Experimental Investigation of an Inclined Combined Solar Hot Water and Desalination System

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ABSTRACT

The main aim of this research is to design a new solar collector for heating the water and use it in water desalination. This study gives information about the inclined solar water desalination and heating system design, construction and the results of the system.

The performance of the inclined solar water desalination and heating system was studied with different mass flow rates and systems. Different systems and mass flow rates were compared. In this study 6 different mass flow rates and 2 different systems were tested. In the first system, two different storage tanks were used. In the first system one storage tank sends the water to the solar collector and then hot water goes to second storage tank. There is no circulation in this system. This system was tested with 3 different mass flow rates and the average efficiency of the system is 65% and average daily water production is 2134,1 ml/m^2. In the second system one storage tank was used. The second system has circulation and because of this the inlet temperature of the water increases. The same water circulates in this system and this reduces the water quality. This system was tested with 3 different mass flow rates. The average efficiency of the system is 72% and daily average water production is 2833.17 ml/m^2. The cost of the collection and payback analysis of the system are shown in the economic analysis section.

Keywords: Solar energy, inclined water desalination and heater, efficiency, daily water production

ÖZ

Bu tezde Kıbrıs'taki insanların sıcak su elde etmek için kullandıkları güneş enerji panellerini yeniden tasarlayarak, ülkede yaşanan su sorununu çözmek amaçlanmaktadır. Bu tez, yatay su arıtma ve su ısıtma cihazının tasarımı, üretimi, maliyeti ve sonuçları hakkında bilgi vermekte ve ayrıca diğer su arıtma yöntemlerinin çalışma prensipleri de anlatılmaktadır.

Güneş enerjisi ile yatay su ısıtma ve arıtma sisteminin performansı farklı debiler ve sistemler ele alınarak incelenmiştir. Güneş panelinden alınabilecek en verimli sistem dizayını belirlenmiştir. Bu belirlenme olana kadar debiler ve sistemler birbirleriyle mukayese edilmiştir. İki farklı sistemde 6 farklı debi denenmiştir. İlk sistem iki tanklı sistem olarak tasarlanmıştır. Sistem, güneş paneline sürekli yeni su girişi yaparak çıkan sıcak suyun başka bir tankta toplanması şeklinde tasarlanmıştır. Bu sistemde 3 farklı debi kullanarak elde edilen ortalama verimlilik 65% ve içilebilir günlük su üretimi 2134,1 ml/m^2'dir. İkinci sistem ise tek tanklı sistem olarak tasarlanmıştır. Tek tanklı sistem, suyun sürekli döngüsünü sağlayarak giriş suyundaki sıcaklığın artışını hedeflemektedir. Aynı su sürekli döndüğü için panele giren suyun kalitesi düşecek ama sıcaklık oranı yükselecektir. Bu sistemde 3 farklı debi kullanarak elde edilen averaj verimlilik 72% ve içilebilir günlük su üretimi 2833.17 ml/m^2'dir. Güneş panelinin üretim alanında olan maliyet ve geri dönüşümü hakkında bilgiler raporun ekonomik analizi kısmında mevcuttur.

Anahtar Kelimeler: Güneş enerjisi, yatay su arıtma ve ısıtma, verimlilik, içilebilir günlük su üretimi

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

The most important enviromental problem in the world today is global warming and this is due to the increase in carbondioxide emmission to the atmosphere and greenhouse effect. The fossil based energy sources reserves are limited and therefore the need to alternative energy increases. Solar energy is a clean source and mostly used in hot countries. Solar energy is the most usefull renewable energy in Cyprus which is an island in Eastern Mediterranean region. It is mostly used in the water heating systems in Cyprus. The Daily average duration solar radiation time in Cyprus is 7.5 hrs.

World Resource Institute's (WRI) Aqueduct project recently evaluated, mapped, and scored water risks in many countries. This project is the first country-level water assessment. WRI found that 36 countries face "extremely high" levels of baseline water stress. As it is seen in Table 1.1. This means that more than 80 percent of the water available to agricultural, domestic, and industrial users are withdrawn annually leaving businesses, farms, and communities vulnerable to scarcity (Paul Reigh, 2013). Cyprus has one of the highest water stress ranking (5.0). The country is densely populated and has no freshwater lakes or aquifers, and its demand for water far exceeds its naturally occurring supply.

Table 1.1: Top countries facing water stress *(Paul Reigh, 2013)*

Top Countries Facing Water Stress

RANK	COUNTRY NAME	BASELINE WATER STRESS SCORE
1	Antigua and Barbuda	5.00
1	Bahrain	5.00
1	Barbados	5.00
1	Comoros	5.00
1	Cyprus	5.00
1	Dominica	5.00
1	Jamaica	5.00
1	Malta	5.00
1	Qatar	5.00
1	Saint Lucia	5.00
1	Saint Vincent and the Grenadines	5.00
1	San Marino	5.00
1	Singapore	5.00
1	Trinidad and Tobago	5.00
1	United Arab Emirates	5.00
1	Western Sahara	5.00
17	Saudi Arabia	4.99
18	Kuwait	4.96
19	Oman	4.91
20	Libya	4.84
21	Israel	4.83
22	Kyrgyzstan	4.82
23	East Timor	4.81
24	Iran	4.78
25	Yemen	4.67
26	Palestine	4.63
27	Jordan	4.59
28	Lebanon	4.54
29	Somaliland	4.38
30	Uzbekistan	4.32
31	Pakistan	4.31
32	Turkmenistan	4.30
33	Morocco	4.24
34	Mongolia	4.05
35	Kazakhstan	4.02
36	Afghanistan	4.01

The system used in this study has one inclined absorber. This system is a model for the clean water production and also, it decreases the electrical energy consuption which is used for heating water. Cyprus is one of the leading countries in the World, using solar water heating. Developing a combined system to produce both hot water and potable water will be more beneficial to the homeowners.

In this study, chapter 1 is about the introduction, aim, main objectives and scope of the thesis. Chapter 2 gives information about solar desalination and hot water system and previously used systems. Theory and design section of the sandwich type solar collector is discussed in chapter 3. Experimental results and calculation sections are discussed in chapter 4. Chapter 5 is the discussion and conclusion of the study.

1.1 Aims and Objectives

The purpose of this study is to design a sandwich type solar collector which will be used for water heating and purifying brackish water. The proposed system is designed, constructed and experimentally investigated. The main aim is to design an efficient combined hot water desalination system. Both domestic hot water and potable water are essential commodities. Many people in Cyprus are buying potable water in bottles for consumption. Several decades ago water from the mains was edible, but presently brackish water is coming from the mains.

The main objectives of this study are to;

- Produce a sandwich type solar collector which will be used for heating and punfying brackish water
- Obtain the experimental data for the system and evaluate the system efficiency

1.2 Scope

Standart solar collector is constructed with pipes which are 2 mm steel. 2 mm galvanized sheet metal is used in this study because of the sandwich type shape of the collector. Cyprus which is a hot country, is located in Eastern Mediterranean region. Cyprus has long sunny days and is one of the leading country using solar water heating in the World. Also Cyprus has potable water problem. Capacity of natural sources decrease everyday and because of this, new and alternative methods for fresh water production started to be research. One of them is sandwich type solar collector which will be used for water heating and purifying brackish water. The main focus of this thesis is to design and construct one sandwich type solar collector which is used for water heating and prufying brackish water. Solar panel efficiency is evaluated experimentally.

Chapter 2

LITERATURE REVIEW

2.1 Desalination System

Desalination is a process that removes salt and other dissolved solids from brackish water or seawater. Sometimes, the term for the process is spelled as desalinization; also, it is referred to as desalting or is shortened to desal. In this thesis, the term desalination will be used. Table 2.1 shows the classification of saline water based on TDS:

Table 2.1: Classification of saline water based on TDS (Trieb, 2009)

River water / low concentrated brackish water	500-3.000 mg/L TDS
Brackish water	3.000-20.000 mg/L TDS
Sea water	20.000-50.000 mg/L TDS
Brine	>50.000 mg/L TDS

The World Health Organization (WHO) recommends water with a salinity below 1000 mg/L for drinking water and irrigation. Industrial process or process water for power plants require a much higher water quailty with a TDS less than 10 mg/L. (Trieb, 2009).

The US Environmental Protection Agency (EPA) states that drinking water with TDS greater than 500 mg/L can be distasteful. Brackish water has a salinity between that of fresh and saline sea-water, and usually results from mixing of seawater with fresh water, as in estuaries, or in brackish fossil aquifers. In addition to removing salt, some desalination processes, like reverse osmosis, can remove many forms of minerals, suspended solids, viruses and organic compounds, such as algae and bacteria. Figure 2.1 shows global installed desalination capacity by feed water sources. (Frederick, 2010)

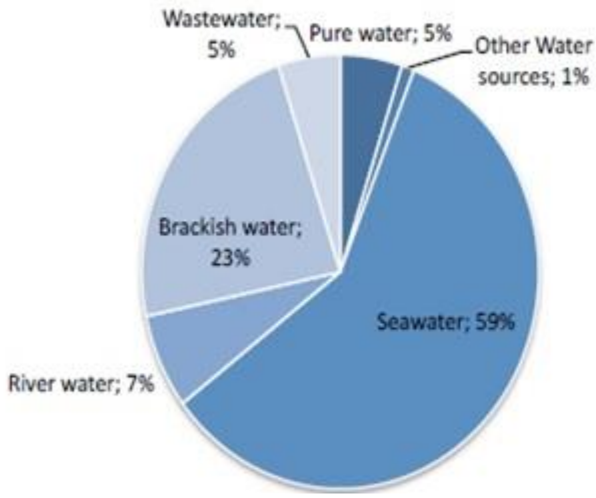


Figure 2.1: Global installed desalination capacity by feed water source (Frederick, 2010)

The idea of separating salt from water is old. As populations and demands for fresh water expanded, entrepreneurs began to look for ways of producing fresh water in remote locations and, especially, on naval ships at sea. Aristotle (384-322 BC) wrote that “Salt water when it turns into vapour becomes sweet and the vapour does not form salt water again when it condenses”.

The first patents for seawater distillation in the history of western science have been published at the end of the 17^{th} century, 1675 by William Wilcot and followed 1683 by Robert Fitzgerald (Forbes, 1970). In 1790, United States Secretary of State

Thomas Jefferson received a request to sell the government a distillation method to convert salt water to fresh water. A British patent was granted for such a device in 1852. The first place to make a major commitment to desalination was the island of Curaçao in the Netherlands Antilles. Plants have operated there since 1928 and even the local beer is made with desalinated water.

A major seawater desalination plant was built in 1938 in Saudi Arabia. Research on desalination was conducted during World War II to identify ways to meet military needs for fresh water in water-short regions. The United States and other countries continued to work after the war. The U.S. Congress passed the Saline Water Conversion Act in 1952, which created and funded the Office of Saline Water within the Department of the Interior's Bureau of Reclamation.

Methods of solar distillation has being employed by mankind for thousands of years. From early Greek mariners to Persian alchemists, this basic technology has been utilized to produce both freshwater and medicinal distillates. Solar stills were in fact the first method used on a large scale to process contaminated water and convert it to a potable form. (Kalogirou, 2009).

The first commercial land-based seawater desalination plant was installed by the Ottomans in Jeddah, Saudi Arabia. This crude distillation unit was a boiler working under atmospheric pressure. But this unit suffered from severe scale deposits and corrosion problems. It is now part of a historical monument on Jeddah Corniche (Al-Shayji, 1998).

In the 1960s and 70's several modern solar distillation plants were constructed on the Greek islands with capacities ranging from 2000 to 8500 m^3/day. In 1984 a MED plant was constructed in Abu-Dhabi with a capacity of 120 m^3/day and is still in operation (Dellyannis, 2003).

Desalination technologies are categorized into two main groups, thermal and membrane desalination. These are then broken down into subgroups that process salty water technically in many different ways. The following section discusses the operational aspects of the current seven most prominent desalination technologies, Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), Mechanical Vapor Compression (MVC) and Thermal Vapor Compression (TVC), Solar Distillation (SD), Reverse Osmosis (RO), Electro-Dialysis (ED) (Frederick, 2010). Figure 2.2 shows the Worldwide installed desalination capacity by technology

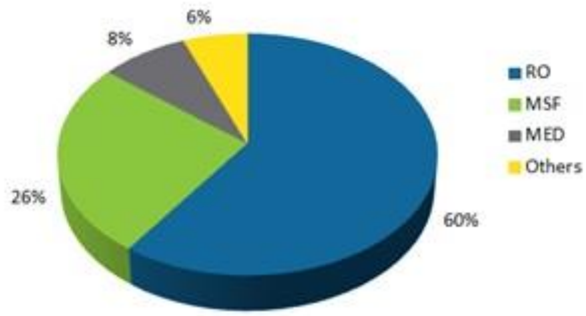


Figure 2.2: Worldwide installed desalination capacity by technology
(Definition Desalination and Global Situation, 2012)

Figure 2.2 shows that reverse osmosis is the dominant desalination technology which is membrane, mainly it has lower capital costs and lower energy requirements and because of the modularity of the technology. The other two are related with thermal desalination which is multi-stage flash and multi effect disalination. The other is solar desalination , electrodialysis etc.

