able to inspect and clean inside the tank. An inspection hatch fitted in the lower part of the tank can enable this. These are bolted or screwed onto the tank's side and opened after draining the water out. These hatches can also allow removable internal heat exchangers to be fitted and cleaned. The colder the climate, the more sensible it is to keep the storage tank inside the building. Not only does this reduce the risk of freeze damage but any heat loss will usefully add heat to the building. Internally located tanks are more efficient.

3.5 Required domestic hot water temperature

The proportion of fuel that the solar will replace varies according to the intended DHW temperature, sometimes called the 'target' DHW temperature, and is measured at DHW outlets. The temperature produced may vary between these outlets, so an average is assumed. Most people use DHW between 40°C (104°F) and 60°C (140°F).

The DHW in the distribution pipes, tanks and boilers will be at a higher temperature than the target DHW, which is why cold water is often added to 'mix down' the temperature. Sometimes the target DHW temperature is fixed by the supplier or manufacturer of the taps and the shower mixer valve to reduce the risk of scalding. More often, the temperature is adjusted by the user.

The higher the target DHW temperature the more total energy will be required, and so the smaller the solar fraction and fractional energy saving for a given size of solar collector. In general, both annual fractions will reduce by about 10 per cent when water is at 60°C (140°F) as compared to the lower temperature of 45°C (113°F).

Ideally, the target DHW temperature should always be stated alongside any solar performance figures. When comparing theoretical solar performance between systems then the target DHW temperature should be assumed to be the same, even though in reality this differs depending on personal preference.

Another factor affecting the proportion of solar-replaced fuel is the temperature in the distribution pipes, tanks and boilers. If it is higher this will incur greater losses, which also tends to reduce both fractions by increasing the overall energy requirement.

The temperature of the cold water can vary between winter and summer, as well as between different locations. This has two effects. If the feed temperature is low, for example in winter, the total energy demand for DHW will increase and therefore both fractions will be reduced. However, a colder feed temperature improves solar efficiency as there will be less heat loss from the collector. This results in a complex balance that may actually cancel itself out.

3.6 Controls for safety, performance, and information

Controls enhance a system's operation. They sense deviations in a particular characteristic of the system (for example, an unwanted rise in temperature) and then either set off an alarm or automatically initiate action. Control devices are used to improve safety and performance or to provide information. They may be electrical or mechanical, automatic or require manual operation. They can also anticipate operational problems and provide long-term monitoring of performance. Where a control is a safety feature, it should be readily accessible and verifiable in operation during commissioning and maintenance. All solar water heating systems require temperature-based safety controls to reduce the risk of very hot fluids reaching vulnerable components and water outlets (like showers). Electrically powered differential thermostat controls (DTCs), which use temperature sensors fitted into the collector and solar tank to control the pump, are very common. They monitor and compare the information provided by these two sensors, and then use this information to decide when to turn the pump on or off. The sensors are wired to the DTC with thin cable and work at a low voltage. The DTC uses a small lamp diode to indicate whether the pump is on or off, and can also show an electronic readout of temperatures. If the solar storage becomes too hot, the DTC can also switch the pump off.

3.7 Heat Circulation and Pumps

Solar heat can be moved from collector to tank by an electrical pump, a natural thermo syphon pressure, incoming cold water pressure or self-pumping phase change. Electrically driven pumps are often used to circulate heat transfer fluids (HTFs) in a closed loop circuit. Pumps can also be used in open-ended systems, for example to boost the flow rate and pressure of a shower. Because a circuit or pipe-loop is closed, the HTF always comes back to its starting point so the pump doesn't need continually to work as hard as in open-ended systems. Pumps are not simply left running all the time – this would waste electricity and disperse useful heat already in the storage tank. Pumps have a range of specifications that need to be considered.

Most pumps in solar circuits are 'centrifugal' pumps. They use a rotodynamic centrifugal mechanism such as an 'impeller' shaped like a wheel with angled blades. The term 'centrifugal force' refers to an outward force away from the center of rotation. The centrifugal force in a pump drives the HTF against the sides of the spinning wheel. The HTF is then caught by the angled blades of the impeller, which compresses the HTF and shoots it forward in a jet of liquid inside the outlet port. Centrifugal pumps are especially common in solar circuits due to their ability to spin freely, even if the circuit becomes closed due to a valve or other blockage. Positive displacement pumps, which must use a safety bypass valve to relieve pressure in the event of a circuit blockage, are not common.

highly diffuse light conditions, because a sufficient temperature difference may not occur. Pumps provide more flexibility in the solar layout, higher rates of heat circulation and improved controls such as overheating prevention and frost protection.

Chapter Four

Experimental System Setup

Contents:

Chapter Four

Experimental System Setup

4.1 Layout of the system

Figure (4.1) shows the complete layout of the proposed system. For experiments half the system is used, which has two hot water storage tanks, and one flat-plate solar collector, every tank consist of one sensor to measure the tank's temperature, and two valves, one is connecting the pipes that comes from collector and the other one is connecting the pipes that comes from home. Also, the collector has two sensors one for inlet water temperature and the other one for outlet water temperature. In addition, the system has a control panel to control and manage the solar domestic hot water.

The system's prototype that the experimental executed scaled by 2:1 from the layout, so it consists of two hot water storage tank, and one flat-plate solar collector as shown in figure (4.2).

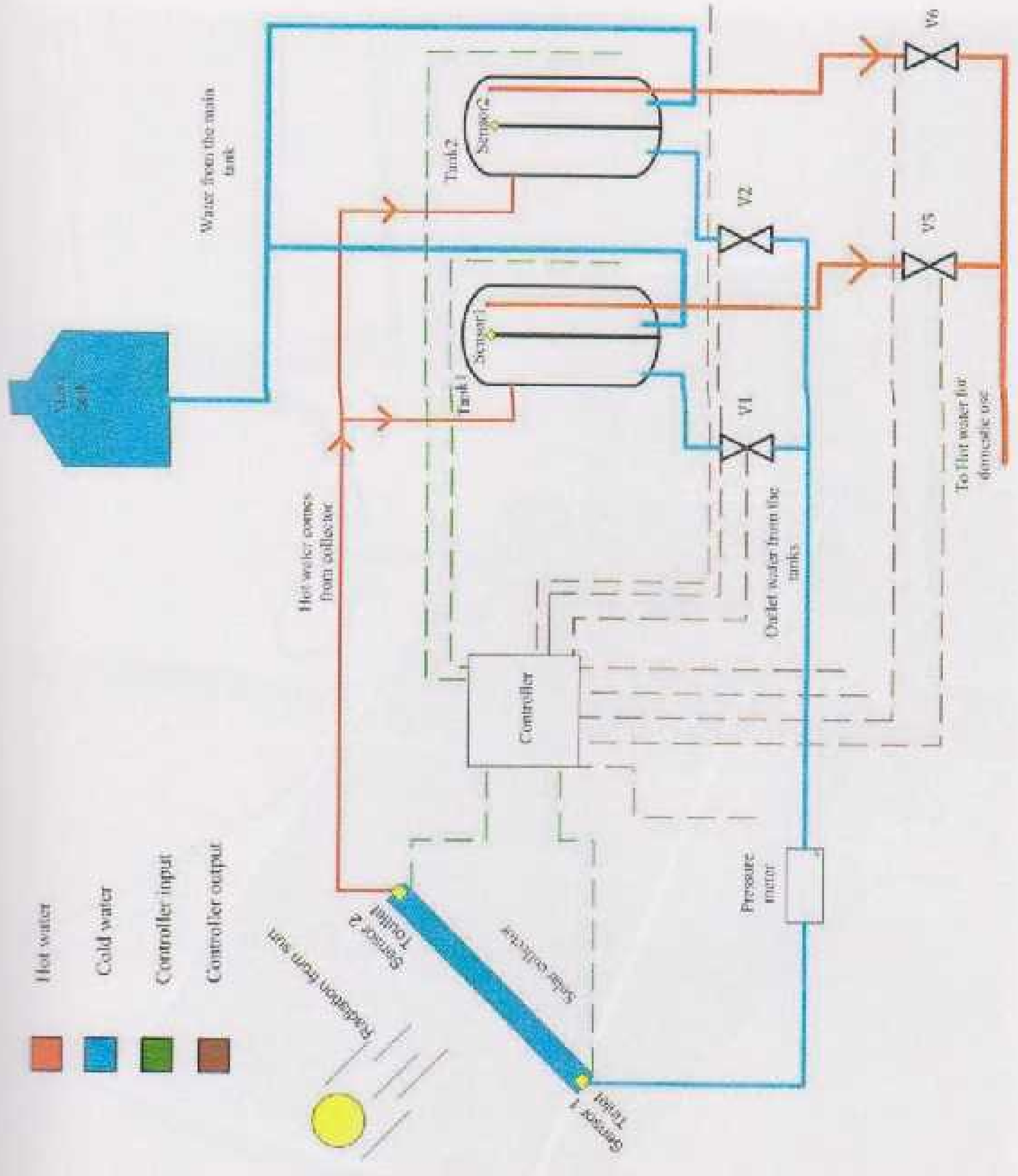


Figure (4.1): Layout of the system

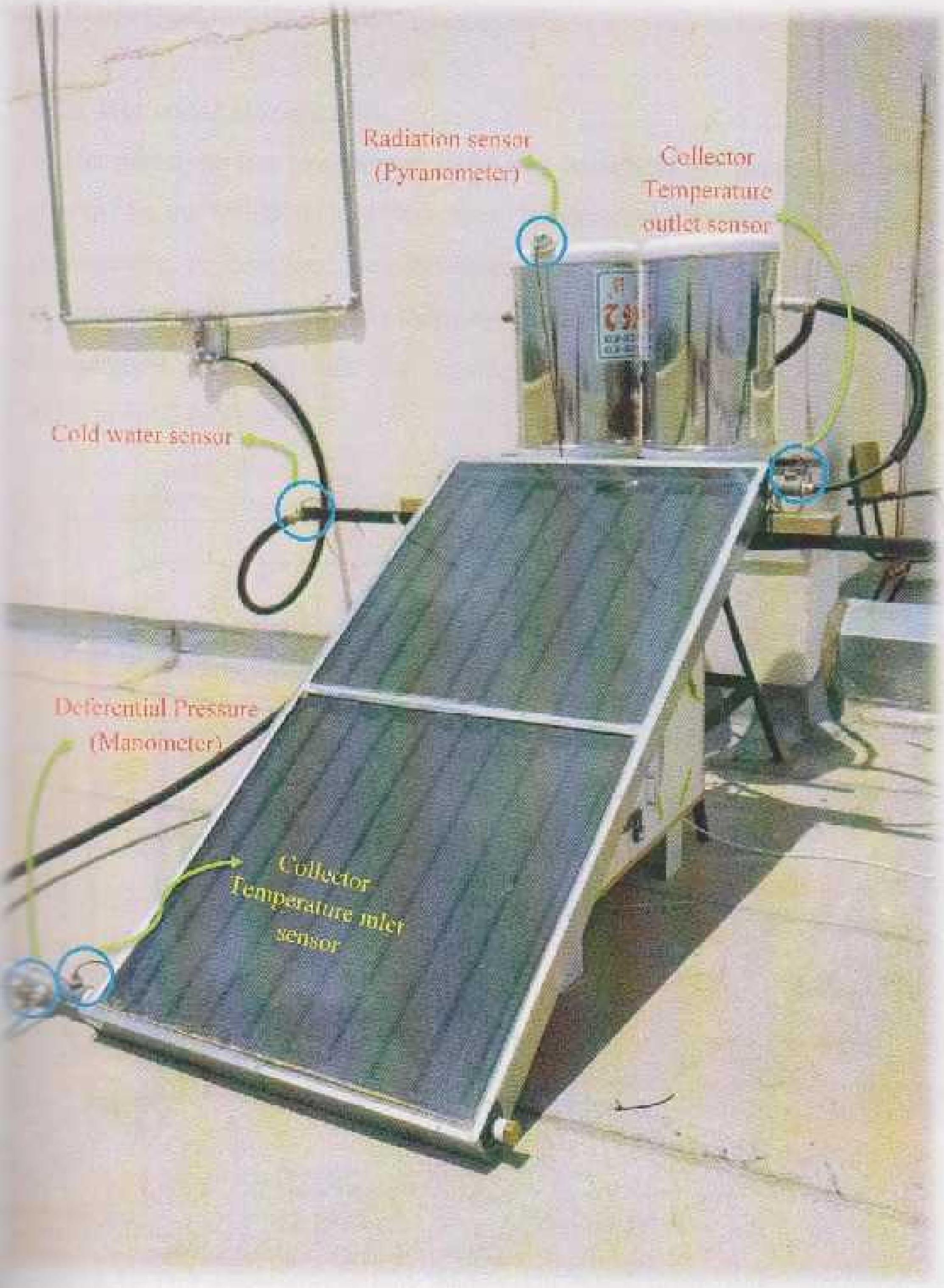


Figure (4.2): Prototype of the system

4.2 Prototype components

4.2.1 Hot water storage tank

The prototype has two storage tanks that have 50 Liter capacity of water as shown figure (4.3); tank 1 has four temperature sensors, one sensor for management process, and the other three sensors used for experimental process at different levels to study the thermosyphon phenomenon, and tank 2 has two temperature sensors, one for management process, and the other for experimental process.