2.1.1 Thermal Desalination

2.1.1.1 Multi-Stage Flash

Multi-stage flash distillation (MSF) is a water desalination process that distills sea water by flashing a portion of the water into steam in multiple stages of what are essentially countercurrent heat exchangers. Multi-stage flash distillation plants produce about 60% of all desalinated water in the World (Multi-stage flash distillation, 2014).

The process consists of many stages. In each stage the steam produced in the previous stage condenses and simultaneously preheats the feed water. Thus, the temperature difference between the hot source and seawater is fractionated into a number of stages. Therefore, the system approaches ideal total latent heat recovery. The operation of such a system requires pressure gradients in different stages; i.e. stages should be at successively lower pressures. Seawater, preheated in various stages, enters the solar collector, where it is heated to nearly saturation temperature at the maximum system pressure. As the water enters the first stage through an orifice, its pressure is reduced, thus becomes superheated and flashes into steam. The steam produced passes through a demister to remove any suspended brine droplets, then to a heat exchanger where it condenses. This process is repeated through the various stages. (Al-Kharabsheh, 2003).

2.1.1.2 Multi-Effect Distillation

Multiple-effect distillation (MED) is a distillation process often used for sea water desalination. It consists of multiple stages or "effects". In each stage the feed water is heated by steam in tubes. Some of the water evaporates, and this steam flows into the tubes of the next stage, heating and evaporating more water. Each stage essentially reuses the energy from the previous stage (Multiple-Effect Distillation, 2014). The heat transfer in MED is with dual phase flow, thus degassing occurs during evaporation. However the tube surface can only be cleaned chemically. The maximum steam temperature is limited to 70°C due to scaling, i.e. the number of stages is also limited.

2.1.1.3 Vapor Compression

Vapor compression desalination refers to a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapor. Since compression of the vapor increases both the pressure and temperature of the vapor, it is possible to use the latent heat rejected during condensation to generate additional vapor. The effect of compressing water vapor can be done using two methods which are Mechanical Vapor Compression and Thermal Vapor Compression (Vapor-Compression Desalination, 2014).

2.1.1.4 Solar Distillation

Solar distillation is the use of solar energy to evaporate water and collect its condensate within the same closed system. Unlike other forms of water purification it can turn salt or brackish water into fresh drinking water (i.e. desalination). The structure that houses the process is known as a solar still and although the size, dimensions, materials, and configuration are varied, all rely on the simple procedure wherein an influent solution enters the system and the more volatile solvents leave in the effluent leaving behind the salty solute behind (Solar Distillation, 2012).

The basic concept of using solar energy to obtain drink-able fresh water from salty, brackish or contaminated water is really quite simple. Water left in an open container in the backyard will evaporate into the air. The purpose of solar stills in to capture this evaporated water by condensing onto cool surface, using solar energy to accelerate the evaporation. Figure 2.3 shows the basic concept of the solar distillation of water.

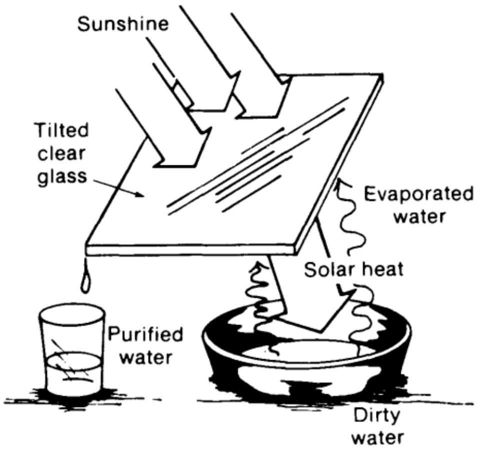


Figure 2.3: Basic concept of the solar distillation of water (McCluney, 1984)

The rate of evaporation can be accelerated by increasing the water temperature and the area of the water in contact with air. A wide, shallow pan painted black makes an ideal vessel for the water. It should probably be baked in the sun for a while before it is used in order to free the painted of any volatile toxicants which might otherwise evaporate and coondense along with the drinking water. The pan is painted black to maximize the amount of solar energy absorbed. It should also be wide and shallow to increase the water area exposed to air. The addition of a spongy material to the water would further increase the surface area, assuming the availability of a substance with good solar absorbing properties and durability in heated salt water.

To capture and condense the evaporated fresh water, we need some kind of surface close to heated salt water which is several degrees cooler than the water. A means is then needed to carry this fresh water to a storage tank. The evaporating pan usually is covered by a sheet of clear glass which is tilted at a slight angle to let the fresh water that condenses on its underside trickle down to collecting trough. The glass also holds the heat inside. Figure 2.4 combines all these components in a single still design.

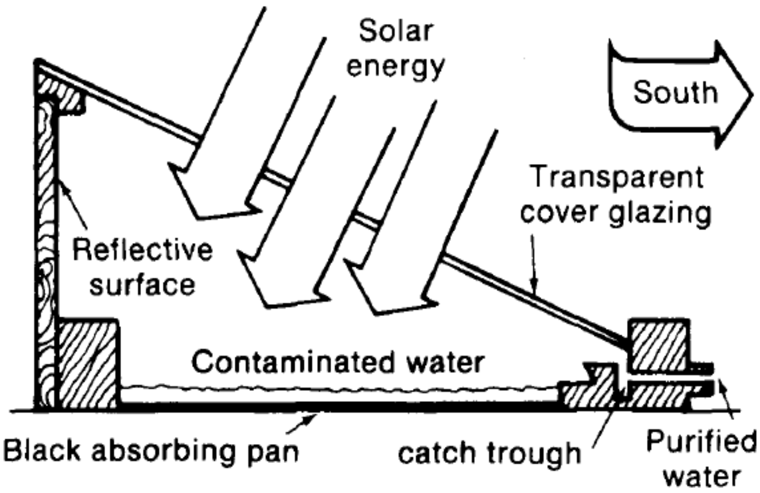


Figure 2.4: A simple solar still design (McCluney, 1984)

2.1.2 Membrane Desalination

2.1.2.1 Reverse Osmosis

Reverse osmosis (RO)uses pressure on solutions with concentrations of salt to force fresh water to move through a semi-permeable membrane, leaving the salts behind. The amount of desalinated water that can be obtained ranges from between 30% and 85% of the volume of the input water, depending on the initial water quality, the quality of the product needed, and the technology and membranes involved. (Heather Cooley, 2006).

2.1.2.2 Electro-Dialysis

Electrodialysis (ED) can be economical process particularly on brackish water with TDS level of up to 5.000 mg/L. For seawater desalination, ED is restricted to small-scale desalination plants with low to medium salinity water (<3.000 mg/L). The ED method comprises only 5% of desalination capacity in the World.

ED works by forcing ions of salt to move from the seawater to seperate compartments through the membranes. Some pre-treatment of the feedwater is needed to prevent the membranes from clogging. The membranes are placed in both side of feedwater channel, Electrodes are placed on the sides, one attracts positive ions and the other attracts negative ions. When an electric current is applied to the feedwater, it forces positive ions to move to one side and negative ions to the other side, but not both sides. This results in two solutions, one is highly concentrated saline solution and the other is the freshwater. Some post-treatmen might be needed to adjust the pH level and remove gases such as hydrogen sulphide.

2.2 Thermal Solar Collectors

There are basically three types of thermal solar collectors: Flat-Plate, Evacuated-Tube and Concentrating. Each type of collector is explained in brief in the following sub-sections.

2.2.1 Flat Plate Solar Collector

These type of collectors include an insulated, weatherproof box containing a dark absorber plate under one or more transparent (i.e. glass or plexiglass). Water or heat conducting fluid passes through pipes positioned below or the absorber plate. As the fluid flows through the pipes it is heated. This type of collector is less efficient in many ways compared to evacuated tube collectors, but is still the most general type of collector in many countries. Figure 2.5 shows the schematic view of Flat-Plate Solar Collector.

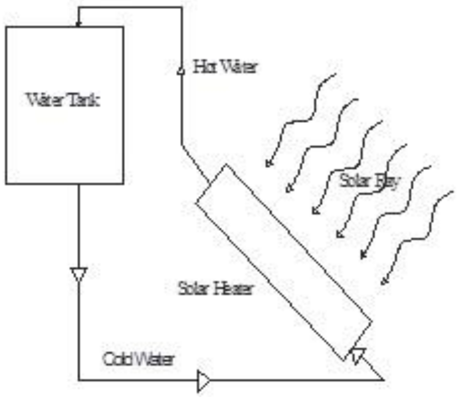


Figure 2.5: Schematic view of flat-plate solar collector

Figure 2.5 also shows natural circulation solar water heater, consisting of a collector, a water storage tank and the connecting tubes. When solar radiation falls on the collector, it brings a temperature difference between the lower and upper ends of the collector. The temperature difference causes a density variation given rise to buoyancy forces.

2.2.2 Evacuated Tube

Evacuated tube solar collector water heaters are made up of rows of parallel, glass tubes. There are several types of evacuated tubes used in solar thermal collectors. Each evacuated tube consists of glass tubes made from extremely strong glass.

The transparent outer tube allows sunlight to pass through with minimal reflection. The inner tube is coated with selective coating. This selective surface is excellent absorbing solar radiation with minimal reflection losses (Active Solar Water Heating System).

2.2.3 Concentrating Collectors

These type of collectors are usually parabolic trough that use mirrored surfaces to focus the sun's energy on an absorber tube containing a heat-transfer fluid, or the water itself. This type of solar collector is generally used for business power production applications, as very high temperatures can be achieved. It is however dependent on direct sunlight and therefore does not perform well in cloudy conditions, and for maximum performance tracking is required.

2.3 Inclined Solar Water Desalination System

The inclined solar water desalination (ISWD) system consists of an inclined flat solar absorber plate covered with glass. The heating and evaporating processes take place on the absorber plate, and then the condensing process takes place on the glass cover. The most important feature of the system is the fact that the system produce shot water while it produces fresh drinking water. The heated water can be used as domestic hot water if it is not briny to increase evaporation a porous medium is used.

Many researchers study about developing and improving the ISWD systems. One important study is the work of the Aybar, Egelioğlu and Atikol (Aybar, 2004). This study shows that system can produce potable water and hot water at the same system.

In system the feedwater comes from an intermediate tank and goes into a distribution pipe. The water then falls through this slot onto the black absorber plate or onto black wick, creating a layer of water all over the absorber plate. Solar energy warms the absorber plate. Some of the water evaporates and condenses as it touches the cool glass cover. The condensed water flows into a condensation channel and is taken out of the side of the cavity. The rest of the feed water, which is hot water, flows into another collection channel called the remaining water channel. The hot water is taken out from the bottom center of the remaining water channel. The fresh water and hot water are collected in seperate tanks (Aybar, 2004).

Chapter 3

THEORY

In this chapter, the theory of the solar collector and its operating principles, as well as a description of the system design, material selection, thermal calculation, are given.

3.1 System Design

An inclined solar desalination and solar water heater system having a sandwich type collector is designed. First of all, collector is designed for both water heating and desalination part. Secondly, the box is designed to consider water inlet and outlet way, also it is designed as a collector. Then this two parts are assembled. System explained as collector design, box design and final assembly of the sandwich type solar collector.

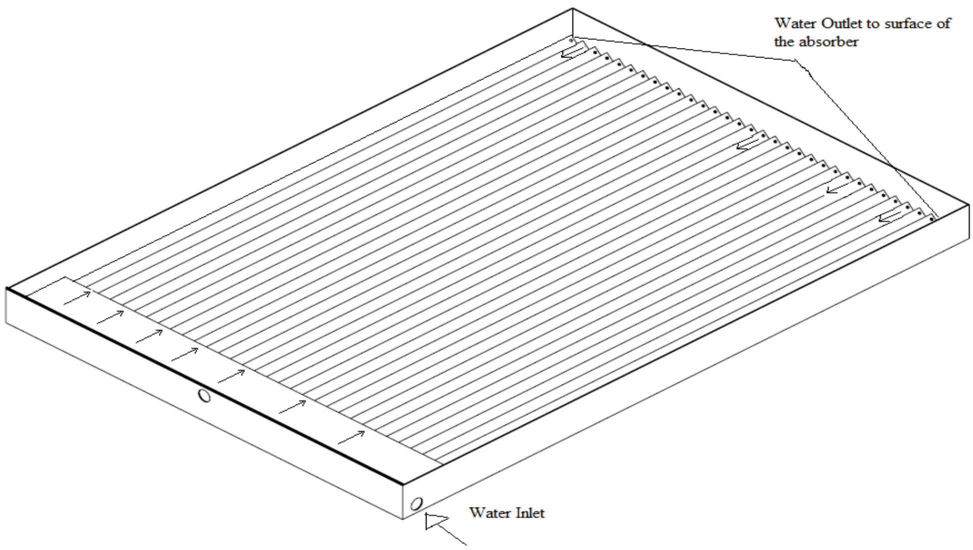


Figure 3.1: Working principle of the absorber

The water enters the collector at bottom right side of the absorber and starts to divide the channels which is 'ʌ' shape and 32 pieces. The water passes through, the plates and exits at the top of the absorber plate, then it goes back to the bottom of the absorber. Figure 3.1 explains working principle of the absorber.

At this step, some part of the water starts to desalinate, the water goes to bottom of the absorber from surface and is collected at the glass cover. Then it goes to clean water channel which is constructed from sheet metal, and it helps to store the water at clean water storage tank. Rest of the water is collected at the bottom of the absorber and it goes to the hot water storage tank. Figure 3.2 shows the working principle of the system.

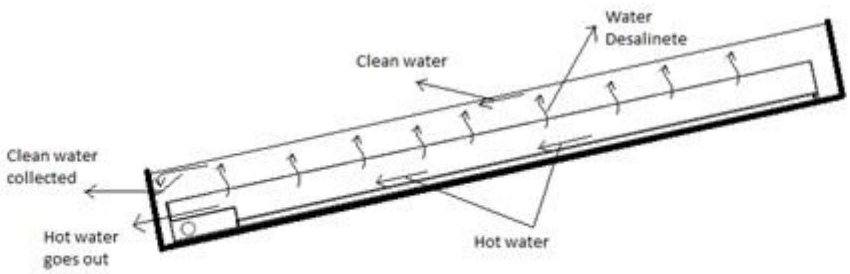


Figure 3.2: Working principle of the system

3.1.1 Solar Collector Design

A sandwich type collector consists of three sheet metals placed two on top of the other. The sides are soldered and the plates are further joined by spot welding. The main aim of the spot welding is to provide better contact of water with absorber plate, that will increase the heat transfer from the absorber plate to the fluid (i.e. water). In the design process, it is decided to build a smaller size solar collector. Because this project is experimental and we wanted to use less equipment for production. For this production, 1 mm galvanized sheet metal which is 1000 mm wide and 2000 mm high is used. Collector is designed at three steps, firstly upper part of the collector.

For upper part, half of the galvanized sheet metal which is 1000 mm wide 1000 mm high is designed, and for better heat transfer, shape of sheet metal looks like ‘ʌ’ is used. This will increase the surface of the collector and it will help for better spot welding. Hovewer the size of the shape is smaller than before and for water supply. 100 mm gap is given.

Because of this reason 100 mm from upper part is cut and shape would have aproximately 750 mm width and 900 mm height. Then small holes at highest point for water to go out from the collector is designed. Those holes are not bigger than 3mm in diameter. Figure 3.3 shows plan and isometric view of the upper part of the collector.

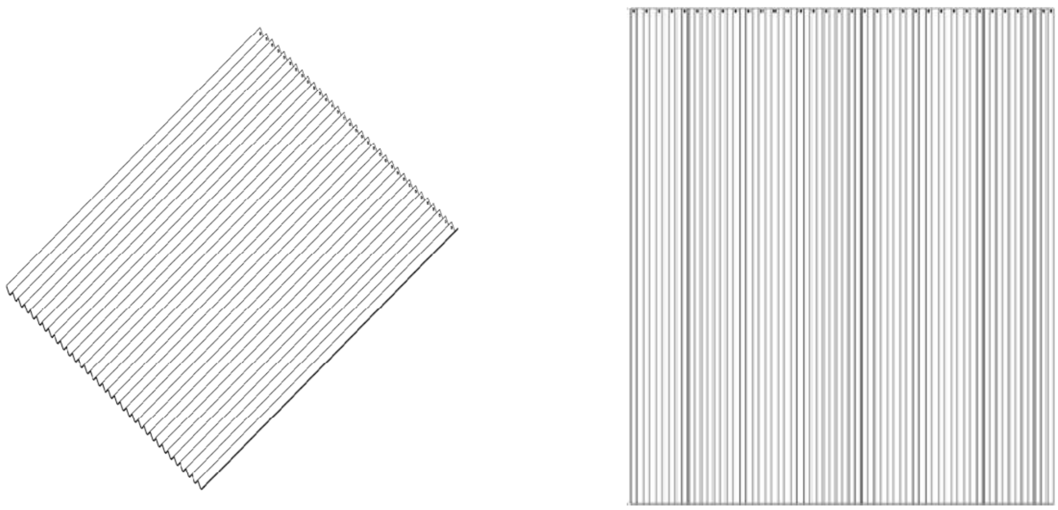


Figure 3.3: Isometric and plan view of the upper part

Upper part have ‘ʌ’ shape and it has spot welding. Because of this, one water supply for seperating the water to the channels which is ‘ʌ’ shape is designed. The sides of the shape is 1,5 cm because of this the depth of the highest point is aproximately 10 mm. Figure 3.4 show the shape of the single channel.

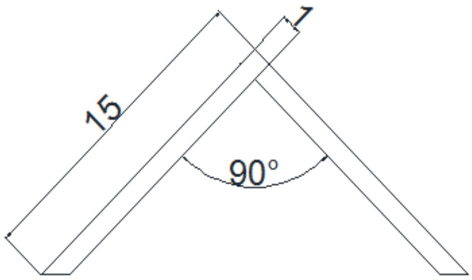


Figure 3.4: Shape of the single channel (dimensions are in mm)

In the design, water comes from bottom right to the collector and it has one area for going to each channel. That area has 100 mm height, 750 mm width which is same with upper part and 30 mm depth. Depth is 30 mm because 20 mm steal pipe for sending the water to the water supply is used. Figure 3.5 show the water supply.

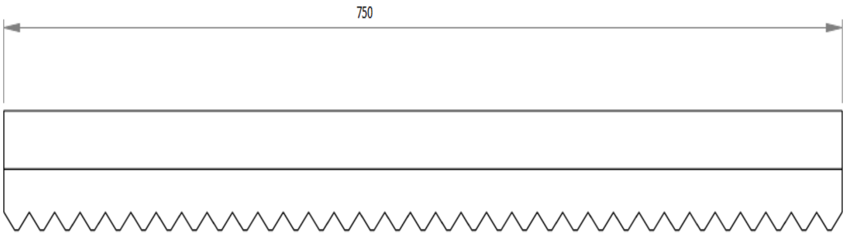


Figure 3.5: Water supply (dimensions are in mm)

Bottom part of the collector is like a box. 50 mm depth for easy collection of the water is designed. Also the hot water flows to the hot water storage tank easily, from back side of the collector. Collector has two pipes. One of them is under the collector, and it send hot water to the storage tank and the other one which is at the right side of the absorber, sends cold water to the collector. The collector works due to gravity; heated water rises as it becomes less dense, the circulation is natural i.e., the system is passive.

3.1.2 Box Design

In this part, the box that contains the absorber plate is galvanized-sheet metal having 1,5 mm thickness and is bended in shape of rectangular-prism and top is covered with glass. The height is 1050 mm, depth is 240 mm and width is 800 mm. When absorber is placed into the collector, there are 25 mm gaps between each edge of the panel and absorber. These gaps are filled with glass wool for insulation. And box have one water channel for clean water which comes from the glass surface.

To cover the panel and keep the air inside, a 3mm thick glass is cut in size of 1050 mm x 800 mm. The purpose of glazing is to trap the solar radiation passing through the glazing and condensed the water vapor to the water and send to the clean water channel for collecting at clean water storage tank.

3.1.3 Final Assembly of Sandwich Type Solar Collector

Final assembly of the collector includes connection of bronze units to the inlet and exit water holes. Glass is placed on top and is made air tight using heat resistant silicone. Figure 3.6 shows the final assembly drawing of the solar collector in Solid Works drawing.

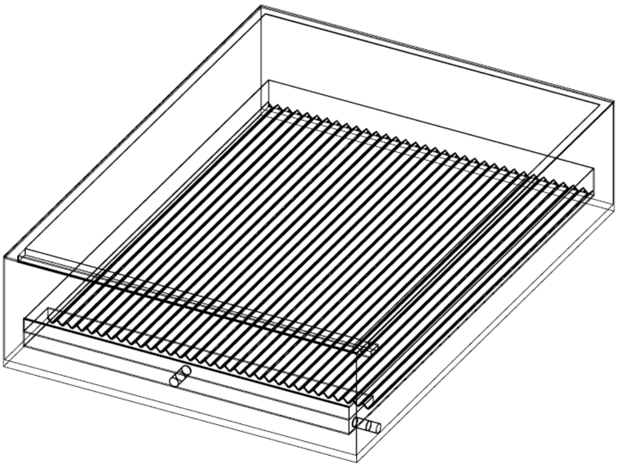


Figure 3.6: Final assembly drawing of the solar collector

Figure 3.7 shows the sectional view of the solar panel, i.e., to prevent heat loss through the bottom. Glass is placed on the top of the panel to allow solar radiation to pass and trap it within the collector. All drawings inculude in Appendix C.

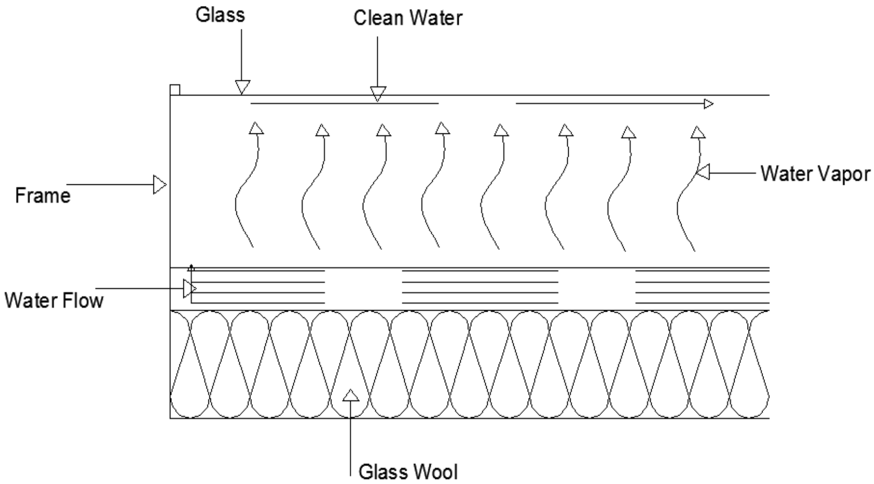


Figure 3.7: Sectional view of solar panel

3.2 Material Selection

In this project, low cost materials were used to benefit from sun as much as possible and to keep the cost lower than conventional systems. This Project is similar to solar water heating system. However, it has desalination part. Galvanized sheet metal is used for producing absorber which heats the water, and soldered for sticking the galvanized sheet metal. Heat resistant silicon are used for closing the small holes which is not soldered. For constructing the box, the same procedure are followed, that is same with conventional system such as; glass wool, glass etc.

3.2.1 Galvanized Sheet Metal

Galvanized metal is simply steel in some form that has received a thin coating of zinc oxide. The purpose of the zinc is to protect the steel from elements that normally would lead to oxidation, corrosion and the eventual weakening of the steel. In this sense, the zinc coating acts as what is called a sacrificial anode. In other words, the zinc will protect the steel from corrosion by acting as a barrier between the steel and the corrosive agent, at least until the zinc coating has been completely oxidized. Galvanized metal is often used in the constructions. Other possible materials can be copper plate, aluminium or stainless steel. All these are more expensive compared to galvanized steel plate.

A 1 mm and a 1.5 mm galvanized sheet metal is used at this project. One of them is for absorber plate, the other is for covering box. One sheet metal has 1000 mm width and 2000 mm length.