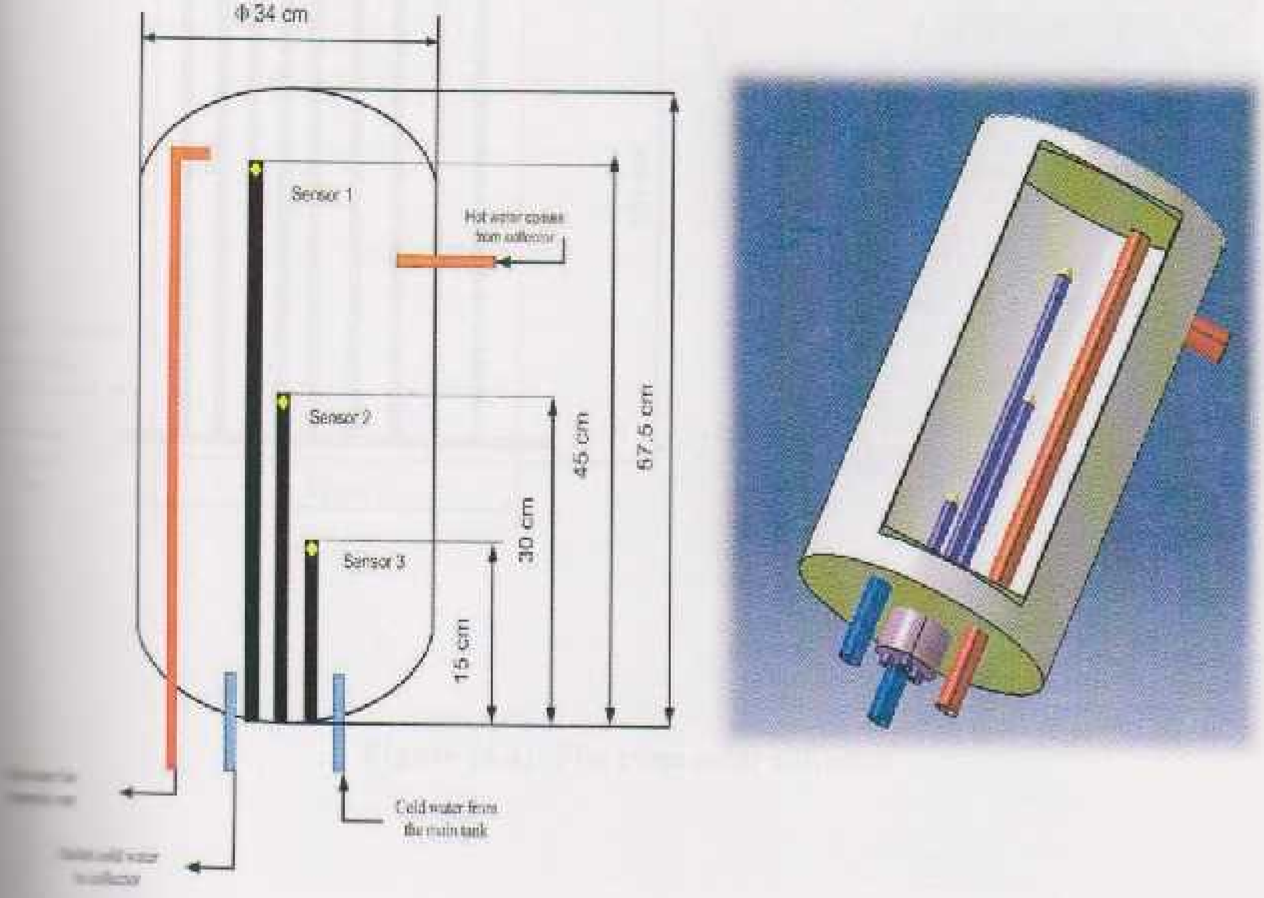


Figure (4.3): Hot water storage tank design that shows inside temperature sensors locations.

4.2.2 Flat-plate solar collector

The prototype has one typical flat-plate solar collector that has an effective area of 1.62 m^2, and this collector has two temperature sensors and one differential pressure measurement device, one temperature sensor and the pressure sensor exists on the inlet of the collector, and the other temperature sensor exists on the exit of the collector as shown in figure (4.4).

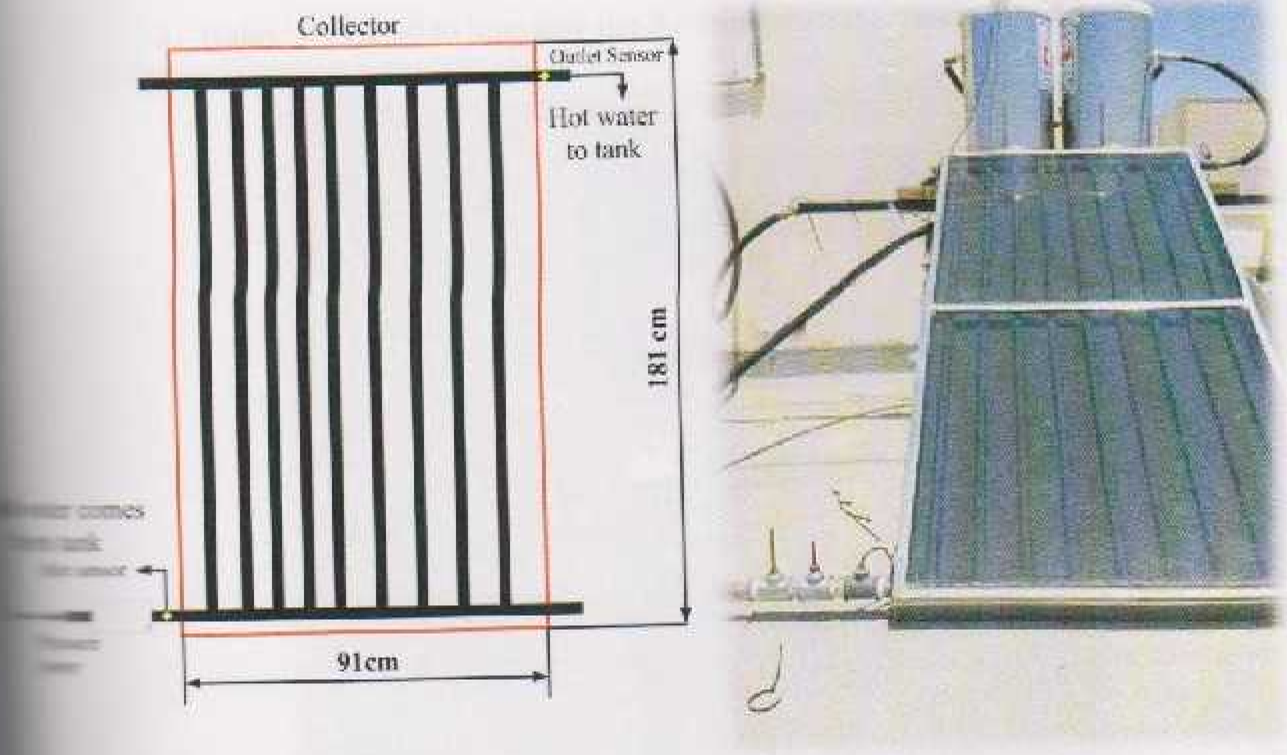


Figure (4.4): Flat plate solar collector

4.2.3 Control panel

The project control panel is used to manage the tanks in the system by timing the open and close for each valve according to the tank temperature, and it consists of some devices as shown in figure (4.5) such as:

1. Arduino UNO: it is used to control the valves by getting data from temperature sensors that exists in the tanks.
2. LCD display: it is used to display the tanks temperature.
3. Relay: it is used to interface the Arduino with the valves.

Figure (4.5): Control Panel

4.3 Measuring and controlling instrumentation in the project

4.3.1 Temperature measurements

Ten temperature measurements are required during testing and management:

1. Fluid inlet temperature to the system (T_{cold}).
2. Fluid inlet temperature to the collector ($T_{c(in)}$).
3. Fluid outlet temperature from the collector ($T_{c(out)}$).
4. Six storage tanks temperature (T_{t2}, $T_{t1(15cm)}$, $T_{t1(30cm)}$, $T_{t1(45cm)}$, $T_{t1(LM35)}$, $T_{t2(LM35)}$).
5. Ambient temperature (T_a).

The measurements were performed using 12-bit Temperature Smart Sensor fitted in the correct places. The probe used to measure the storage tank and collector temperature is fitted as shown in figure (4.6).

Figure (4.6): 12-bit Temperature Smart Sensor

4.3.2 Irradiance measurements

A Pyranometer, used to measure the irradiance over the test plane. When measure the irradiance the device should be parallel to the flat-plate solar collector as shown in figure (4.7).

Figure (4.7): Pyranometer

4.3.3 Pressure measurement

Measure the difference between static and dynamic pressure at the inlet of the collector as shown in the figure (4.8), and it used to calculate the change in the flow rate by using special equation.

Figure (4.8): Differential Pressure Manometer

4.3.4 Wind speed measurement

Measure the wind speed for the system, which can be measured by Anemometer model (AM-4217SD) as shown in figure (4.9).

Figure (4.9): Anemometer model (AM-4217SD)

4.3.5 Data Logger

A data logger is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on digital processor (or computer). They generally are small, battery powered and portable.

All sensors and measuring instruments were connected to the data loggers system, which consists of a data reception device that takes the signals generated by the sensors and convert it to a suitable signal and transmit it to a computer device, to use it in the program which calculates the coefficient to predict the performance of SDHW system. The data loggers used in the system are:

1. HOBO Energy Logger Pro as shown in the figure (4.10a).
2. Squirrel Data Logger(SQ2010)as shown in the figure (4.10b).

Figure (4.10a): HOBO Energy Logger

Figure (4.10b): Squirrel Data Logger

4.4 Project programs

In this project four programs were used, four programs are already exist used to getting the data from measurement instruments, these programs are (HOBOware pro program, Squirrel View, MANOMETER 5PSI and Microsoft Excel program).

1. HOBOware pro program

HOBOware pro program is software for easy launch readout of HOBO data logger as well as flexible plotting of data as shown in figure (4.11), data can be exported for more in depth analysis using other programs including spreadsheets. The software allow to set launch parameters such as which channels to record, sample interval, and start type (immediate, delayed, interval, or triggered); monitor battery level; and synchronize logger clocks to computer clock. With the graphing capability, it can be view multiple parameters from a single logger on one graph, zoom in on data of interest, set axes ranges, display data in different formats, and display recorded events in graphs or file exports. It can be also verify logger operation before launch or during logging, as well as displaying real time sensor reading, memory used and battery voltage. One click conversion allows for easy data upload into Microsoft Excel or other programs.

The windows version offers enhanced feature which allow for the combination of data from multiple loggers or deployments, saving of current data for future use, linear scaling for external inputs listing of recently-accessed files, and automatic internet updates. Software, USB interface cable and manual included.

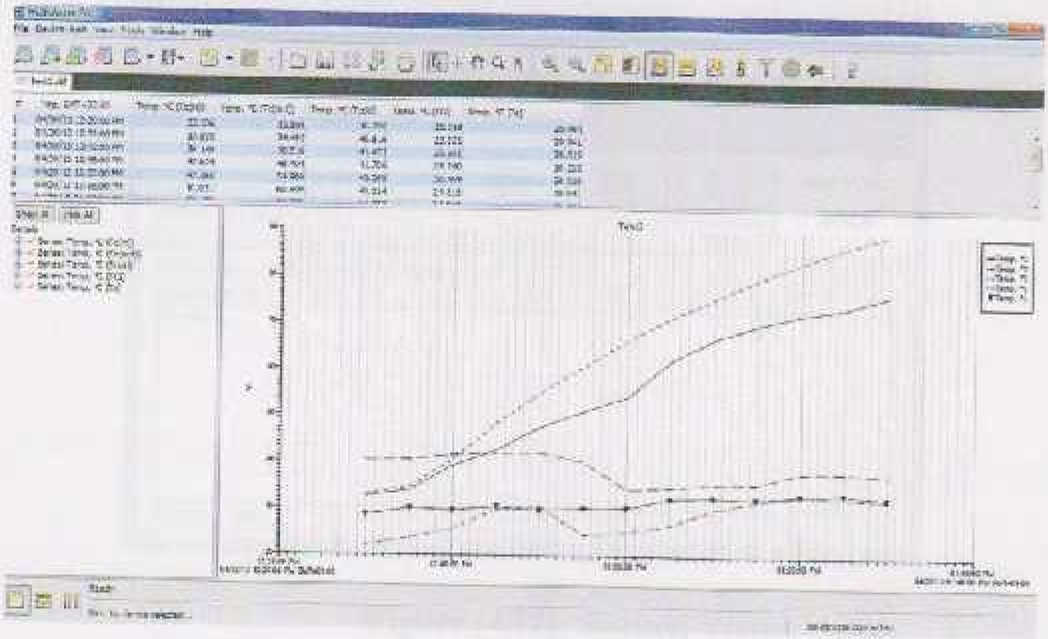


Figure (4.11): HOBOware pro program software

2. Squirrel View

Squirrel View is a universal software package that works with any Grant Squirrel data logger and is included free with every new logger as shown in figure (4.12). It enables easy setup of the logger, speedy download of data, and direct export to Excel spreadsheets. Squirrel View Plus gives you the additional benefits of graphically analyzing your historical and on-line data, along with advanced reporting.

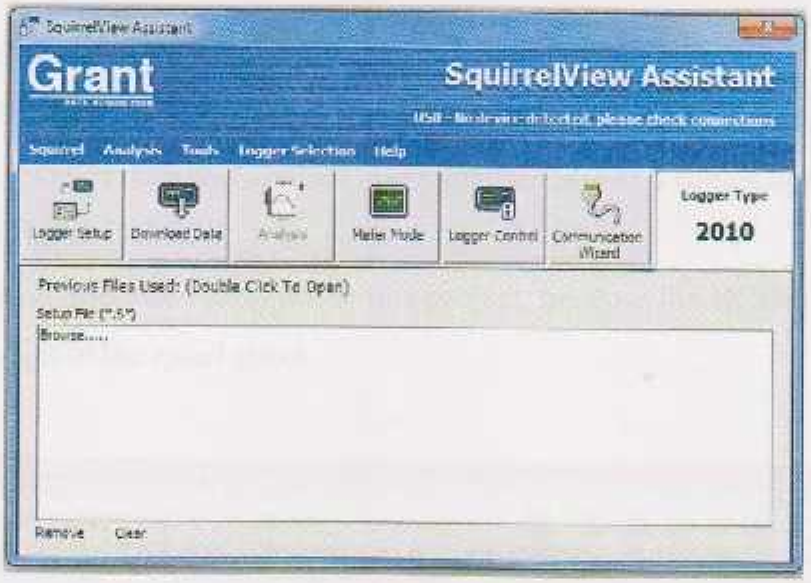


Figure (4.12): Squirrel View

3. Manometer 1.5 5PSI

Figure (4.13) shows the Manometer universal software package that works with HD-700 differential pressure measurement.