3.2.2 Solder

Solder is a fusible metal alloy used to join metal workpieces and having a melting point below that of the workpiece. Soft solder is typically thought of when solder or soldering is mentioned, with a typical melting range of 90 to 450 °C. It is commonly used in electronics, plumbing, and assembly of sheet metal parts. Manual soldering uses a soldering iron or soldering gun. Alloys that melt between 180 and 190 °C are the most commonly used. Soldering performed using alloys with a melting point above 450 °C is called 'hard soldering', 'silver soldering', or brazing (Solder, 2014).

Solder would be used for easy stick. Galvanized sheet metal is not welding very well and it has some liking spaces because it is not to withstand temperatures. Soldered is sticky at very low temperature so it is better than other welding.

3.2.3 Heat Resistant Silicon

Heat resistant silicone is a one component silicone sealant for high temperature applications. It is a one part acid-curing sealant which reacts with atmospheric moisture to form elastic silicone rubbers that are especially designed for high temperature applications. Heat resistant silicon is particularly recommended for sealing and joining in applications where high heat resistance is required for extended periods, such as oven doors and fire flues.

Heat resistant silicon closes each small space which is in the box. Solder is not used for the box. Therefore heat resistant silicon is used for the air space.

3.2.4 Glass Wool

Glass wool is made from silica sand, an inorganic raw material, which is obtained domestically. It is produced through heating silica sand at 1200˚C - 1250˚C and transforming it into fibres. It can be manufactured in the forms of blanket, board, pipe or loose in different sizes and with different technical properties, with different facing materials according to the intented use and the place of use. It is used for thermal insulation, sound insulation, acoustic comfort as well as fire safety.

Glass wool is a cheap material and it is found easly in North Cyprus. Also it is a good material for thermal insulation.

3.3 Thermal Calculation

Energy can be transferred to or from a given mass by two mechanisms: heat transfer Q and work W. An energy interaction is heat transfer if the driving force is a temperature difference.

For calculating the efficiency of the absorber, some usefull equations are needed. In the Cengel's book which is related with thermodynamics and heat transfer show the energy equations and efficiency calculations. Also the heat loss of the plate is calculated.

3.3.1 Output Energy

Total solar energy received by the absorber equals the sum of the heat energy escaping the collector and the useful heat energy extracted from it, because energy never disappears. If Q_a represents the rate of solar heat gain (expressed in W) by the absorber, Q_e and is the rate of heat loss, then the rate of useful heat collection, Q_c , is given by

$$Q_c = Q_a - Q_e \qquad (1)$$

Usually Q_c and Q_a are the easiest quantities to calculate, and Q_e is expressed as the difference between them.

The rate of solar heat collection is easily determined by measuring the mass of the fluid m (kg) and the inlet and outlet temperatures T_{in} and T_{out} [°C]. The solar heat extracted, in W of collector per hour, is then

$$\dot{Q}_c = \dot{m} * C_p * (T_{out} - T_{in}) \qquad [W] \qquad (2)$$

$$\dot{q}_c = \frac{\dot{Q}_c}{A_s} \qquad [W/_{m^2}] \tag{3}$$

Where; C_p is the specific heat of the fluid 4.1855 [kJ$/kg * k$] for water and A_s is the surface area of the collector which is 0,72 m^2. (Çengel, 1998)

For desalination part, energy is calculated with $\dot{Q}_d$ with the unit of W. $\dot{Q}_d$ and $\dot{Q}_c$ is a total used energy of the system. The equation of desalination is that

$$\dot{Q}_d = \dot{m} * h_{fg} \qquad [W] \tag{4}$$

$$\dot{q}_d = {\dot{m} * h_{fg}}/{A_s} \qquad [W/_{m^2}] \tag{5}$$

Where; $\dot{m}$ is the mass flow rate of the fresh water, h_{fg} is heat of vaporization of water which is 2257,1 $[kJ/kg]$. (Çengel, 1998)

3.3.2 Solar Energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaics, solar thermal electricity, solar architecture and artificial photosynthesis. Solar radiation calculated by pyranometer with the equation given below. The pyranometer is put on the surface of the solar panel. It will take the data from the sun which the solar radiation comes with angle to the surface of the solar panel. The data substituted into is the equation to calculate the solar radiation which is (Q_{rad}). Pyranometer is shown in appendix A when it is used for receiveing datas.

$$\dot{Q}_{rad} = {}^{1000}/_{10,5} * P * A_s \quad [W] \tag{6}$$

$$\dot{q}_{rad} = {}^{1000}/_{10,5} * P \quad [{}^{W}/_{m^2}] \tag{7}$$

Where; P is the pyranometer value which measured with voltmeter, A is the area of the solar collector surface. (Çengel, 1998)

3.3.3 Thermal Efficiency

The fraction of the heat input that is converted to network output is a measure of the performance of a heat engine and it is called thermal efficiency (η_{th}). Performance or efficiency, in general, can be expressed in terms of the desired output.

$$Performance = \frac{Desired\ output}{Required\ input} \tag{8}$$

For solar collector, the desired output is the output energy by collector ($\dot{Q}_c$), and the required input is the solar energy ($\dot{Q}_{rad}$). Then the thermal efficiency of a solar collector can be expressed as

$$Thermal\ Efficiency = \frac{Output\ Energy}{Solar\ Energy} \tag{9}$$

Or

$$\eta_{th} = \frac{\dot{Q}_c + \dot{Q}_d}{\dot{Q}_{rad}} = \frac{\dot{q}_c + \dot{q}_d}{\dot{q}_{rad}} \tag{10}$$

This equation shows the efficiency or performance of the solar panel. (Çengel, 1998)

Chapter 4

EXPERIMENTAL PROCEDURE

4.1 Construction

1 and 1,5 mm galvanized sheet metals were used in the collector as absorber plate. 1.5 mm galvanized sheet metal is used for the box and 1 mm galvanized sheet metal is used for the absorber. The upper plate of the absorber is 1000 mm width and 1000 mm length. For increasing the surface area, '^' shape is given to the galvanized sheet metal, with a bending machine. At every 15 mm, sheet metal is bended with 90 degrees angle and the highest debth is nearly 10 mm as shown Figure 4.1.

Figure 4.1: Sheet metal is bended

At last, 32 pieces channel is formed with bending machine and the width is changed to 720 mm. Bending machine is shown in Figure 4.1. Small holes are opened at the top of the absorber for sending water to the surface of the absorber. Those holes are opened with driller which is 2 mm diameter. 32 holes send the water to surface of the absorber for evaporation.

Water supply part was produced with 1 mm galvanized sheet metal. This part is used to separate the water to the channels which is 32. Sheet metal cutted with 280 mm width, 100 mm length. It is bended with bending machine for giving the 3 mm depth. Front view of the water supply part is cut by cutter for sending the water to the channels. Figure 4.2 shows the water supply part of the absorber.

Figure 4.2: Water supply part

For bottom part, 1 mm galvanized sheet metal is used, and cut in 1 m length and 720 mm width. This part is like a pan and is prepared by bending machine. The edges are cut with cutter and bended with bending machine by giving 50 mm depth to the shape. Firstly, the edges are welded with spot welding. Than, for better welding, solder is used. For water inlet, holes are opened at bottom and left side, which water supply part and bottom part is connected, at this of bottom part with 20 mm diameter. For outlet water, 20 mm diameter holes are opened at bottom part. Figure 4.3 shows the bottom part.

Figure 4.3: Bottom part

Upper part and bottom parts are connected with spot welding. Spot welding are used at each channel for better connection and sandwich type of collector is constructed. Water supply part are put on the bottom part and all parts are connected with solder. Solder is best option for this project because of low welding temperature point. Absorber is shown in Figure 4.4.

Figure 4.4: Absorber

The sandwich-type absorber was ready for leakage test after surface control. The absorber was filled with water for testing leakage. Surprisingly there were 4 spot-welded points. To prevent these leakages, all leaking points were fixed with solder. The absorber was tested again by filling it with water and there were no leakage.

Frame was produced with 1.5 mm galvanized sheet metal. The length is 1000 mm, width is 800 mm and depth is 200 mm of the frame. The glass cover prepared with same measurement which of length 1000 mm, width 800 mm and depth 200 m. All edges and spaces are connected with bronze welding. The glasswool are put on the bottom surface of the frame. Then absorber is fixed on the glasswool surface. Black paint is used for better efficiency and one channel prapared for fresh water and put to the top of collector and frame is closed with glass cover. Some leakages are closed with silicone and also for glass connection, silicone was used. Figure 4.5 shows the sandiwich type of the collector.

Figure 4.5: Sandwich type solar collector

4.2 Setup

There are two types of setup used in this project. One of them is with two storage tank and other is with one storage tank. One of the stands which were used in older projects was chosen for the stand of system

The system has two storage tanks, one of them is water storage. This tank is placed at higher level than solar collector. Other tank is hot water storage tank and it collects hot water from exit to the solar collector. The hot water is stored in the water storage tank, when it was full. The thermocouple tips were fixed with silicone to the points where data collection was desired. For the fresh water, one small pipe is connected to the fresh water collector which made by sheet metal, with silicone and fresh water send to the bottle for storage.

A pump is used for circulation in one of the storage tank. Storage tank is put on the ground level which is below the solar collector and the water is sent to the collector by a pump. That water turns to the storage tank after finishing the circulation. Figure 4.6 shows the final assembly of the system.

Figure 4.6: Final assembly of the system

The support of solar panel is positioned on 45 degrees angle in order to get use solar energy perpendicular to the surface of collector all the year. The direction of the panel's front face should look to south so that sun light will be able to enter into the panel during all the day. When these adjustments were applied on the supporter frame and the panel and system was ready to take measurements and record data. All photos of the system is included in Appendix A.

4.3 Experimental Equipment

For this experiment, same basic equipments were used. They were needed for calculating results, measuring the datas and working of the system. The three most important equipments are pyranometer, thermocouple and pump used in the experiment. In this section this devices will explain and give some information, they will be used at this experiment.

4.3.1 Pyranometer

Pyranometers are used to calculate the efficiency or Performance Ratio (PR) need to be mounted in the same plane as the panel or collector. This means that the leveling feet has to be removed. The bottom of the pyranometer housing is accurately parallel to the detector. Radiation measured in this way is called Global Tilted Radiation. Global Radiation measured by a meteorological station is always done with a pyranometer mounted and leveled horizontally (Zoen). Eppley payranometer under natural daylight conditions, typical error is ±5%. Figure 4.7 shows the eppley pyranometer which is used in the experiment. Pyranometer value is measured with voltmeter.

Figure 4.7: Eppley Pyranometer (Zoen)

4.3.2 Thermocouple

Thermocouple is a sensor used to measure temperature. Thermocouples consist of two terminals made from different metals. The terminals are welded together at one end, creating a junction and this junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.

There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility. Type J, K, T, & E are “Base Metal” thermocouples, which are the most common types of thermocouples. Type R, S, and B thermocouples are “Noble Metal” thermocouples, which are used in high temperature applications (Thermocouples, 2011).

The k- type thermocouple was used for measuring the temperatures of the system. The temperatures of importance for analysis are the water inlet temperature and water outlet temperature. These thermocouples are fixed at inlet water location and outlet water location for the temperature data. Ten channel digital thermometer registered the temperature of the inlet water and outler water with thermocouples. The range of the thermocouple is between -270^{o}C and 1260^{o}C. Figure 4.8 shows the ten channel thermometer. Type K has a margin of error related to a percentage of the temperature measured. For this thermocouples, it is ±0.75%.

Figure 4.8: Ten channel thermometer (Thermocouples, 2011)

4.3.3 Pump

Pump is a device that is used to transfer water to the absorber from water storage tank. Pump was needed for second setup with one storage tank is used. Pump sends the water to the solar collector and completes circulation. In this project, washing machine pump was used. This helps us to understand the efficiency of the system which is better than two storage tank or not. This pump was used for small sized systems and easy to install. This system needs small pump because of holes which are at the upper part of the solar collector. If large pump was used, the pressure would be a problem. Figure 4.9 shows the pump of the system.

Figure 4.9: Pump

4.3.4 pH Meter

pH meter is a device that is a measure the pH value and TDS value of the water. pH meter has one sensor for measuring the ph value of the water. With same device, TDS value of the water is measured. pH meter has a two button for pH and TDS values of water. Range of the pH value is between 0.00-14.00. Error sensitivity for the pH value is ±0.02%. Range of the TDS value is between 0.00-42.00 ppt. Error sensitivity for the pH value is ±1%. Appendix A11 shows the ph meter.

Chapter 5

RESULTS AND DISCUSSIONS

This chapter gives information about the experimental results. The efficiency of the system was calculated at this section. Data analysis and economic analysis are also given in this chapter.

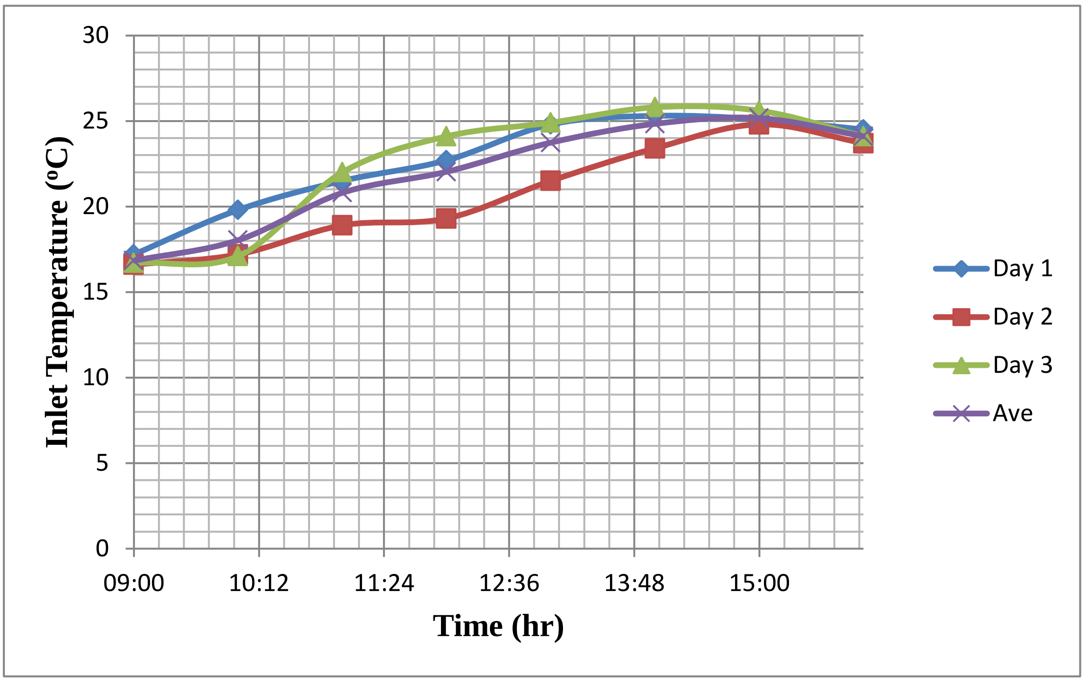
5.1 Data Analysis

In this project 2 systems were studied. One of them is two storage water tank system and other is one storage water tank system. For each system, data are taken for 3 different mass flow rates. Also, each mass flow rate is studied for three days. All Data were taken hourly between 09.00 and 16.00. To ease the data recordings, a record sheet template is created and used while recording. This sheet consists of five different data recordings which are given as:

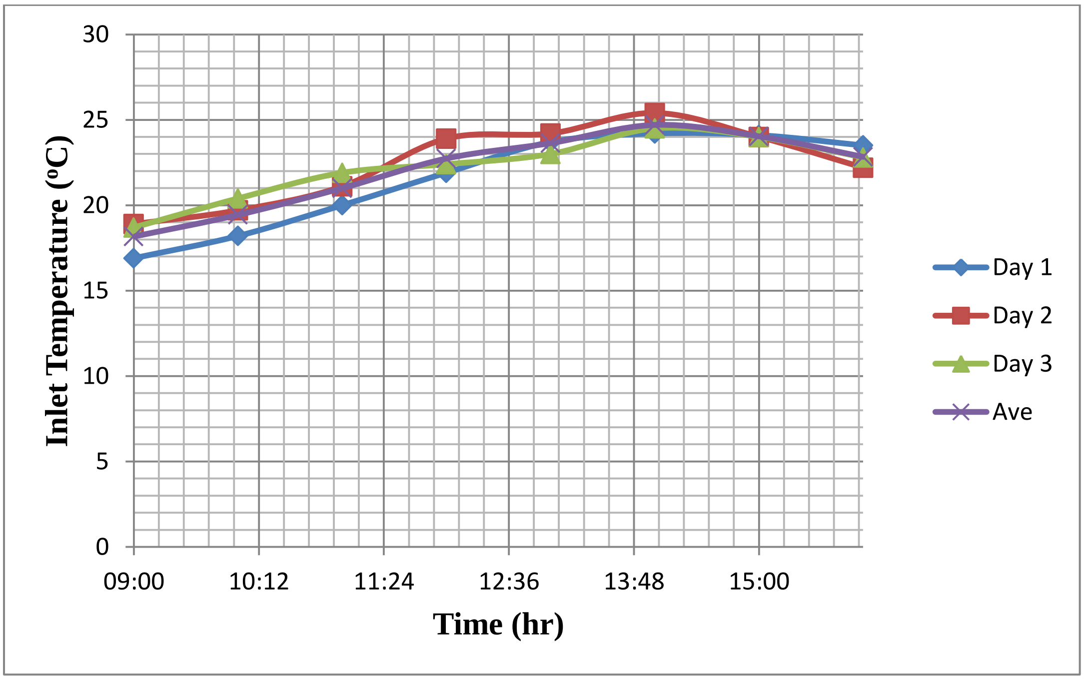
- T_{in} : Water inlet temperature into the panel, ^oC
- T_{out}: Water outlet temperature from the panel, ^oC
- T_{amb}: Ambient temperature, ^oC
- P: Pyranometer value
- FW: Fresh water, ml

5.1.1 Two Storage Tank System

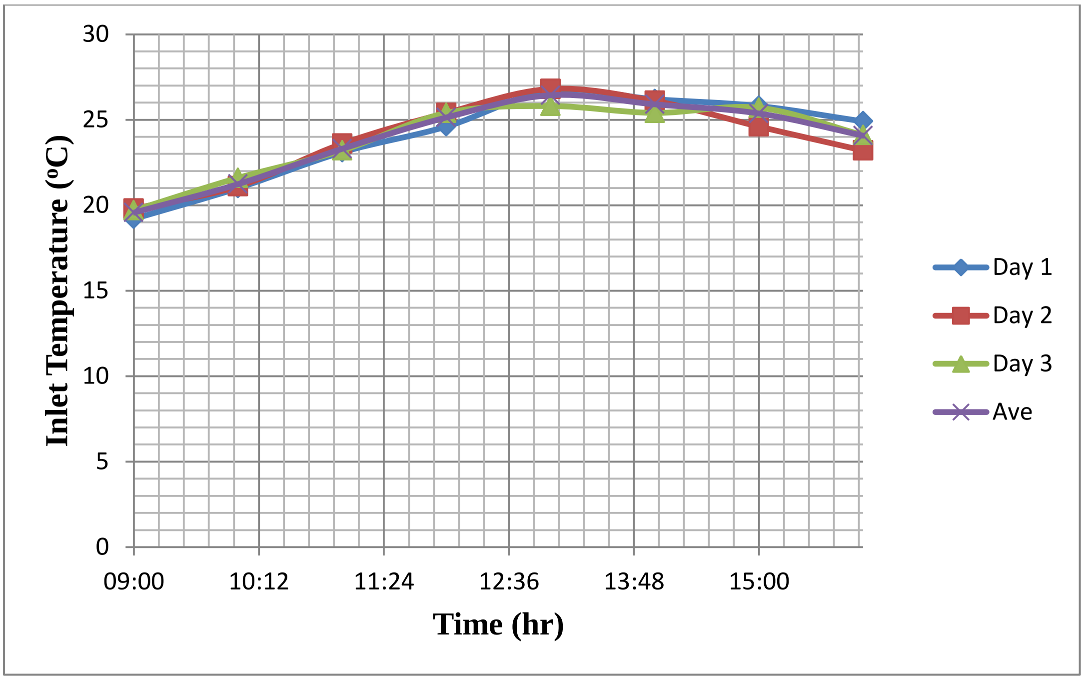
The data of two storage tank system were given in this section. There data were recorded between 30 May and 11 June which is totaly 9 days. Three mass flow rates were used for experiment. Each mass flow rate tested for three days. Those mass flow rates were 0,00963 kg/s, 0,02012 kg/s and 0,00673 kg/s respectively. This section shows the inlet, outlet and ambient temperature, solar radiation and fresh water of the system with graphs. There different mass flow rates are shown at graphs and those mass flow rates are compared at Figure5.10. Inlet temperature is the temperature of water that enter to the solar collector. The highest inlet temperature was 26,8 ^{o}C and the lowest inlet temperature is 16,6 ^{o}C. Inlet temperatures are shown at Figure 5.1. Outlet temperatures are that when the water exit from collector after finishing the circulation, the temperature of the water is called outlet water temperature. The maximum and minimum outlet temperatures were 45,1 ^{o}C and 20,3 ^{o}C respectively. Outlet temperatures are shown in Figure 5.2. Ambient temperature is the atmospheric temperature. Those temperatures are measured with thermometer. Ambient temperatures are shown in Figure 5.3. The solar radiation pattern in each case of the experiment agrees with the theory. The experiment reveals that solar radiation is high in Cyprus specially during the summer season. The solar radiation recorded during the experiment is 1238,1 W/m^2. Solar radiation is shown in Figure 5.4. The daily production of the fresh water related with the solar radiation inlet water temperatue and mass flow rate. This experiment shows the best option for best daily production. The maximum fresh water were 270,83 ml/m^2 at 12 o'clock. Fresh water shown in Figure 5.5. Shematic diagram of the two storage tank is in Appendix C.



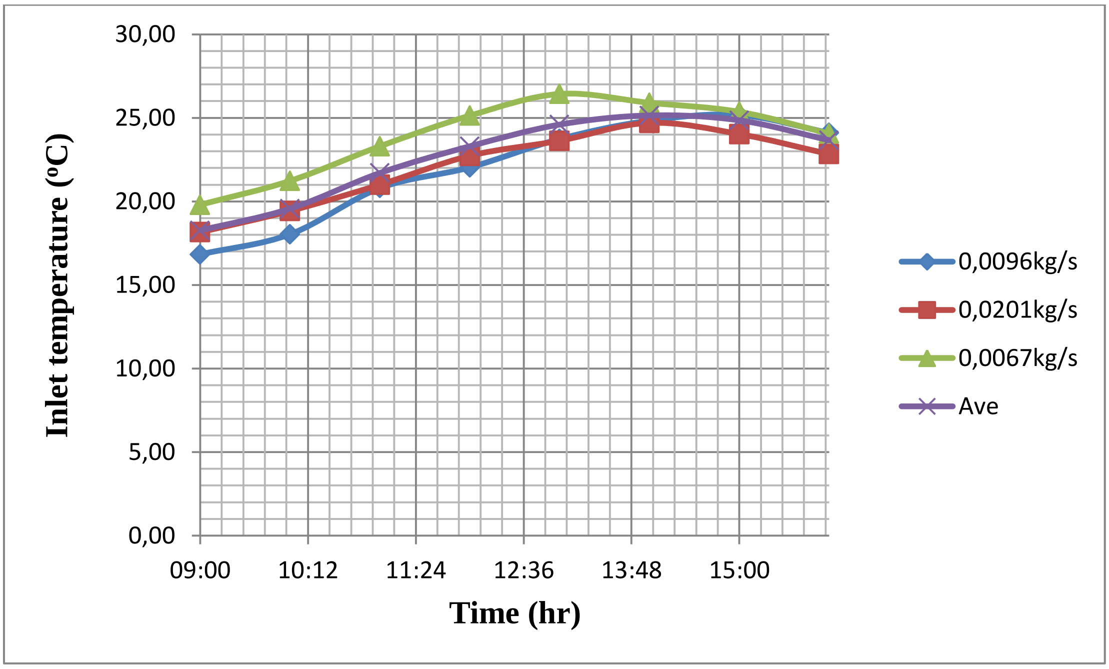
(a) Inlet temperature of the first mass flow rate (0,00963 kg/s)



(b) Inlet temperature of second mass flow rate (0,02012 kg/s)