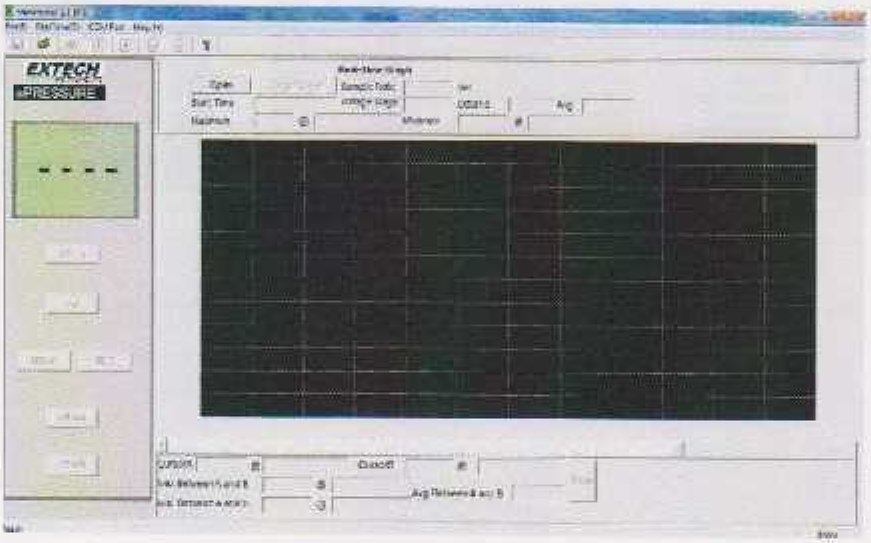


Figure (4.13): Manometer

4. Microsoft Excel program

Microsoft Excel program is a famous program using in calculations of large numbers of data and applied many mathematic and statics operation as shown in figure (4.14).

Also, it is an important program in this project, because the HOBO program send the data to the excel sheet.

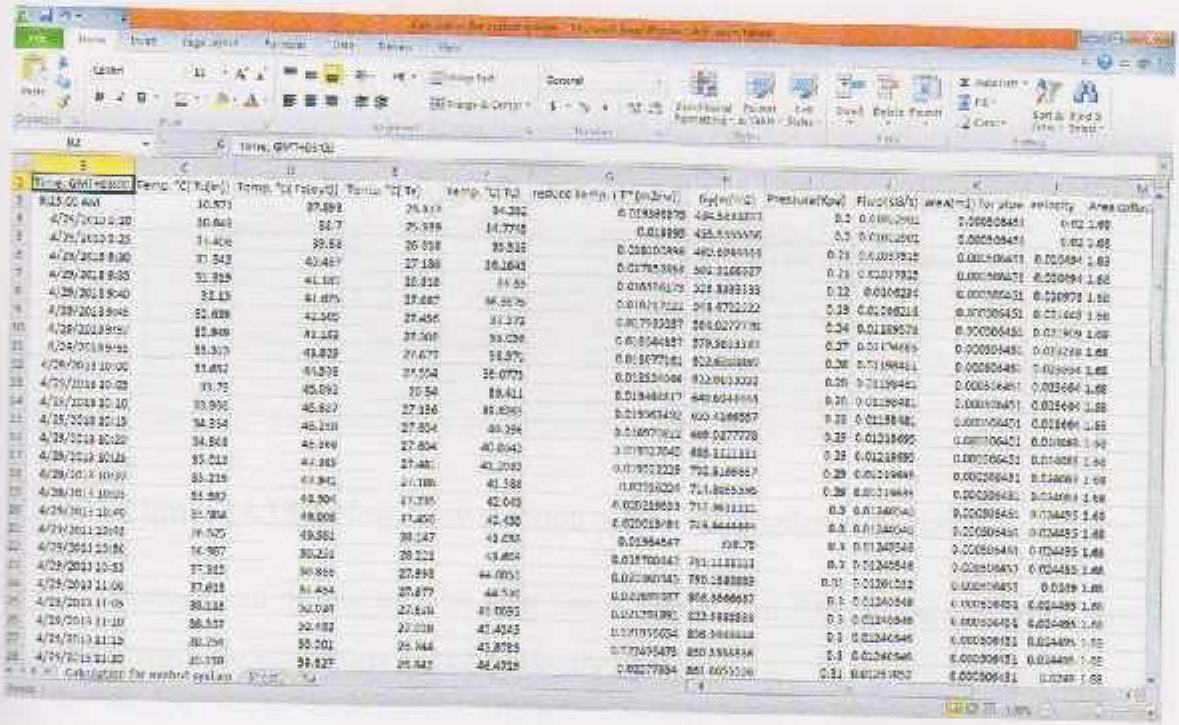


Figure (4.14): Microsoft Excel program

4.5 Experimental system modeling

Figure (4.15) shows a schematic drawing of the heat flow through a collector. The question is how to measure its thermal performance, i.e. the useful energy gain or the collector efficiency.

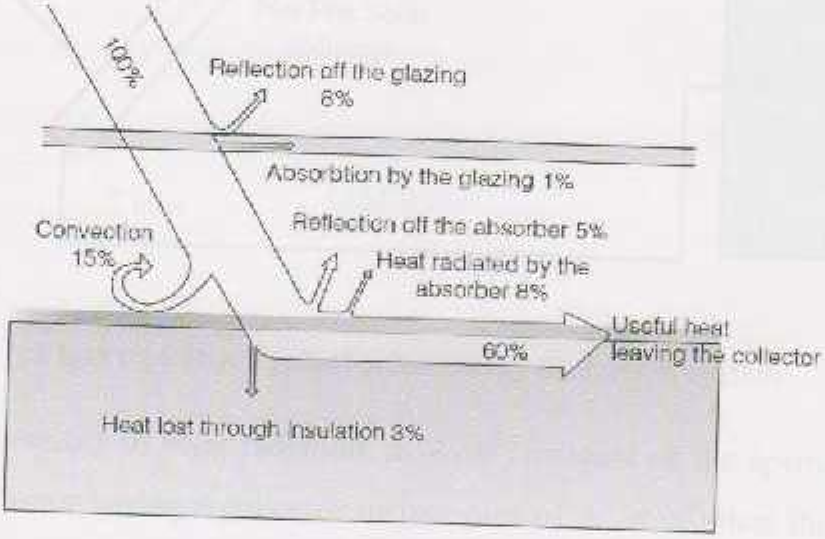


Figure (4.15): Heat flow through a Flat Plate solar collector

Thus it is necessary to define step by step the singular heat flow equations in order to find the governing equations of the collector system.

Figure (4.16) shows the schematic of a typical solar system employing a flat plate solar collector and a storage tank.

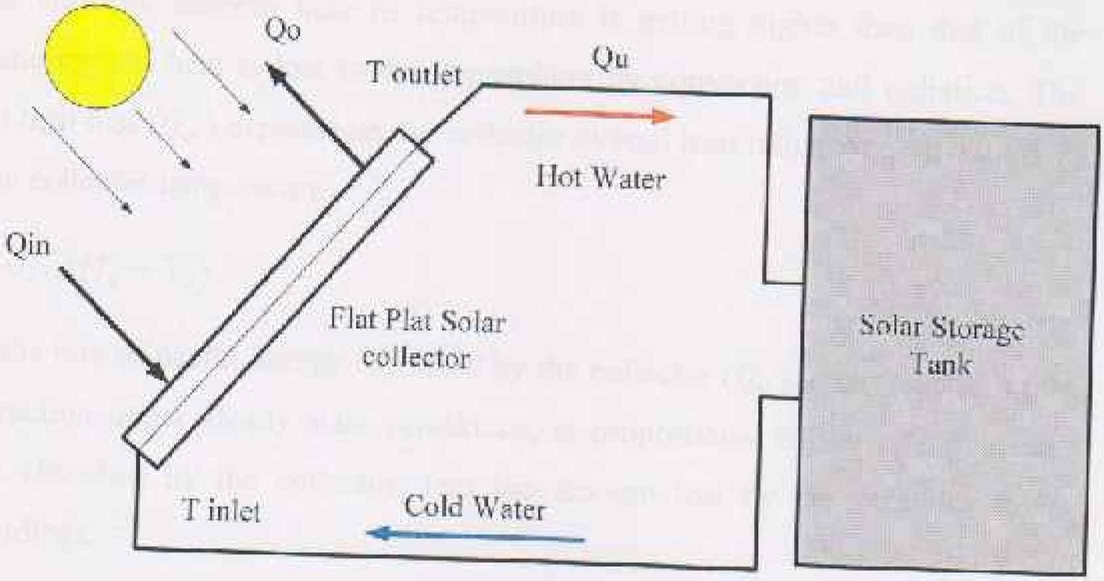


Figure (4.16): Typical solar energy collection system

If is G_T the intensity of solar radiation, in W/m^2, incident on the aperture plane of the solar collector having a collector surface area of A, in m^2, then the amount of solar radiation received by the collector is:

$$Q_{in} = G_T . A \qquad ..... (4.1)$$

However, as it is shown in figure (4.15), a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.

Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation. The rate of heat loss (Q_o) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature.

$$Q_o = U_L.A(T_c - T_a) \quad \text{..... (4.2)}$$

Thus, the rate of useful energy extracted by the collector (Q_u), expressed as a rate of extraction under steady state conditions, is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings.

This is expressed as follows:

$$Q_u = Q_{in} - Q_o = (G_T.A) - (U_L.A(T_c - T_a)) \quad \text{..... (4.3)}$$

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

$$Q_u = (mc)_c.(T_i - T_o) \quad \text{..... (4.4)}$$

Analytical study of performance characteristic of solar thermal energy using dynamic system, modeling modified to account heat transfer efficiency in solar panel, pipes, etc.

Solar plate internal heat change rate:

$$(mc)_c \frac{dT_c}{dt} = A_c[G_T - U_l(T_c - T_a)] - \eta_c(\dot{m}c_p)_f(T_c - T_f) \quad \text{..... (4.5)}$$

Where:

T_c: The mean collector temperature.

$(mc)_c$: The mass and the heat capacity of collector.

A_c: The area of collector.

G_T: The solar radiation comes from the sun.

U_L: Overall heat transfer coefficient.

T_a: The ambient temperature.

η_c : The efficiency of collector.

$(\dot{m}c_p)_f$: The mass flow rate and heat capacity for the fluid.

T_f: The fluid temperature.

$$\frac{dT_c}{dt} = -\left(\frac{A_c U_l + \eta_c(\dot{m}c_p)_f}{(mc)_c}\right)T_c + \frac{\eta_c(\dot{m}c_p)_f}{(mc)_c}T_f + \frac{A_c(G_T + U_l T_a)}{(mc)_c}$$

$T_f = T_t$

Where T_t *is the temperature of the tank*

$$\frac{dT_c}{dt} = -\left(\frac{A_c U_l + \eta_c(\dot{m}c_p)_f}{(mc)_c}\right)T_c + \frac{\eta_c(\dot{m}c_p)_f T_t}{(mc)_c} + \frac{A_c(G_T + U_l T_a)}{(mc)_c}$$

$$\frac{dT_c}{dt} = -\left(\frac{A_c U_l + \eta_c(\dot{m}c_p)_f}{(mc)_c}\right)T_c + \left(\frac{\eta_c(\dot{m}c_p)_f}{(mc)_c}\right)T_t + \left(\frac{A_c}{(mc)_c}\right)G_T + \left(\frac{A_c U_l}{(mc)_c}\right)T_a$$

Where is :

$$\alpha = -\left(\frac{A_c U_l + \eta_c (\dot{m}c_p)_f}{(mc)_c}\right)$$

$$\beta = \left(\frac{\eta_c (\dot{m}c_p)_f}{(mc)_c}\right)$$

$$u_s = \left(\frac{A_c}{(mc)_c}\right) G_T \ \ Input\ from\ the\ sun\ radiation$$

$$u_a = \left(\frac{A_c U_l}{(mc)_c}\right) T_a\ Input\ from\ ambint\ tempreature$$

$$\frac{dT_c}{dt} = -\alpha T_c + \beta T_t + u_s + u_a \qquad \text{..... (4.6)}$$

Storage tank internal heat change rate with η_t to account for heat exhange efficiency and pipes losses:

$$(mc)_t \frac{dT_t}{dt} = \eta_t (\dot{m}c_p)_f (T_c - T_t) - Q_t$$

$$\frac{dT_t}{dt} = -\frac{\eta_t (\dot{m}c_p)_f}{(mc)_t} T_t + \frac{\eta_t (\dot{m}c_p)_f}{(mc)_t} T_c - \frac{Q_t}{(mc)_t} \qquad \text{..... (4.7)}$$

$$\gamma = \frac{\eta_t (\dot{m}c_p)_f}{(mc)_t}$$

$$u_t = -\frac{Q_t}{(mc)_t}\ wher\ Q_t\ is\ the\ losses\ from\ tank$$

$$\frac{dT_t}{dt} = -\gamma T_t + \gamma T_c + u_t$$

From equation (6) and (7), convert to state space modle

$$\begin{bmatrix} \dot{T}_c \\ \dot{T}_t \end{bmatrix} = \begin{bmatrix} -\alpha & \beta \\ \gamma & -\gamma \end{bmatrix} \begin{bmatrix} T_c \\ T_t \end{bmatrix} + \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} u_s \\ u_a \\ u_l \end{bmatrix}$$

Characteristic equation

$$\begin{vmatrix} s & 0 \\ 0 & s \end{vmatrix} - \begin{vmatrix} -\alpha & \beta \\ \gamma & -\gamma \end{vmatrix} = \begin{vmatrix} s+\alpha & -\beta \\ -\gamma & s+\gamma \end{vmatrix} = s^2 + (\alpha+\gamma)s + (\alpha-\beta)\gamma = 0$$

The equations (4.7) and (4.5) will be used later in chapter five to measure the heat capacity for the flat-plate collector, and the heat capacity for the hot water storage tank.