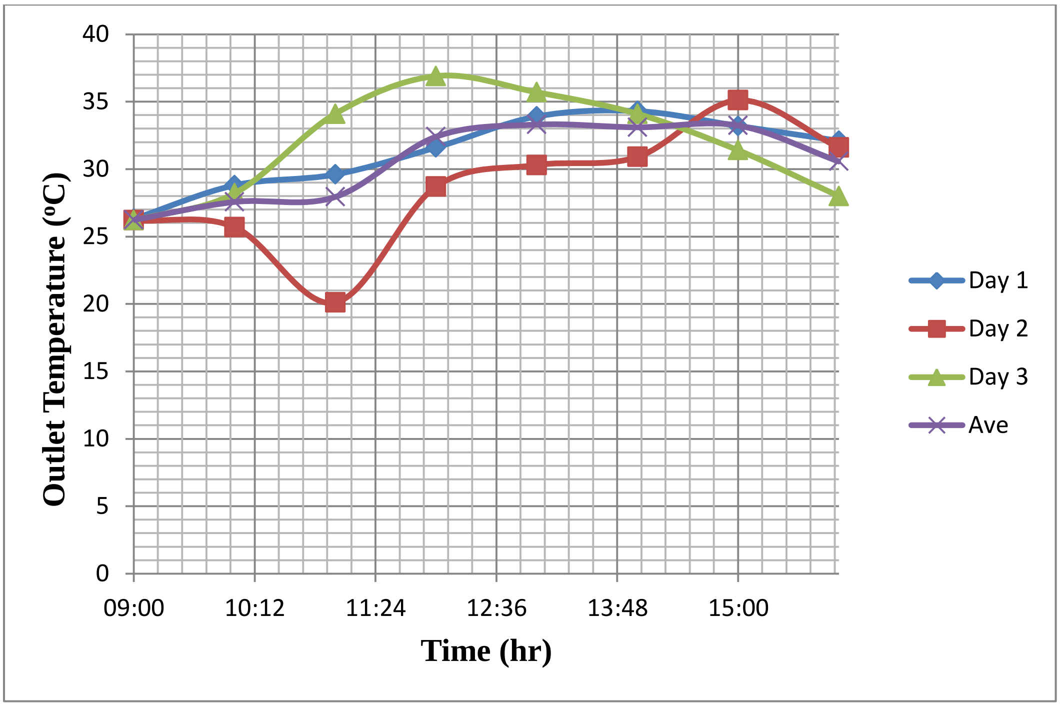


(c) Inlet temperature of the third mass flow rate (0,00673 kg/s)

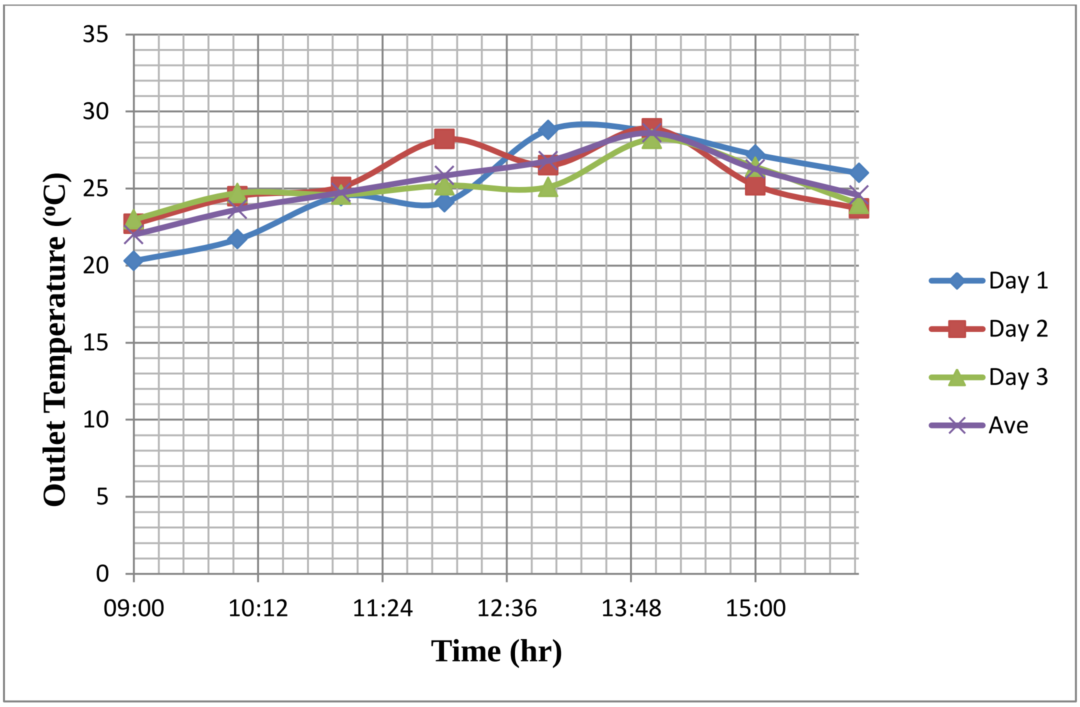


(d) Inlet temperature of the average of the mass flow rates

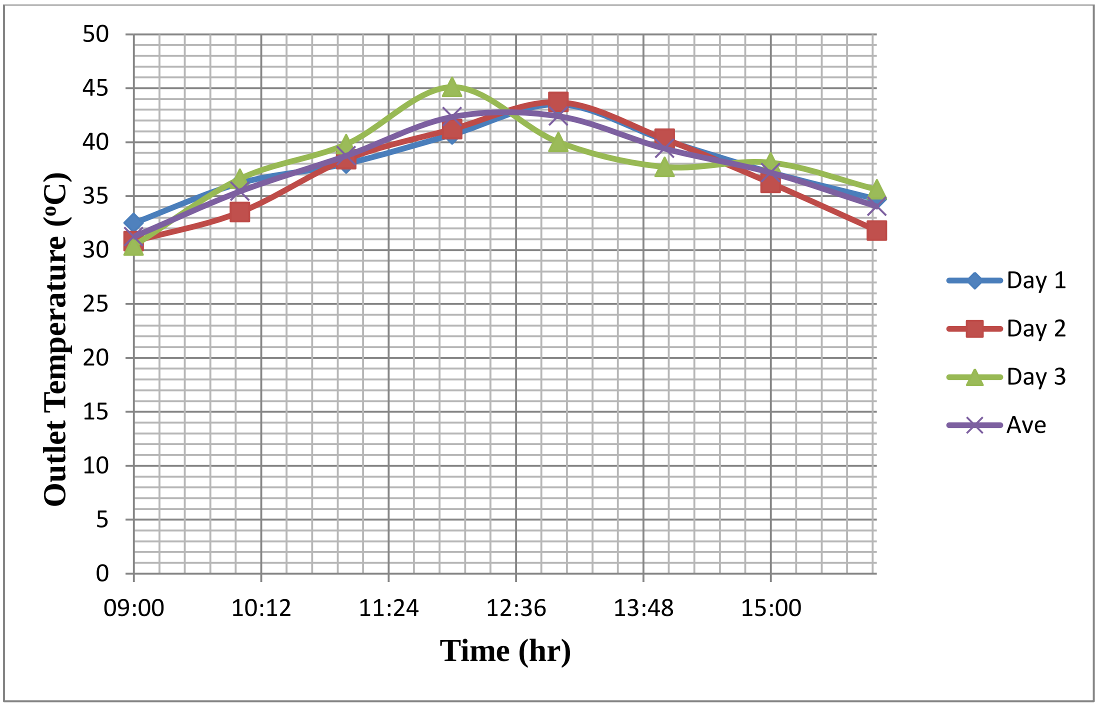
Figure 5.1: Inlet temperature graphs of system 1 ((a),(b),(c),(d))



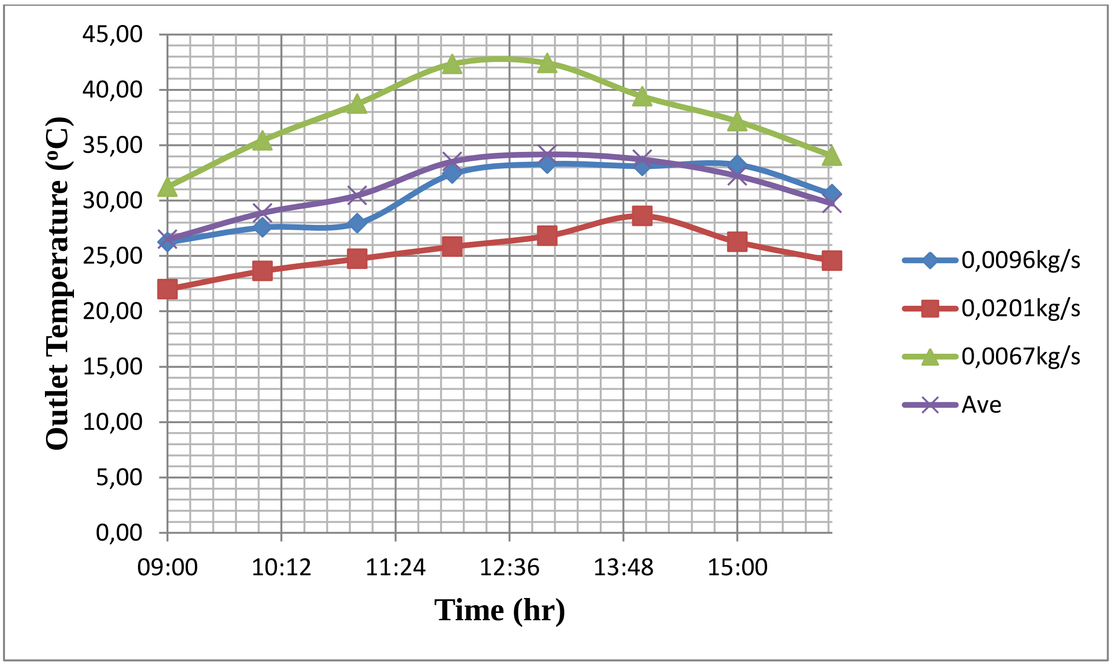
(a)Outlet temperature of the first mass flow rate (0,00963 kg/s)



(b) Outlet of the second mass flow rate (0,02012 kg/s)

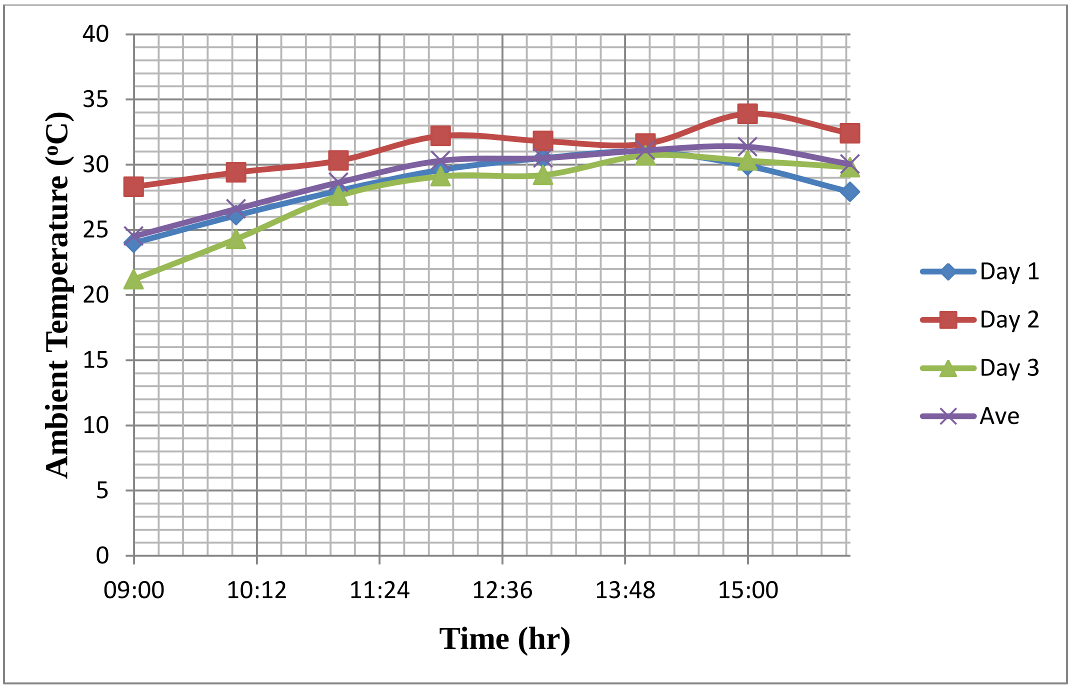


(c) Outlet temperature of the third mass flow rate (0,00673 kg/s)