Chapter Five

Experimental Results

Contents:

Chapter Five

Experimental Result

5.1 Introduction

This chapter will introduce the test methods for the solar domestic hot water system and its condition for each component, and also make some calculation for them such as the thermal capacity for hot water storage tank, the thermal capacity for the flat-plate solar collector, the heat losses and efficiency for the whole solar domestic hot water system, and the thermosyphon phenomenon and its effect on the tank at three different level and its effect on the flow water that enter to the flat-plate solar collector. These tests shows that the system used in this project is more efficient than the commercial system that currently used, because this project is supplied with control panel that used to manage and control each tank alone, so its focus on the morning period when the sun is about to shine, on other hand the user can reduce using the electrical heating elements that consumes a lot of energy and money.

5.2 Testing overview

Before starting tests process there are procedures must be done such as:

- Expose the collector in working position without liquid to sun radiation for three days, during this period the sun radiation measured over the collector plate must be not less than 17000 kJ/m^2 day.
- The collectors must be assembly in a place free from any unwanted reflected radiation over the collector.
- The thermal efficiency test must be done between 11:00 a.m. – 13:00 p.m. And the collectors should assembly in a degree that the falling sun radiation over the collector be perpendicular in the noon period.
- The wind direction must be known, and the wind speed should be measured over a level equal half the collector height, and the wind speed must not more than 4.5 m/s.
- The ambient temperature should be not more than 30° C at the test period.

5.3 Hot water storage tank tests

1. Storage tank heat loss test

The test is carried out to determine the storage heat loss coefficient (UA_s). The test method adopted is described by the European Commission-Collector System Testing Group second international draft (1987), where the storage is charged to a temperature greater than 50 °C and allowed to cool for about 48 hours. During charging, no fluid is added to or extracted from the system; hourly measurement is performed for the store temperature and the ambient air temperature.

The equation for the product of the surface area and heat loss coefficient of the storage tank as follow:

$$UA_s = \frac{-1}{t} M_s\, C_p\, \ln\left[1 - \frac{(T_{sf} - T_{si})}{(T_a - T_{si})}\right] \qquad \ldots\ldots (5.1)$$

where:

T_{si}: Initial water temperature inside the storage tank, °C

T_{sf}: Final water temperature inside the storage tank after 48 hours, °C

T_a: Ambient air temperature, °C

UA_s: The product of the surface area and heat loss coefficient of the storage tank, W/K

M_s: Mass of water inside the storage tank (according to the tank), (kg)

C_p: Specific heat of water at constant pressure, (4.18 kJ/kg°C)

The temperature taken from the data logger is summarized in the table (5.1), and the result is plotted in chart (5.1).

Table (5.1): Data of Storage tank test

T_{si} (°C)	T_{sf} (°C)	T_a (°C)	Duration (hour)	UA_s (W/K)	M_s (Kg)	C_p (KJ/Kg°C)
81.38	35.529	24.73	48	1.8065	45	4.18

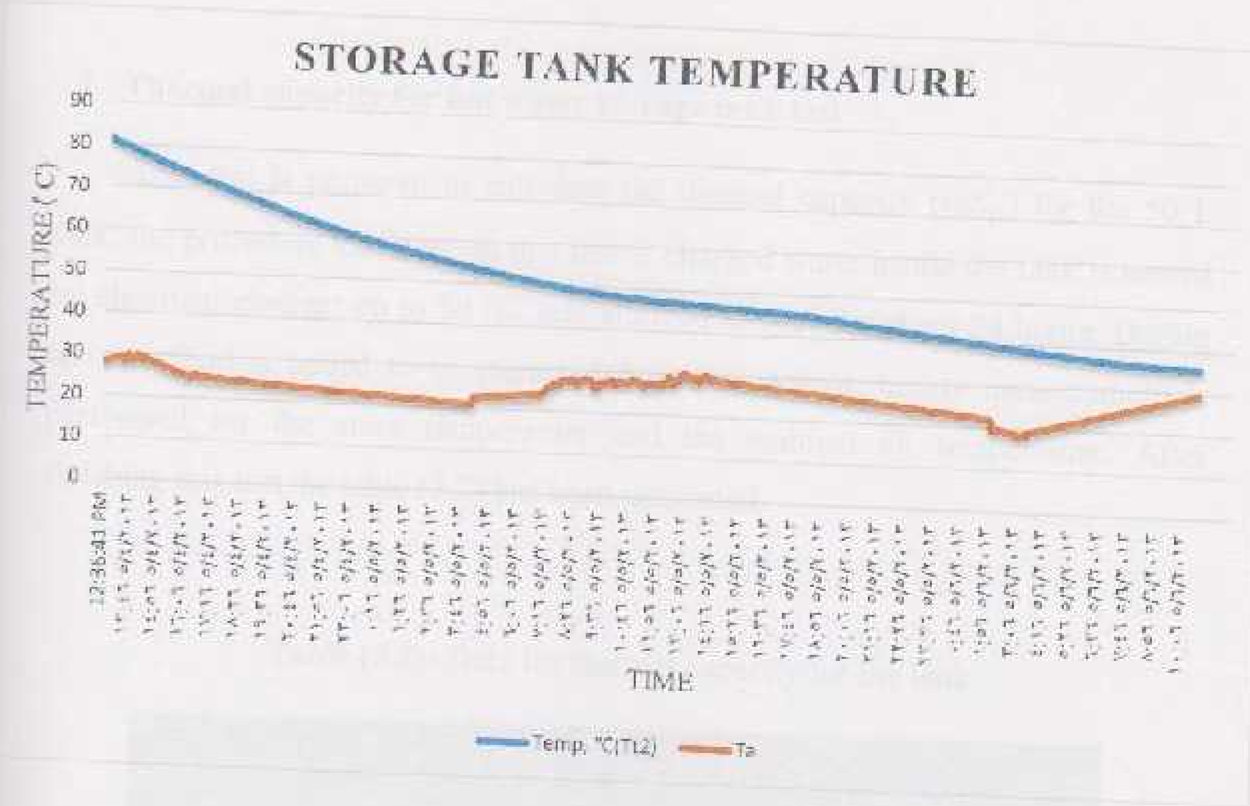


Chart (5.1): Storage tank temperature

t = 48 Hours*60 minutes* 60 second =172800 second.

Ta = average of ambient temperature for a long time of test.

The overall heat transfer coefficient for the storage tank (UA_s)

$$UA_s = -(1\backslash 172800)X45X4.18XLn\left[1-\frac{(35.5-81.35)}{(24.73-81.35)}\right] = 1.8065\ W/K$$

2. Thermal capacity for hot water storage tank test

This test is prepared to calculate the thermal capacity (mC_p) for the 50 L tank, the procedure that done in this test is charged water inside the tank is heated by electrical element up to 80 ^{0}C, and allowed to cool for about 24 hours. During test, no fluid is added to or extracted from the system; hourly measurement is performed for the store temperature and the ambient air temperature. After finishing this test the table (5.2) has been generated.

Table (5.2): Data for thermal capacity for the tank

Date Time, GMT+03:00	Temp, °C(T(2)	Date Time, GMT+03:00	Temp, °C(T(2)
5/4/2013 13:01	80.123	5/5/2013 1:01	57.339
5/4/2013 14:01	77.868	5/5/2013 2:01	56.028
5/4/2013 15:01	75.678	5/5/2013 3:01	54.754
5/4/2013 16:01	73.551	5/5/2013 4:01	53.516
5/4/2013 17:01	71.308	5/5/2013 5:01	52.419
5/4/2013 18:01	69.299	5/5/2013 6:01	51.277
5/4/2013 19:01	67.339	5/5/2013 7:01	50.266
5/4/2013 20:01	65.375	5/5/2013 8:01	49.479
5/4/2013 21:01	63.504	5/5/2013 9:01	48.604
5/4/2013 22:01	61.807	5/5/2013 10:01	48.007
5/4/2013 23:01	60.22	5/5/2013 11:01	47.515
5/5/2013 0:01	58.651	5/5/2013 12:01	47.06

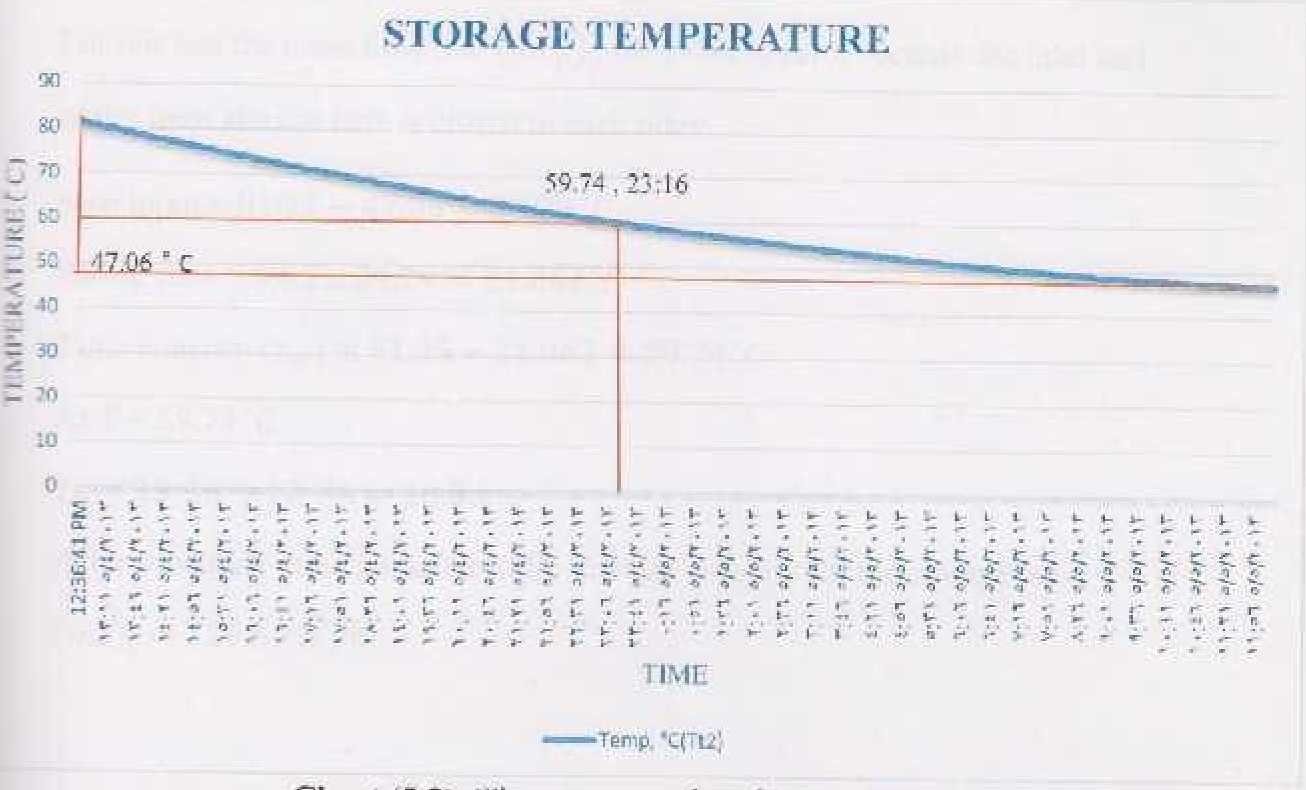


Chart (5.2): Time constant data for storage tank

From chart (5.2), the thermal capacity for the storage tank can be calculated by using equation (5.2). By calculating the time constant where is required for a system whose performance can be approximated by a first-order differential equation, to have its output changed by 63.22 % of its final change in output following a step change in input.

Storage tank internal heat change rate:

$$\frac{dT_t}{dt} = -\frac{\eta_t(\dot{m}c_p)_f}{(mc)_t}T_t + \frac{\eta_t(\dot{m}c_p)_f}{(mc)_t}T_c - \frac{Q_l}{(mc)_t} \qquad \text{.....} (5.2)$$

For this test the mass flow rate $(\dot{m}c_p)_f$ for water is zero, because the inlet and outlet from storage tank is closed to each other.

Step input = $81.35 - 47.06 = 34.29\,^{\circ}C$

Rising time = $0.63\ x\ 34.29 = 21.062\,^{\circ}C$

Time constant (τ_{st}) at $81.35 - 21.062 = 59.74\,^{\circ}C$

At T = $59.74\,^{\circ}C$

$\tau_{st} = 23:16 - 12:36 = 10.8\ h$

After substitute these parameters the thermal capacity for the storage tank:

$(mc)_t = 129.6\ kW/K$

3. Temperature at differant level in storage tank :

Chart (5.3) shows the change in temperature at three different level inside the storage tank. This test aim for studying the heat transfer process which help to increase the heat capacity.

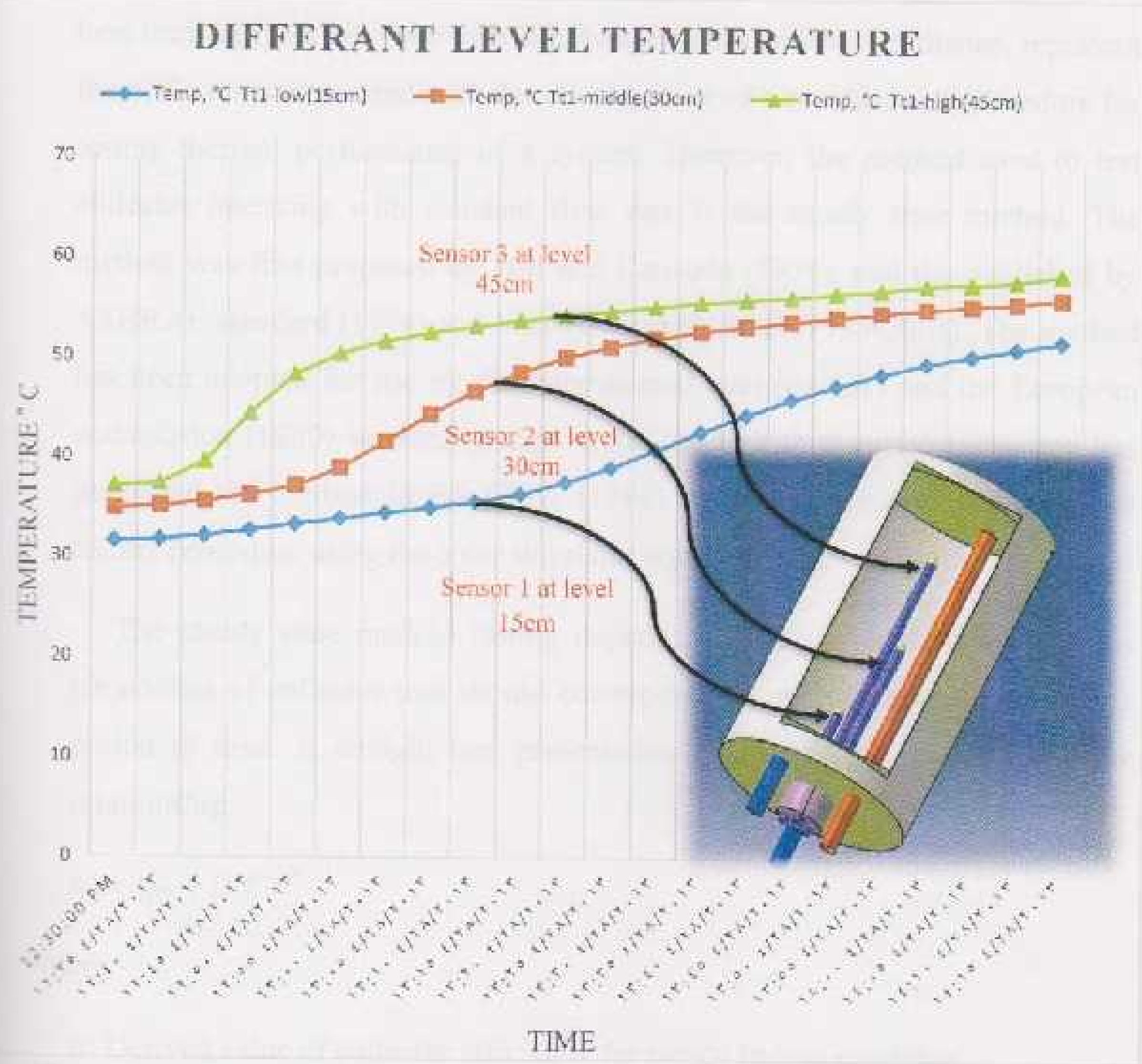


Chart (5.3) : Change in temperature at three different level

5.4 Flat-plate solar collector tests

1. Collector thermal performance test

The transient response of the thermosyphon collector and the change of the heat transfer fluid flow rate with the change in the incident irradiance, represent the difficulties associated with the development of a standard test procedure for testing thermal performance of a system. However, the method used to test collector operating with constant flow rate is the steady state method. The method was first proposed by Hill and Kausuda (1974), and the published by ASHRAE standard (1974) and later ANSI/ASHRAE (1993-2003). The method has been adopted for use by the international energy (IEA) and the European commission (1980) working groups. Later the British standard institution has published the method in BS 6757: (1986) there was recommendation for a testing procedure using the solar simulator was included.

The steady state method testing depends on measuring the instantaneous parameters of collector that should correspond the stationary condition over a period of time. A straight line presentation could then be plotted using the relationship:

$$\eta = \eta_0 - U\,T^{*} \quad \text{[9]} \qquad \text{..... (5.1)}$$

where:

η: Derived value of collector efficiency for steady indoor condition, dimensionless

η_0: Zero loss collector efficiency, dimensionless

T^*: Is the reduced temperature different; which takes the form

$T^* = (Tc-Ta)/G_t$

T_c: Mean plate operating temperature, °C

T_c: $(T_{in} + T_{out}) / 2$

G_T: Equivalent normal solar irradiance on a collector plane, w/m^2

T_{in}: Water inlet temperature. °C

T_{out}: Water outlet temperature, °C

The slope U in the equation (5.1) represents the collector heat loss coefficient.

- **Energy of collector**

The energy output of the collector is calculated as:

$$Q_{out} = \dot{m}C_p(T_{out} - T_{in}) \quad ..... (5.3)$$

Also, $Q_{out} = (U_L.A(T_c - T_a)$ ..... (5.4)

substitute equation (5.3) in equation (5.4)

$$U_L = \frac{\dot{m}C_p(T_{out}-T_{in})}{A(T_c-T_a)} \quad ..... (5.5)$$

where :

$$T_c = (Tin + Tout)/2 \quad ..... (5.6)$$

$$Q_{in} = G_T Ac \quad ..... (5.7)$$

$$Q_u = Q_{in} - Q_{out} = (G_T.Ac) - \dot{m}c_p(Tin - Tout)) \quad ..... (5.8)$$

The resulting of instantanous efficincy η, is represented by the ratio of the output to input (Q_{out} / Q_u) was plotted versus the reduce temperature difference T^* in the straight line presentation. This enable the determination of the collector performance parameters.

Chart (5.4) to chart (5.8) shows the data getting from this calcualtion drawn in the charts, and shows the collector thermal performance testing, where it can be seen that all the steady state points and all the temperature of the system in table(5.3) .

The flow rate calculation done by measuring the difference between the dynamic and static pressure as shown in figure (5.1).

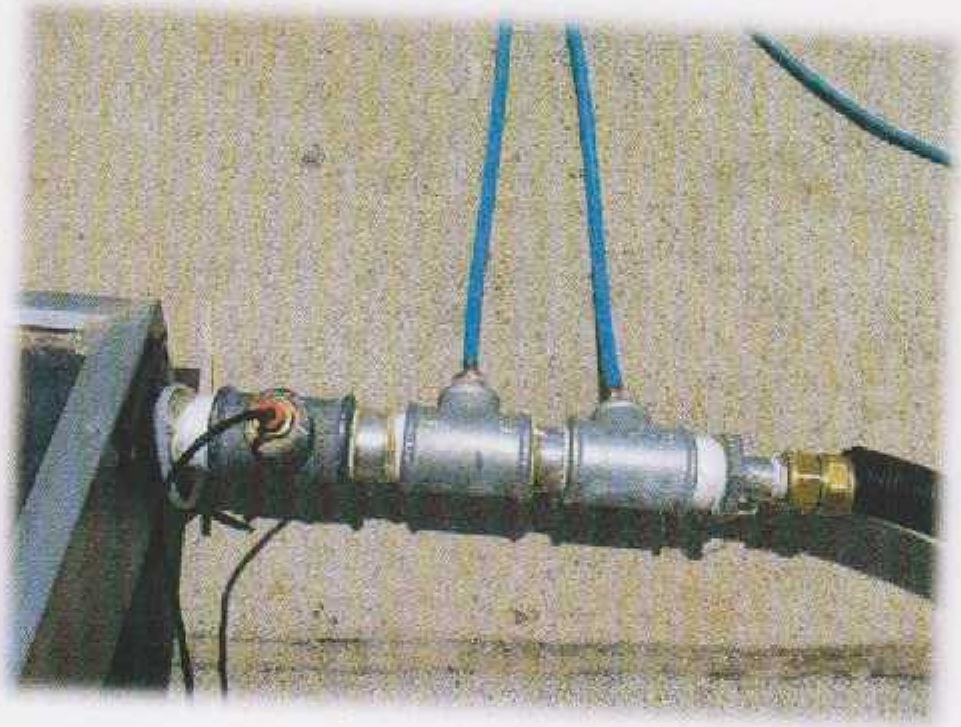


Figure (5.1): Measuring the difference between the dynamic and static pressure

$$v = \sqrt{\frac{2(\Delta p)}{\rho}} \quad \text{..... (5.9)}$$

where: v is velocity of water insid the pipe (m/s)

$$Q_f = v * A_c \quad \text{..... (5.10)}$$

where: Q_f is flow of water insid the pipe (m^3/s)

$$\dot{m} = Q_f * \rho \quad \text{..... (5.11)}$$

where: $\dot{m}$ Is flow rate of water insid the pipe (kg/s)

$$\rho = 1000\ kg/m^3$$

Tables (5.3): Collector performance testing

Time, GMT+03:00	Temp, °C(Tc(in))	Temp, °C(Tc(out))	Temp, °C(Ta)	Temp, °C(Tc)
4/29/2013 9:15	30.571	37.893	25.817	34.232
4/29/2013 9:30	31.842	40.487	27.186	36.1645
4/29/2013 9:45	32.639	42.505	27.456	37.572
4/29/2013 10:00	33.652	44.503	27.554	39.0775
4/29/2013 10:15	34.334	46.258	27.604	40.296
4/29/2013 10:30	35.235	47.941	27.186	41.588
4/29/2013 10:45	36.525	49.581	28.147	43.053
4/29/2013 11:00	37.618	51.454	27.677	44.536
4/29/2013 11:15	38.756	53.001	26.744	45.8785
4/29/2013 11:30	40.171	54.716	27.259	47.4435
4/29/2013 11:45	41.385	56.263	27.136	48.824
4/29/2013 12:00	42.953	57.623	27.727	50.288
4/29/2013 12:15	44.781	59.365	28.171	52.073
4/29/2013 12:30	46.194	61.094	27.53	53.644
4/29/2013 12:45	47.81	62.624	28.27	55.217
4/29/2013 12:50	48.938	63.364	29.414	56.151
4/29/2013 12:55	49.309	63.881	29.04	56.595
4/29/2013 13:00	49.991	64.357	30.293	57.174
4/29/2013 13:05	50.891	65.033	29.54	57.962
4/29/2013 13:10	50.682	65.375	29.015	58.0285
4/29/2013 13:15	51.383	65.77	28.916	58.5765
4/29/2013 13:20	51.454	65.969	29.34	58.7115
4/29/2013 13:25	51.845	66.521	28.642	59.183
4/29/2013 13:30	51.738	66.673	28.543	59.2055
4/29/2013 13:35	52.167	66.928	28.196	59.5475
4/29/2013 13:40	52.855	67.287	29.29	60.071
4/29/2013 13:45	53.405	67.546	28.99	60.4755
4/29/2013 13:50	53.925	68.016	29.615	60.9705
4/29/2013 13:55	54.678	68.599	29.59	61.6385
4/29/2013 14:00	54.906	69.082	29.315	61.994
4/29/2013 14:05	55.638	69.408	28.965	62.523

Time, GMT+03:00	Reduced Temp, (T* (m²/W))	G_T(W/m²)	Pressure(kPa)	Flow(kg/s)
4/29/2013 9:15	0.019363375	434.5833333	0.2	0.01012901
4/29/2013 9:30	0.017852858	502.9166667	0.21	0.01037915
4/29/2013 9:45	0.017935287	564.0277778	0.24	0.01109578
4/29/2013 10:00	0.018524046	622.0833333	0.28	0.01198481
4/29/2013 10:15	0.018970812	669.0277778	0.29	0.01219695
4/29/2013 10:30	0.02016224	714.3055556	0.29	0.01219695
4/29/2013 10:45	0.01964547	758.75	0.3	0.01240546
4/29/2013 11:00	0.020899587	806.6666667	0.3	0.01240546
4/29/2013 11:15	0.022496473	850.5555556	0.3	0.01240546
4/29/2013 11:30	0.022832427	884.0277778	0.27	0.01176885
4/29/2013 11:45	0.023652469	916.9444444	0.3	0.01240546
4/29/2013 12:00	0.02385304	945.8333333	0.3	0.01240546
4/29/2013 12:15	0.024793891	964.0277778	0.31	0.01261052
4/29/2013 12:30	0.026507937	985.1388889	0.31	0.01261052
4/29/2013 12:35	0.026217896	990.2777778	0.32	0.0128123
4/29/2013 12:40	0.026576426	990.9722222	0.31	0.01261052
4/29/2013 12:45	0.026779627	1006.25	0.31	0.01261052
4/29/2013 12:50	0.026629741	1004.027778	0.3	0.01240546
4/29/2013 12:55	0.027270928	1010.416667	0.3	0.01240546
4/29/2013 13:00	0.02649462	1014.583333	0.3	0.01240546
4/29/2013 13:05	0.028288416	1004.722222	0.31	0.01261052
4/29/2013 13:10	0.028793549	1007.638889	0.31	0.01261052
4/29/2013 13:15	0.02927023	1013.333333	0.31	0.01261052
4/29/2013 13:20	0.028937438	1015	0.31	0.01261052
4/29/2013 13:25	0.029958474	1019.444444	0.3	0.01240546
4/29/2013 13:30	0.030110475	1018.333333	0.32	0.0128123
4/29/2013 13:35	0.030812285	1017.5	0.31	0.01261052
4/29/2013 13:40	0.030214479	1018.75	0.32	0.0128123
4/29/2013 13:45	0.031007468	1015.416667	0.33	0.01301095
4/29/2013 13:50	0.031092081	1008.472222	0.3356	0.01312088
4/29/2013 13:55	0.031536039	1016.25	0.345	0.01330337
4/29/2013 14:00	0.032624626	1001.666667	0.3374	0.01315602
4/29/2013 14:05	0.03399713	987.0833333	0.345	0.01330337