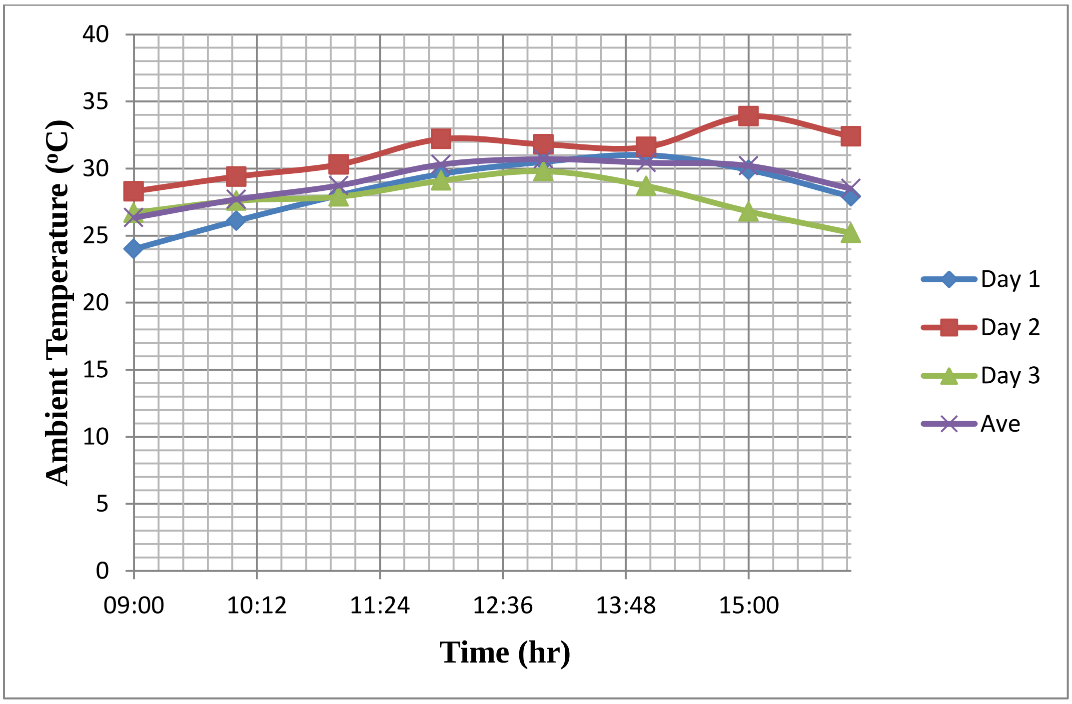


(d) Outlet temperature of the average of the mass flow rates

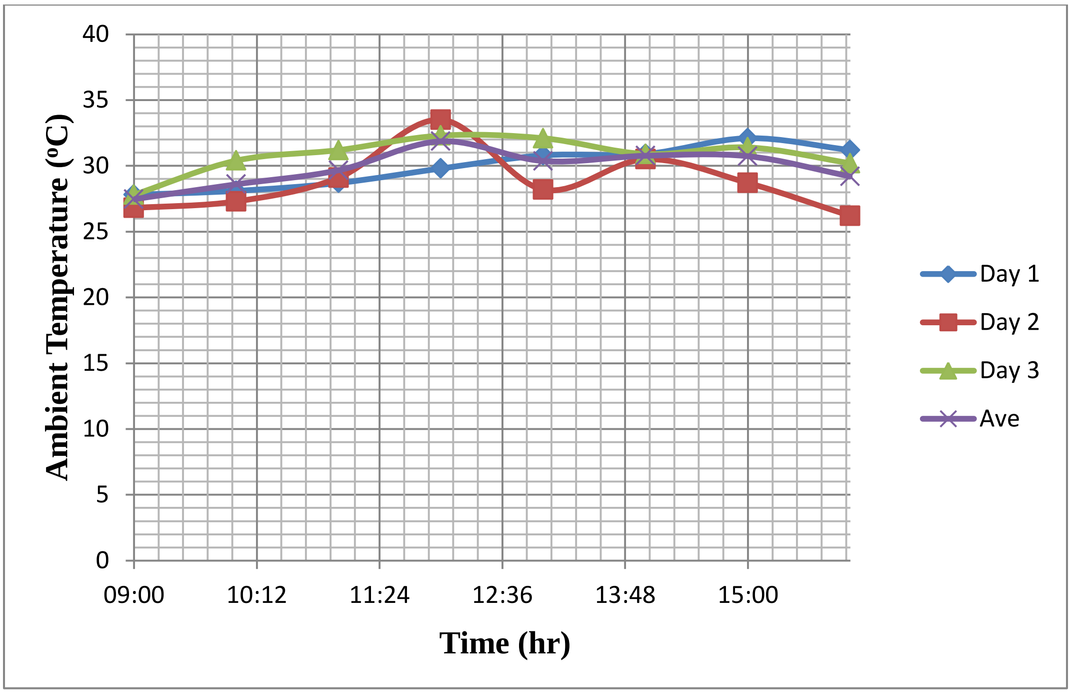
Figure 5.2: Outlet temperature graphs of system 1 ((a),(b),(c),(d))



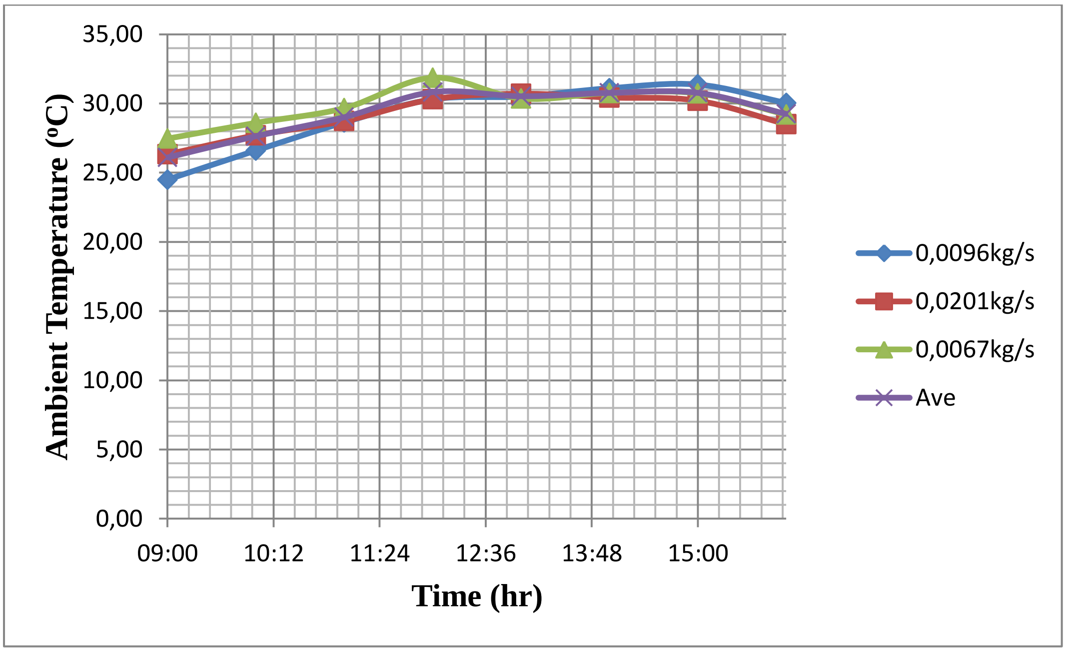
(a) Ambient temperature of first mass flow rate (0,00963 kg/s)



(b) Ambient temperature of second mass flow rate (0,02012 kg/s)

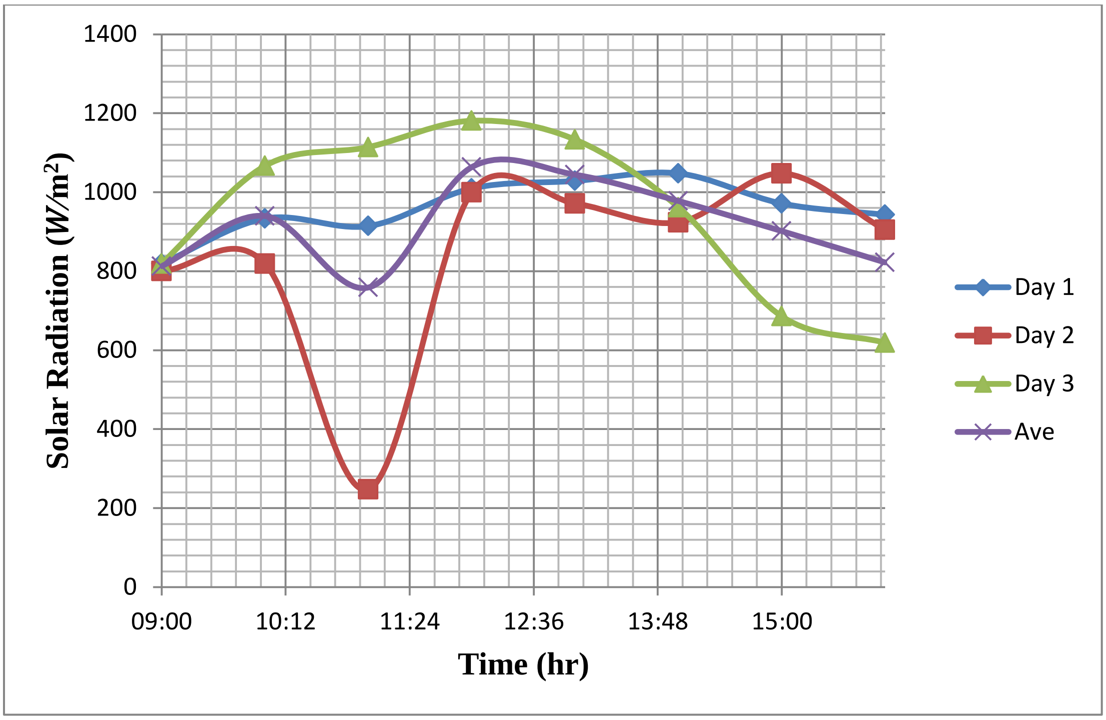


(c) Ambient temperature of third mass flow rate (0,00673 kg/s)