U_L for collector(W/K)	Q_{in} (W)	Q_{out} (W)	Q_u (W)	η (%)
21.19851	730.1	310.0081	420.0919	58.95251
21.19851	844.9	375.062	469.838	62.15459
21.19851	947.5667	457.5885	489.9782	61.97985
21.19851	1045.1	543.5971	501.5029	60.73177
21.19851	1123.967	607.9241	516.0426	59.78469
21.19851	1200.033	647.793	552.2404	57.25904
21.19851	1274.7	677.0163	597.6837	58.35452
21.19851	1355.2	717.4631	637.7369	55.69597
21.19851	1428.933	738.6717	690.2617	52.31081
21.19851	1485.167	715.5236	769.643	51.59864
21.19851	1540.467	771.4958	768.9709	49.86027
21.19851	1589	760.71	828.29	49.43509
21.19851	1619.567	768.7513	850.8154	47.44062
21.19851	1655.033	785.4083	869.625	43.8071
21.19851	1663.667	793.5841	870.0826	44.42195
21.19851	1664.833	767.8552	896.9781	43.66191
21.19851	1690.5	780.8751	909.6249	43.23116
21.19851	1686.767	748.0574	938.7093	43.54889
21.19851	1697.5	755.6282	941.8718	42.18967
21.19851	1704.5	744.9461	959.5539	43.83533
21.19851	1687.933	745.4526	942.4807	40.03275
21.19851	1692.833	774.4969	918.3364	38.96194
21.19851	1702.4	758.3671	944.0329	37.95145
21.19851	1705.2	765.1142	940.0858	38.65692
21.19851	1712.667	761.0211	951.6456	36.49247
21.19851	1710.8	799.8501	910.9499	36.17026
21.19851	1709.4	778.0813	931.3187	34.68252
21.19851	1711.5	772.9117	938.5883	35.94978
21.19851	1705.9	769.0693	936.8307	34.26876
21.19851	1694.233	772.825	921.4083	34.0894
21.19851	1707.3	774.1201	933.1799	33.14827
21.19851	1682.8	779.5691	903.2309	30.84063
21.19851	1658.3	765.7233	892.5767	27.93112

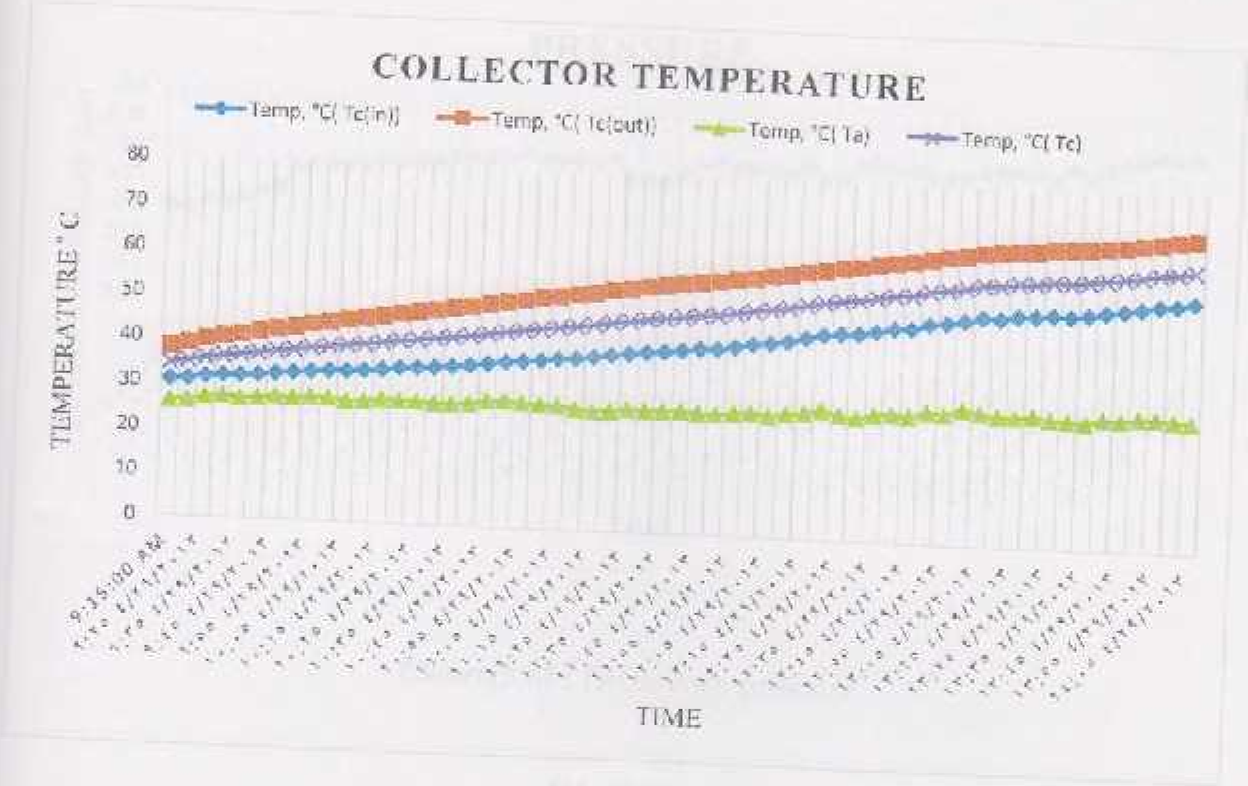


Chart (5.4): Collector temperature

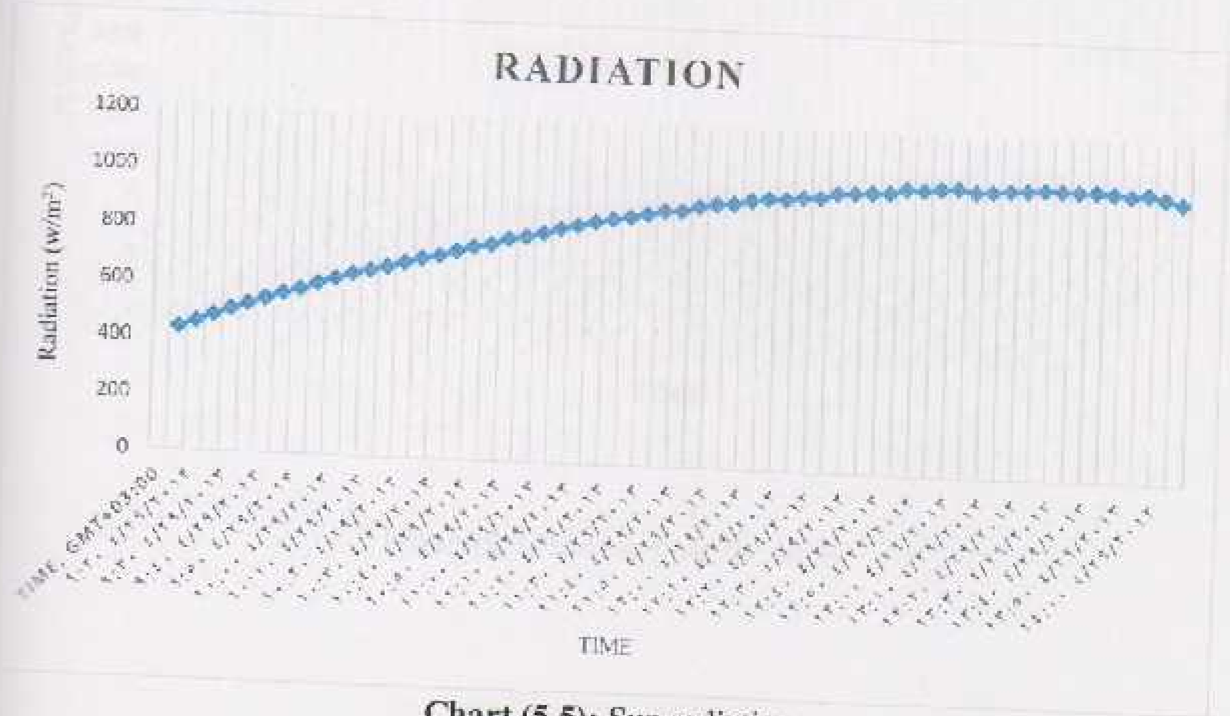
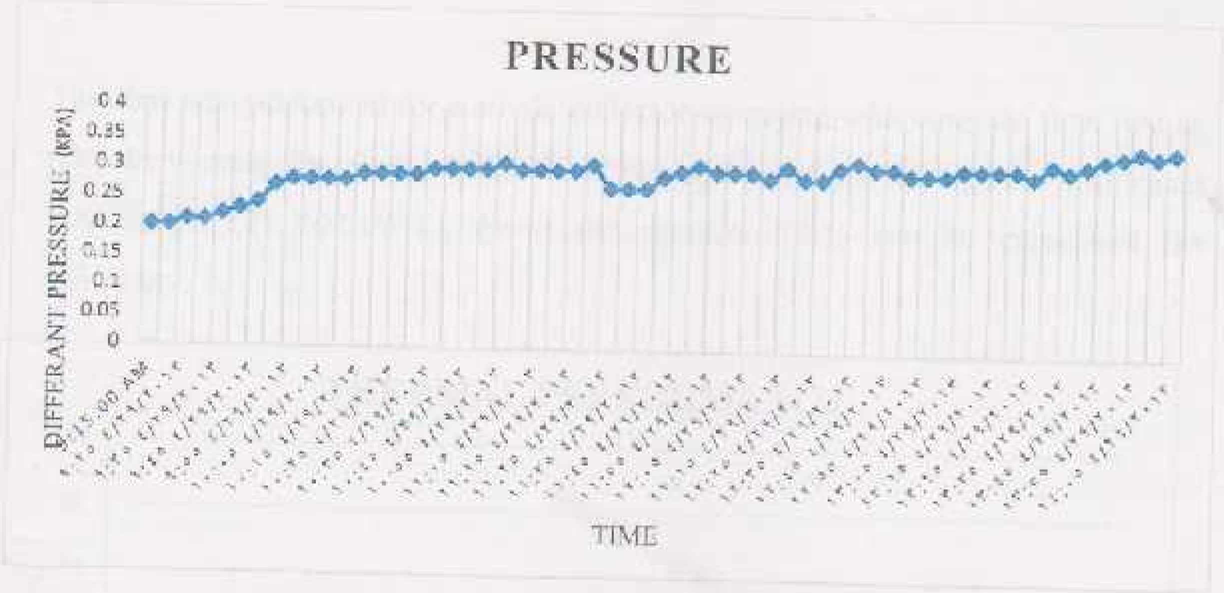
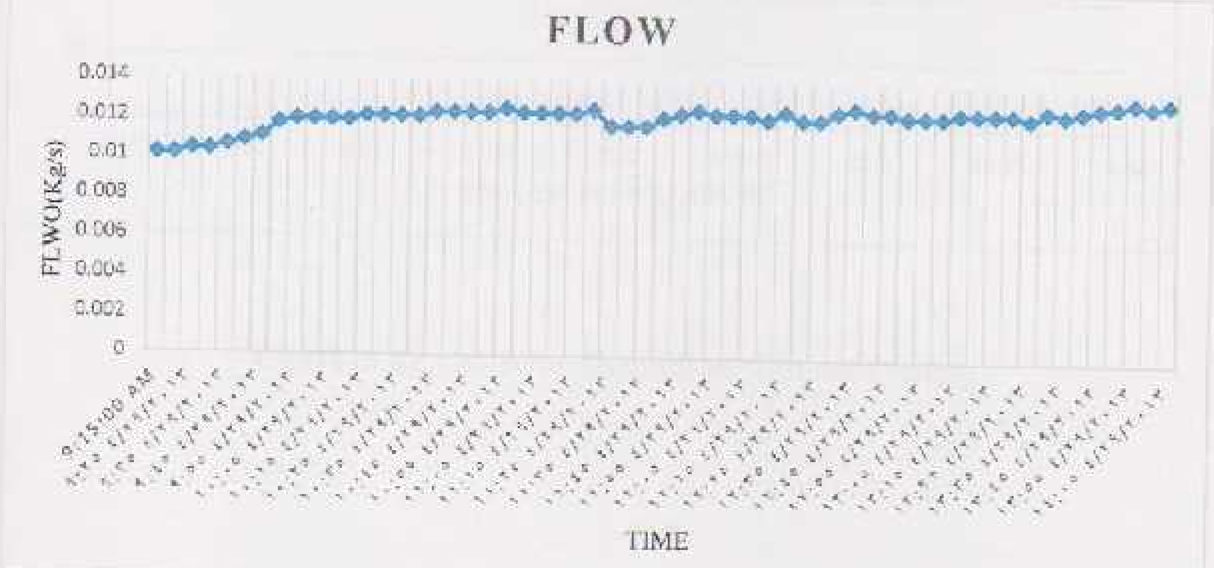


Chart (5.5): Sun radiation



Chart(5.6) : Difference pressure



Chart(5.7) : Mass flow for water

The first was performed for a single collector operating with constatn flow rate by take the avareag for flow rate (0.012209 kg/s.m^2), and the avarege for heat losses that equals (21.19851W/k). From the equation (5.1) can be calculated the efficiency.

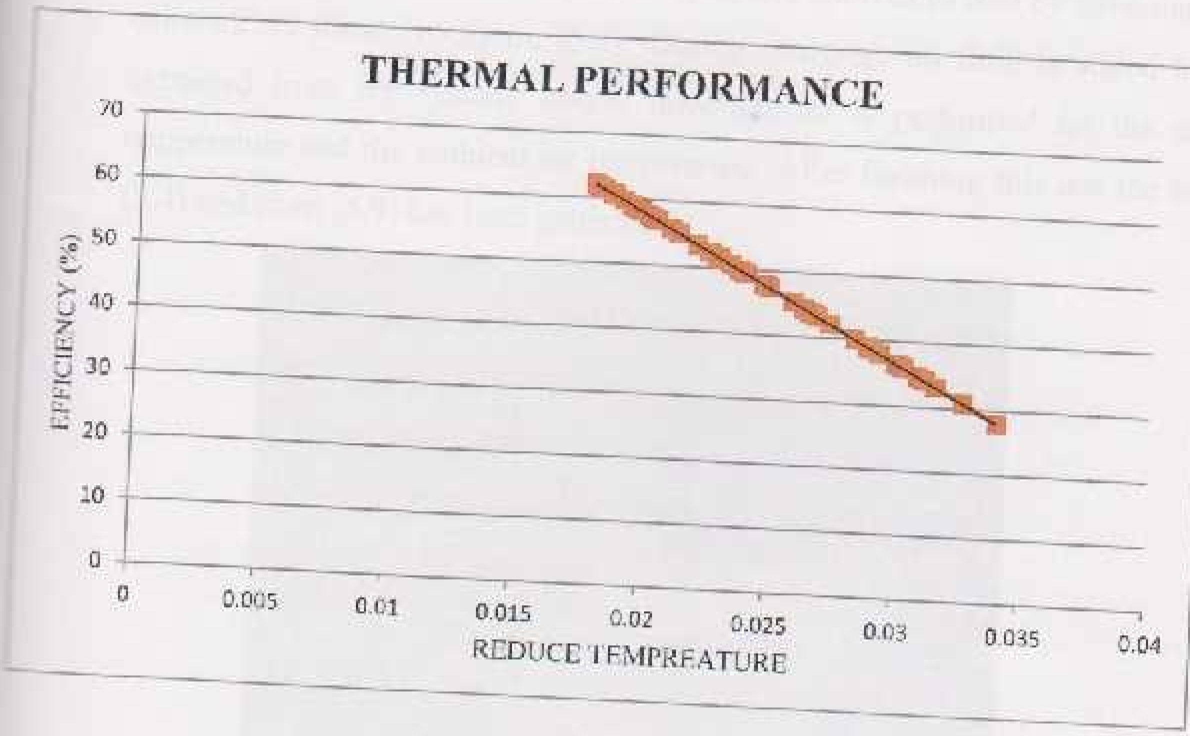


Chart (5.8): Collector Thermal performance testing

2. Thermal capacity for the collector test

This test is prepared to calculate the thermal capacity $(mC_p)_c$ for the flat-plate solar collector. The procedure that done in this test is charged the water inside the collector by sun radiation up to 85 □ C, and allowed to cool by covering the collector as shown in figure (5.2). During charging, no fluid is added to or extracted from the system; hourly measurement is performed for the store temperature and the ambient air temperature. After finishing this test the table (5.4) and chart (5.9) has been generated.

Figure (5.2): Covering the collector

Table (5.4): Temperature of collector and the ambient air

Date Time, GMT+03:00	Temp, °C Tc(in)	Temp, °C Tc(out)	Temp, °C Ta	Tc (°C)
5/6/2013 12:57	68.227	101.542	28.196	84.8845
5/6/2013 13:32	57.218	40.92	26.94	49.069
5/6/2013 14:07	48.737	30.192	27.063	39.4645
5/6/2013 14:37	44.165	27.628	26.182	35.8965
5/6/2013 15:07	41.913	26.818	27.505	34.3655
5/6/2013 15:37	39.943	25.137	27.161	32.54
5/6/2013 16:07	37.811	23.833	26.304	30.822
5/6/2013 16:37	35.022	22.034	24.532	28.528
5/6/2013 17:07	33.313	21.175	23.785	27.244
5/6/2013 17:37	30.925	19.936	23.184	25.4305
5/6/2013 18:07	28.493	18.842	22.681	23.6675
5/6/2013 18:37	25.963	17.748	21.485	21.8555
5/6/2013 19:07	23.569	16.63	20.222	20.0995
5/6/2013 19:37	21.915	15.819	19.46	18.867
5/6/2013 20:07	20.841	15.366	19.318	18.1035
5/6/2013 20:37	20.15	15.175	19.508	17.6625
5/6/2013 20:47	20.007	15.223	19.532	17.615
5/6/2013 20:57	19.888	15.247	19.579	17.5675
5/6/2013 21:02	19.841	15.247	19.579	17.544
5/6/2013 21:07	19.793	15.223	19.579	17.508
5/6/2013 21:12	19.746	15.223	19.603	17.4845
5/6/2013 21:17	19.698	15.223	19.627	17.4605
5/6/2013 21:22	19.651	15.223	19.532	17.437
5/6/2013 21:27	19.603	15.199	19.579	17.401
5/6/2013 21:32	19.555	15.175	19.341	17.365
5/6/2013 21:37	19.508	15.151	19.365	17.3295
5/6/2013 21:42	19.484	15.151	19.365	17.3175
5/6/2013 21:47	19.436	15.103	19.413	17.2695
5/6/2013 21:52	19.389	15.079	19.175	17.234
5/6/2013 21:57	19.365	15.055	19.365	17.21
5/6/2013 22:02	19.318	15.031	19.175	17.1745
5/6/2013 22:07	19.246	14.984	19.032	17.115

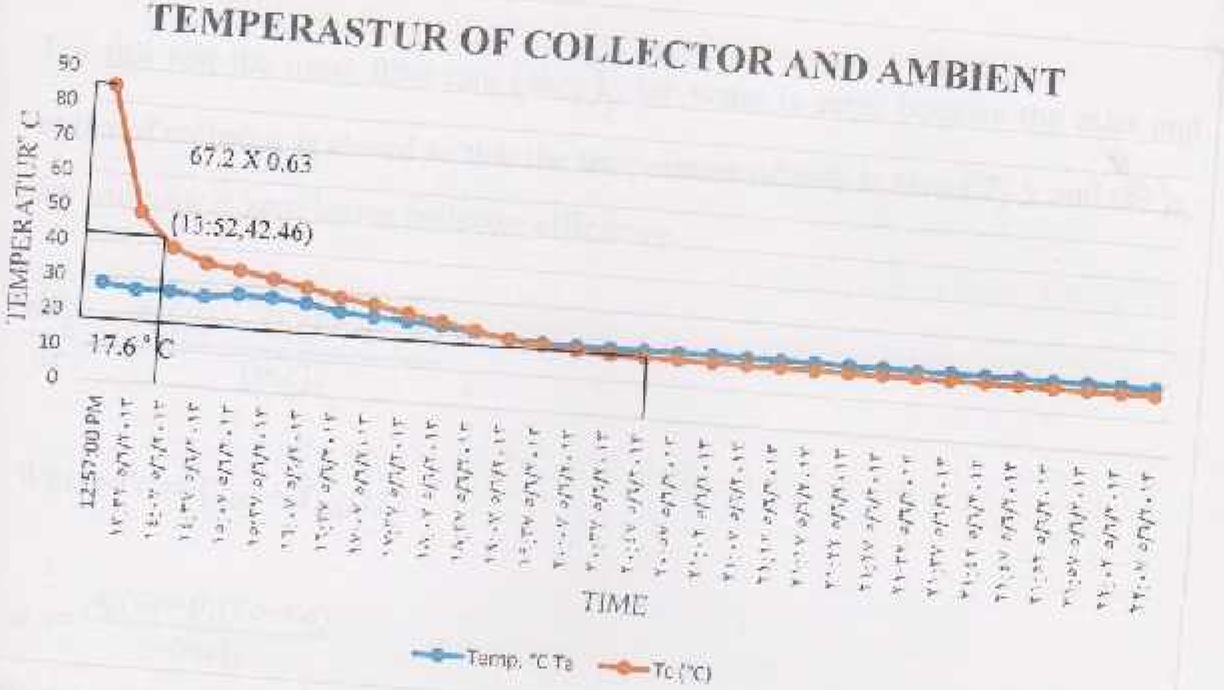


Chart (5.9): Temperature of step input with time

From chart (5.9), the thermal capacity of collector can be calculated by using the equation (5.11). And by calculated the time constant where is required for a system whose performance can be approximated by a first-order differential equation, to have its output changed by 63.22 % of its final change in output following a step change in input.

Solar plate internal heat change rate:

$$\frac{dT_c}{dt} = -\left(\frac{A_c U_l + \eta_c (\dot{m} c_p)_f}{(mc)_c}\right) T_c + \left(\frac{\eta_c (\dot{m} c_p)_f}{(mc)_c}\right) T_i + \left(\frac{A_c}{(mc)_c}\right) G_T + \left(\frac{A_c U_l}{(mc)_c}\right) T_a \quad \ldots..(5.11)$$

For this test the mass flow rate $(\dot{m}c_p)_f$ for water is zero, because the inlet and outlet of collector is closed so that the temperature of tank is zero (T_t), and the η_c for collector is zero losses collector efficiency.

$$\frac{dT_c}{dt} = \frac{A_c(G_T - U_l(Tc - Ta)}{(mc)_c}$$

Where $Tc = (T_{in} + T_{out})/2$

$$a = \frac{A_c(G_T - U_l(Tc - Ta)}{(mc)_c}$$

By observing Eq. (5.11), we find it has the same form as that of a first-order system has.

$$T_c(\tau) = a\left(1 - e^{\frac{-t}{\tau}}\right) \quad \text{..... (5.12)}$$

From chart (5.9) the following calculation are obtained:

Step input at steady state = $84.4 - 17.6 = 67.2\,^\circ C$

At $0.63X67.2\,^\circ C = 42.3\ C$

To find time constant at $(84.4 - 42{,}3 = 42.4\,^\circ C)$

$\tau = 13.32 - 12.57 = 35\ minuts$

τ = 2100 second

The thermal capacity can be calculated from equation (5.12), when a = 29.16

The thermal capacity $(mc)_c = 47.5\ W/K$

5.5 SDHW system with management

Chart (5.10) shows the change in water temperature inside one 50 liter storage tank in the morning period at 7:00 a.m., so by 30 minutes the water temperature reach 50 □ C that the consumer can use this hot water in multi tasks instead of using the electrical heating that cost a lot of money.

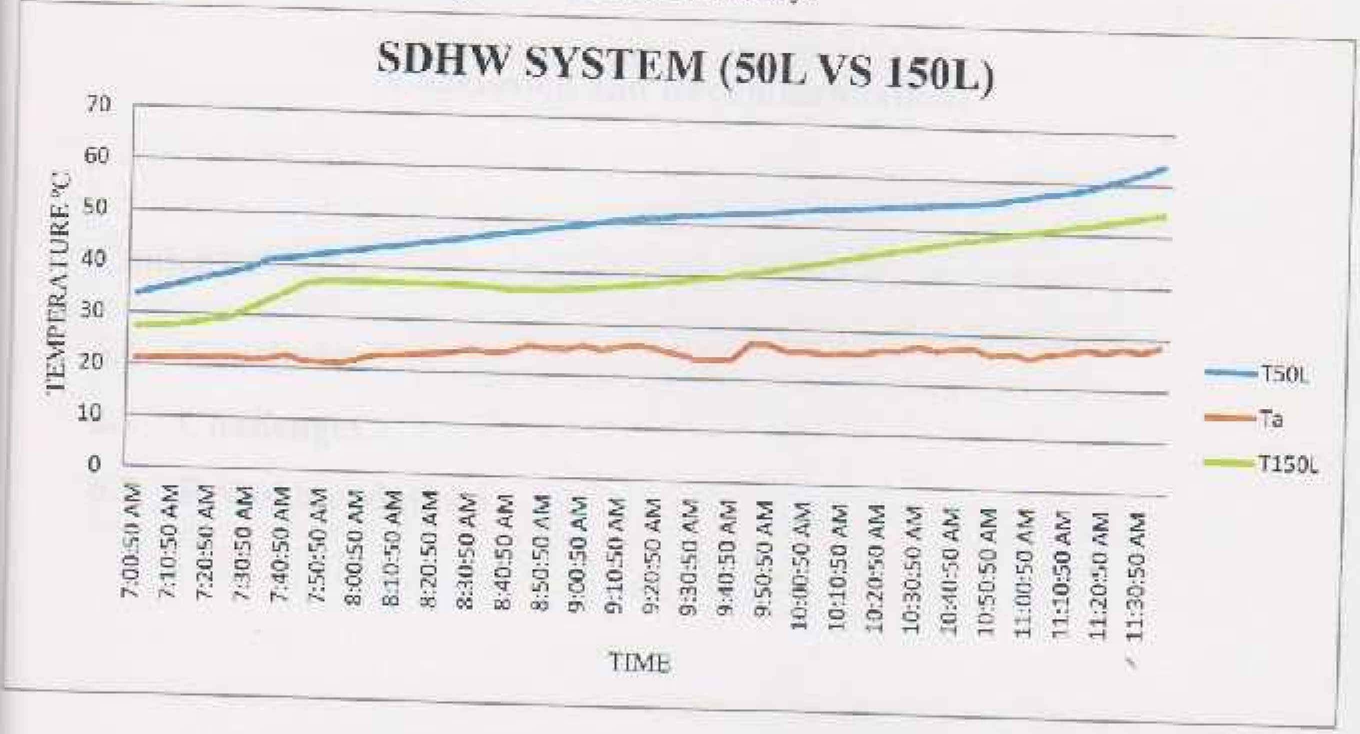


Chart (5.10): SDHW system (for 50 liter tank)

Chapter Six

Conclusion and Recommendations

Contents:

Chapter Six

Conclusion and Recommendations

6.1 Conclusion

There are many tests done in this project to find the performance of the solar domestic hot water system and increase its efficiency by increasing the thermal performance of the flat-plate solar collector, and by dividing the commercial storage tank into multi storage tanks.

However, the conclusion that obtained from this project that the new model system is more efficient than the commercial one, because the period that needed to heat the 50 liter storage tank is less than the 200 liter, especially in the morning period. On other hand, the management and the control panel added some efficiency to the system by store the hot water inside the tank and using it when the sun radiation is decrease.

6.2 Challenges

While designing and testing the system, there are many challenge were faced, such as:

- Not all the sensors locations were fitted correctly.
- The flow meter was not read the data.
- The cloudy weather condition in the last two weeks.

6.3 Recommendations

In this project, the system has been designed to acquire more efficiency for the solar domestic hot water system by increasing the performance for the flat-plate collector, and dividing the solar storage tank into multi tanks and managing them. but these issues did not cover all the things.

This project recommends making additional processes that add a pump to the system and controlling it to control the flow inside the collector, and also add three pipes inside the tanks at three different levels to get a suitable water temperature as user desired.

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[12] http://personal.cityu.edu.hk/~bsapplec/solar1.htm

[13] hp ://burro.cwru.edu/Academics/Astr306/Coords/coords.html

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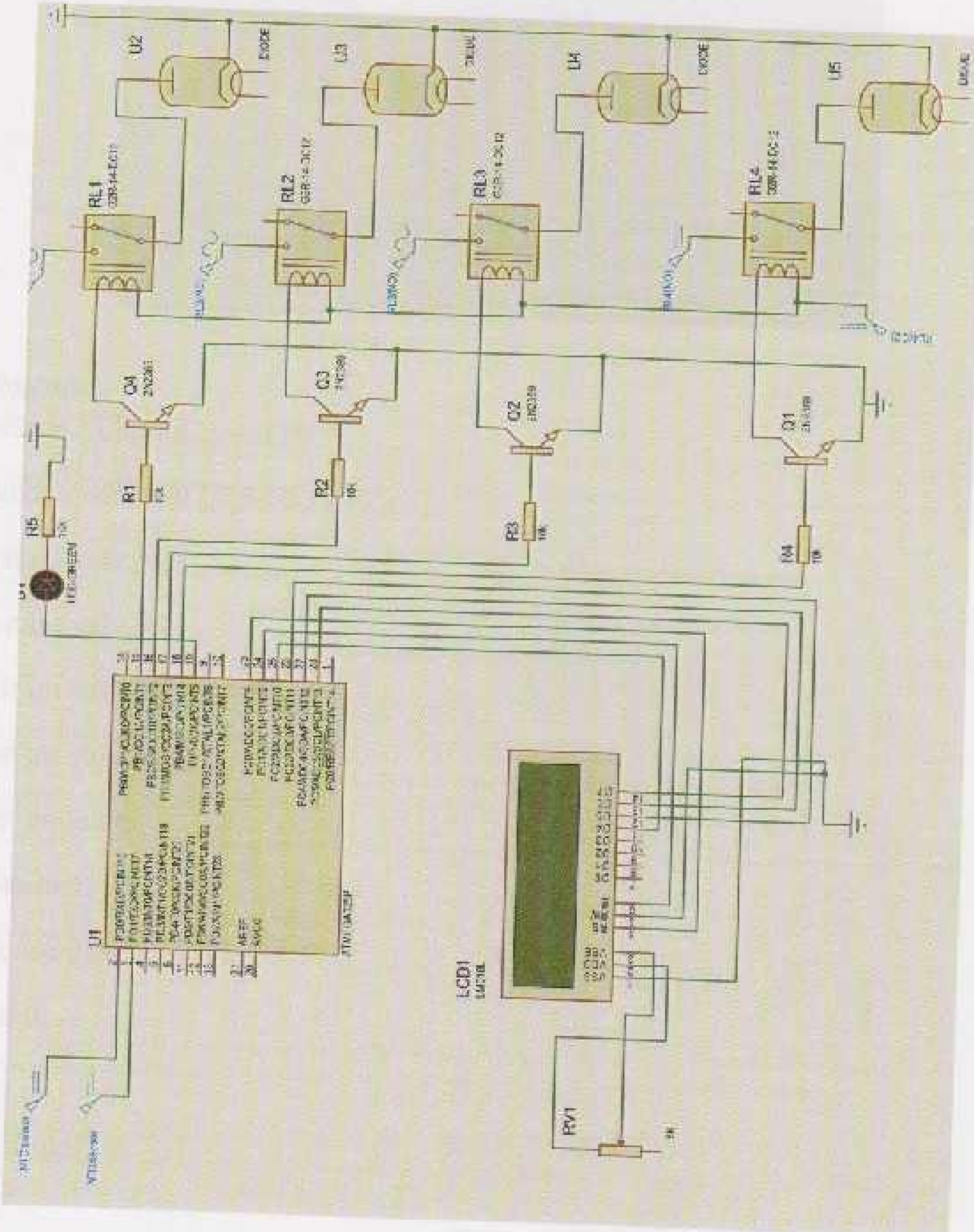
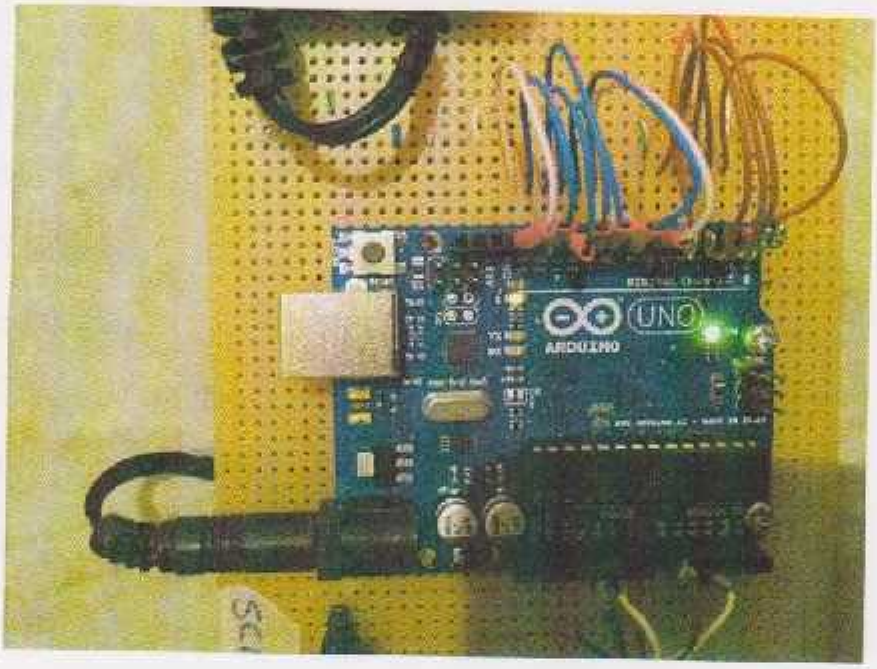
APPENDIX

Appendix (A)

Arduino UNO:

Connection of circuit as shown in the figure()





Program:

```
#include <LiquidCrystal.h>

LiquidCrystal lcd(7,8,9,10,11,12);

const int valv1=1;

const int valv2=2;

const int valv3=3;

const int valv4=4;

const int led=5;

int sensor1;

int sensor2;

int st=0;


void setup()
```

```
{
 lcd.begin(16, 2);
 lcd.setCursor(3, 0);
 lcd.print("Design By: ");
 lcd.setCursor(0, 1);
 lcd.print(" Yahya & Mousa");
 delay(3000);
 lcd.clear();
 lcd.setCursor(3, 0);
 lcd.print("Supervisior:");
 lcd.setCursor(0, 1);
 lcd.print("Momen Zughayyer");
 delay(3000);
 lcd.clear();
 pinMode(valv1,OUTPUT);
 pinMode(valv2,OUTPUT);
 pinMode(valv3,OUTPUT);
 pinMode(valv4,OUTPUT);
 pinMode(led,OUTPUT);
}
void loop()
{
```

```
digitalWrite(lcd,HIGH);
// digitalWrite(valv1,HIGH);
//digitalWrite(valv2,HIGH);
sensor1=analogRead(0)*25.24;
sensor2=analogRead(1)*25.24;
lcd.setCursor(0, 0);
lcd.print("Temp.Tank1=");
lcd.setCursor(0, 1);
lcd.print("Temp.Tank2=");
lcd.setCursor(11, 0);
lcd.print(sensor1/204);
lcd.setCursor(11, 1);
lcd.print(sensor2/204);
lcd.setCursor(15, 0);
lcd.print("C");
lcd.setCursor(15, 1);
lcd.print("C");

switch(st)
{
case(0):
    digitalWrite(valv1,HIGH);
```

```
    digitalWrite(valv2,HIGH);
    digitalWrite(valv3,HIGH);
    digitalWrite(valv4,HIGH);
   st=1;
 break;

 case(1):
     if((analogRead(0)*25.24/204) >= 50 && (analogRead(1)*25.24/204) < 50)
       st=2;
     if((analogRead(0)*25.24/204) < 50 && (analogRead(1)*25.24/204) >= 50)
       st=3;
    if((analogRead(0)*25.24/204) > 50 && (analogRead(1)*25.24/204) > 50)
      st=4;
    if((analogRead(0)*25.24/204) < 50 && (analogRead(1)*25.24/204) < 50)
      st=5;
break;

case(2):
    digitalWrite(valv1,HIGH);
    digitalWrite(valv2,LOW);
    digitalWrite(valv3,LOW);
    digitalWrite(valv4,HIGH);
  st=1;
```

```
break;

case(3):
    digitalWrite(valv1,LOW);
    digitalWrite(valv2,HIGH);
    digitalWrite(valv3,HIGH);
    digitalWrite(valv4,LOW);
    st=1;
break;

case(4):
    digitalWrite(valv1,HIGH);
    digitalWrite(valv2,HIGH);
    digitalWrite(valv3,HIGH);
    digitalWrite(valv4,LOW);
    st=1;
break;


case(5):
    digitalWrite(valv1,LOW);
    digitalWrite(valv2,HIGH);
    digitalWrite(valv3,HIGH);
```

```
        digitalWrite(valv4,LOW);
        st=1;
   break;
  }
}
```

LCD display

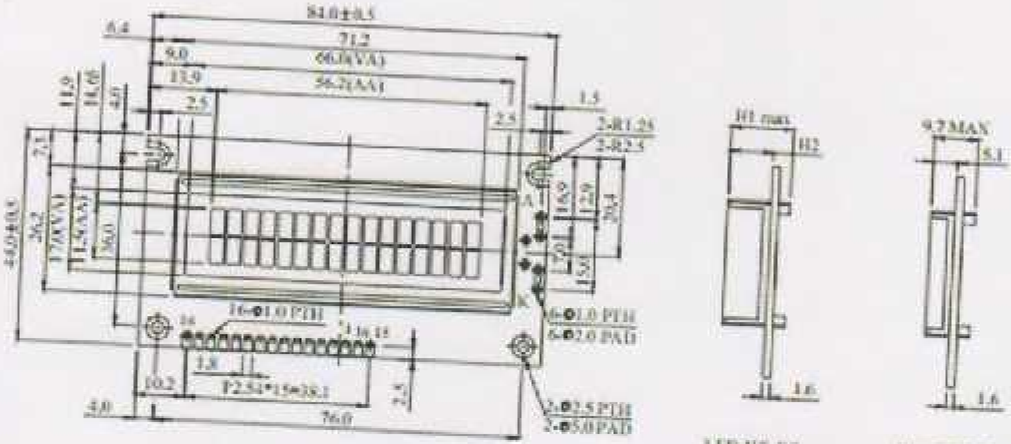
- General specification

Item	Dimension	Unit
Number of Characters	16 characters x 2 Lines	□
Module dimension	84.0 x 44.0 x 13.5(MAX)	mm
View area	66.0 x 16.0	mm
Active area	56.20 x 11.5	mm
Dot size	0.55 x 0.65	mm
Dot pitch	0.60 x 0.70	mm
Character size	2.95 x 5.55	mm
Character pitch	3.55 x 5.95	mm
LCD type	STN, Positive, Transflective, Gray	
Duty	1/16	
View direction	6 o'clock	
Backlight Type	LED Yellow green	

- Interfacing pin function

Pin No.	Symbol	Level	Description
1	V_{SS}	0V	Ground
2	V_{DD}	5.0V	Supply Voltage for logic
3	VO	(Variable)	Operating voltage for LCD
4	RS	H/L	H: DATA, L: Instruction code
5	R/W	H/L	H: Read(MPU→Module) L: Write(MPU→Module)
6	E	H,H→L	Chip enable signal
7	DB0	H/L	Data bit 0
8	DB1	H/L	Data bit 1
9	DB2	H/L	Data bit 2
10	DB3	H/L	Data bit 3
11	DB4	H/L	Data bit 4
12	DB5	H/L	Data bit 5
13	DB6	H/L	Data bit 6
14	DB7	H/L	Data bit 7
15	A	□	LED +
16	K	□	LED□

- Contour Drawing &Block Diagram

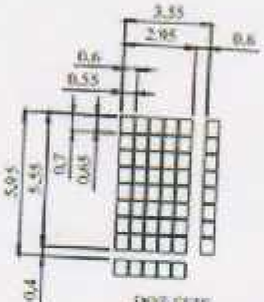


LED-B/L B/L

	High	Low
H1	13.5	12.1
H2	8.9	7.5

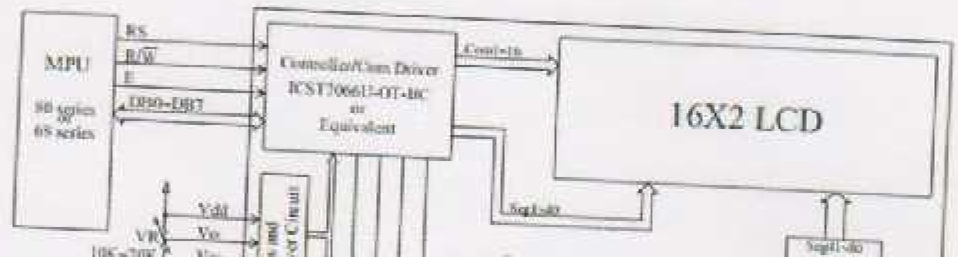
EL or NO B/L

PIN NO	SYMBOL
1	Vss
2	Vdd
3	Vo
4	RS
5	R/W
6	E
7	DB0
8	DB1
9	DB2
10	DB3
11	DB4
12	DB5
13	DB6
14	DB7
15	A/Vcc
16	K



DOT SIZE

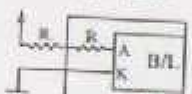
The non-specified tolerance of dimension is ±0.3mm.



LED B/L Drive Method

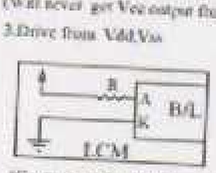
1.Drive from A,K

2.Drive from pin15, pin16



(Will never get Vcc output from pin15)

3.Drive from Vdd,Vss



(Contrast performance may go down.)

Recommanded Value

(1) V_{DD}= 4.2V, I_{LED}= 130mA
R= 6.2Ω (1/2 Watt)

(2) V_{DD}= 4.0V, I_{LED}= 20mA
R= 40Ω (1/2 Watt)

Character located	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DDRAM address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
DDRAM address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F