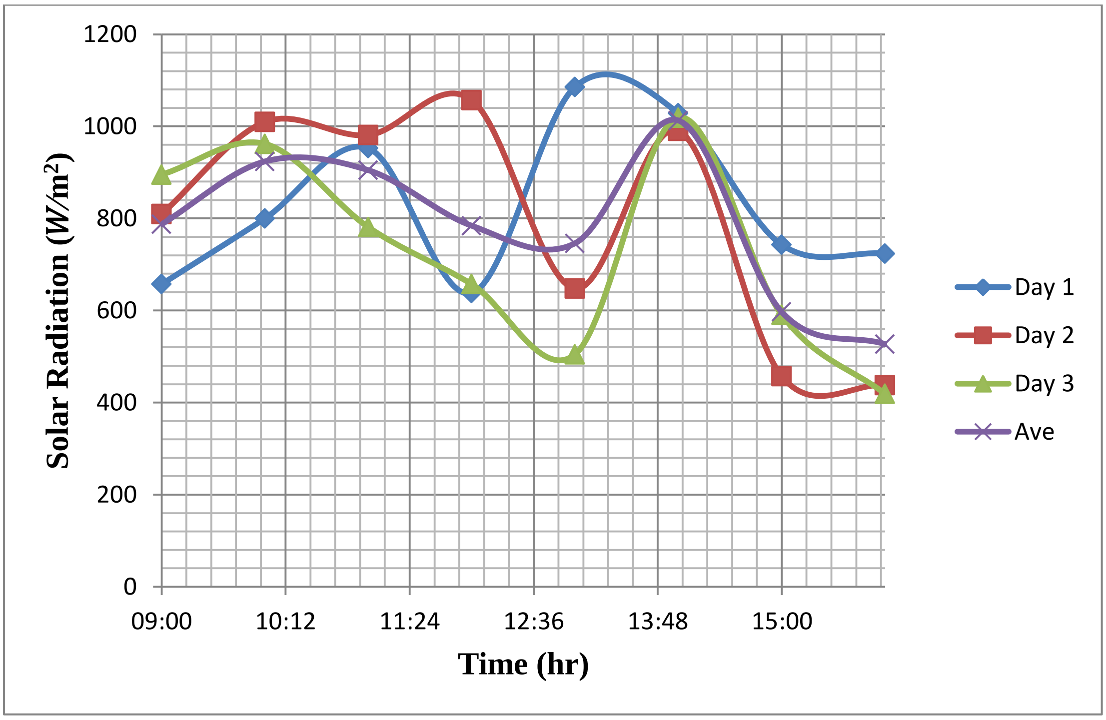


(d) Ambient temperature of average of the mass flow rates

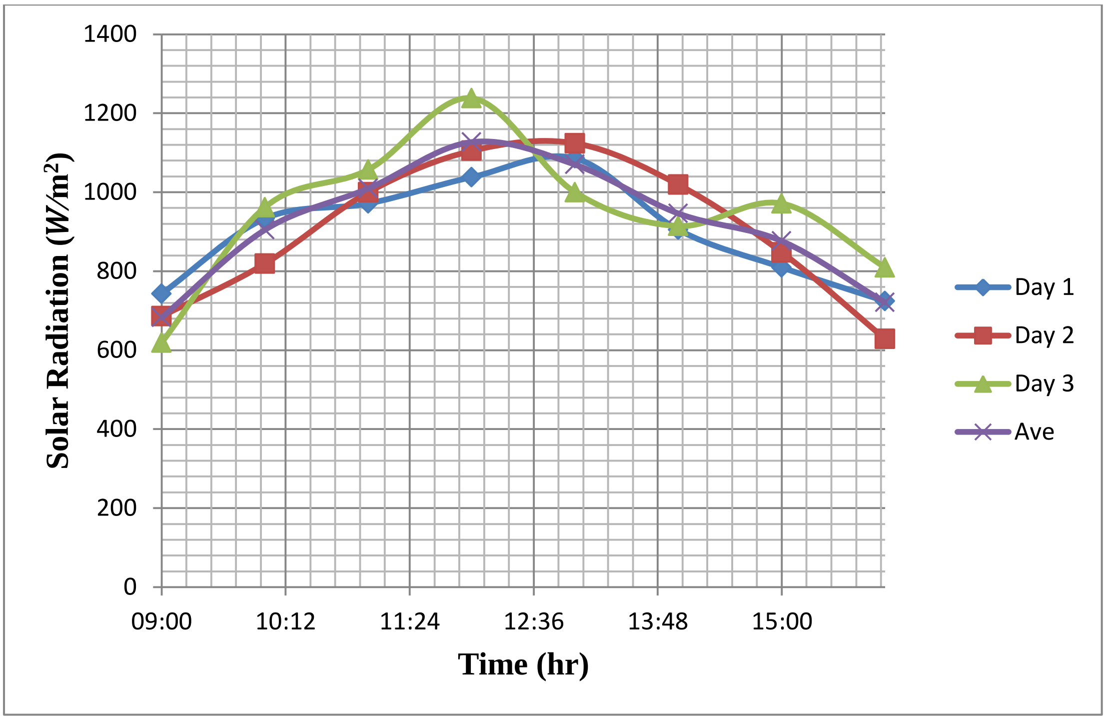
Figure 5.3: Ambient temperature graphs of system 1 ((a),(b),(c),(d))



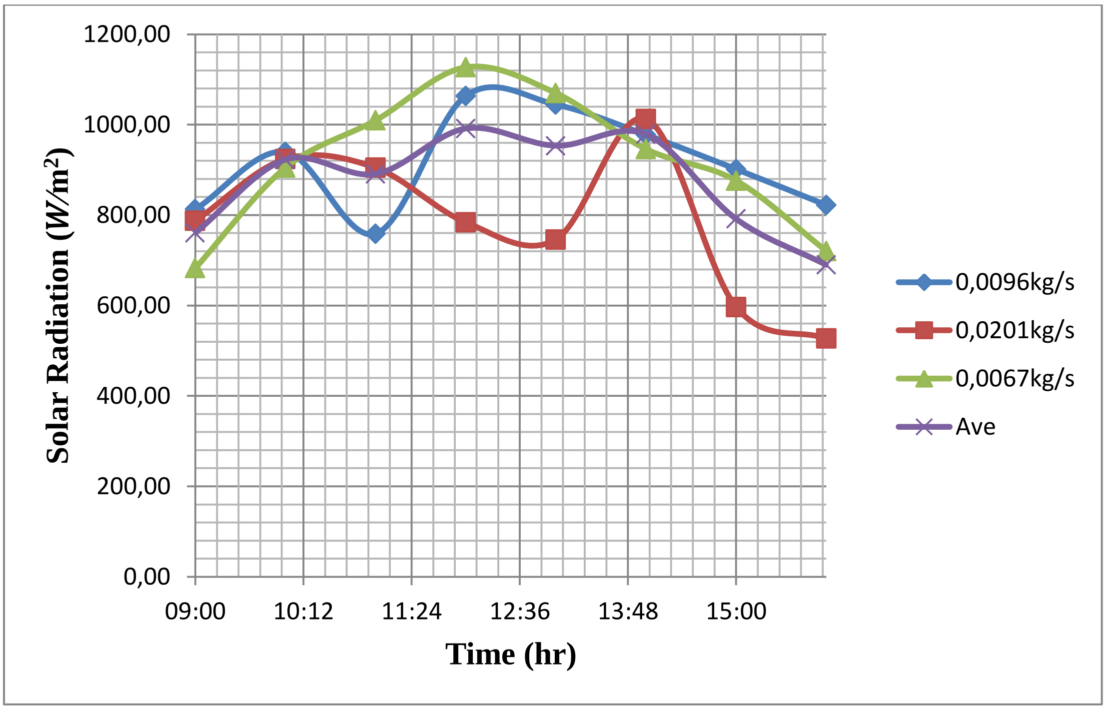
(a) Solar radiation of the first mass flow rate (0,00963 kg/s)



(b) Solar raditaion of the second mass flow rate (0,02012 kg/s)

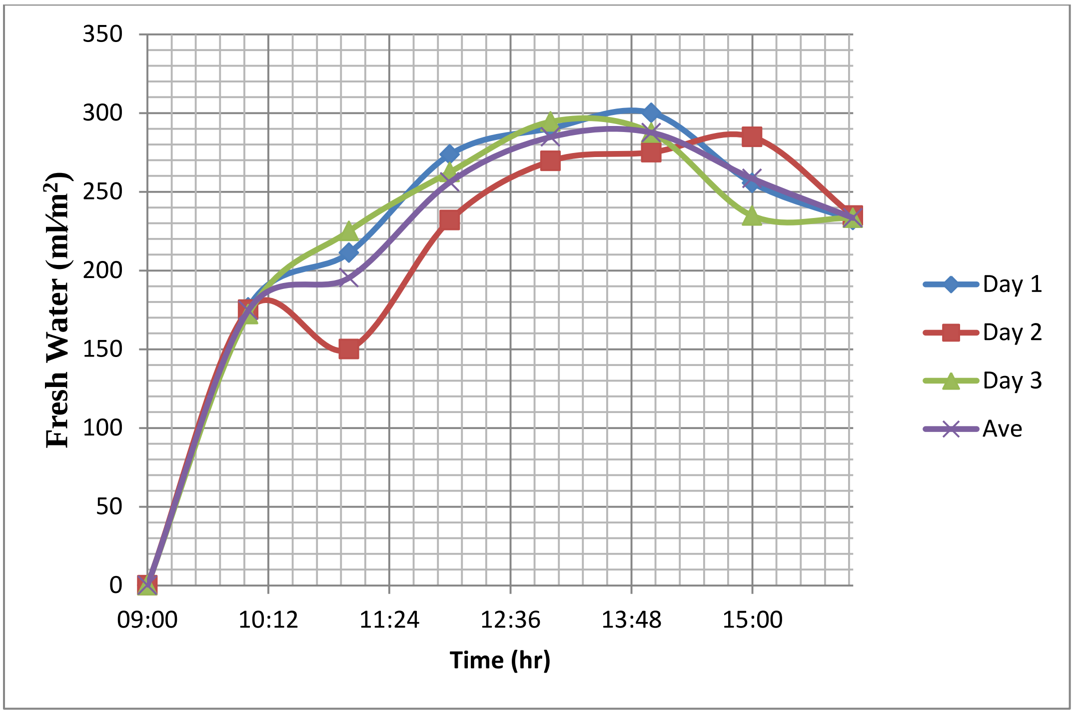


(c) Solar radiation of the third mass flow rate (0,00673 kg/s)

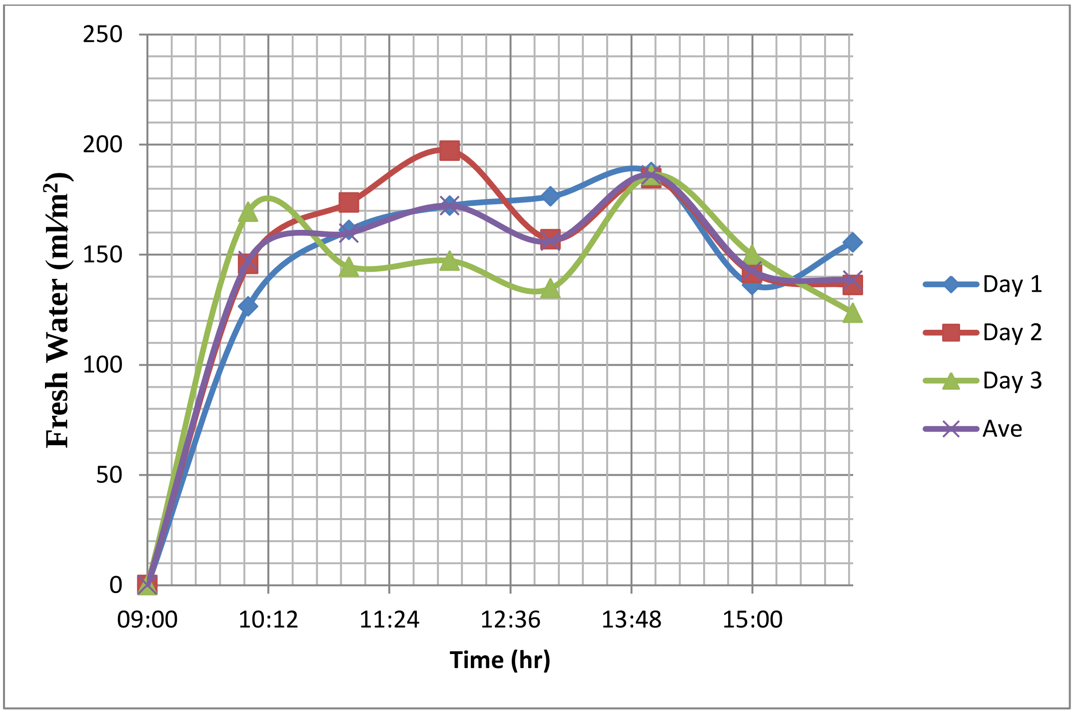


(d) Solar radiation of the average of the mass flow rates

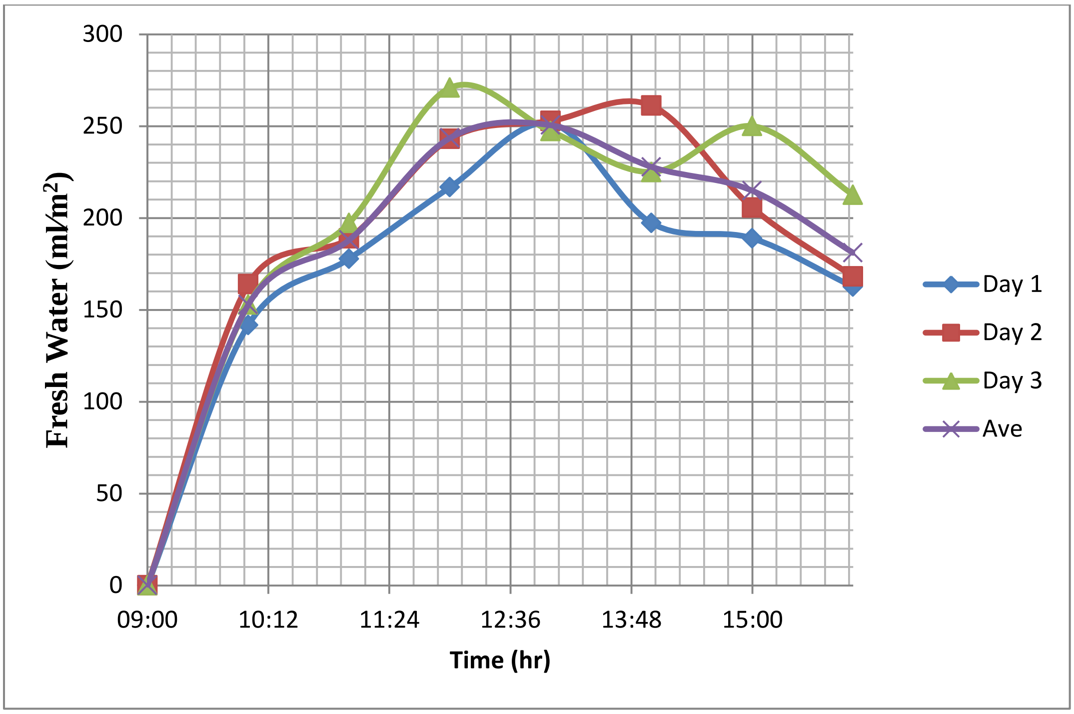
Figure 5.4: Solar radiation graphs of system 1 ((a),(b),(c),(d))



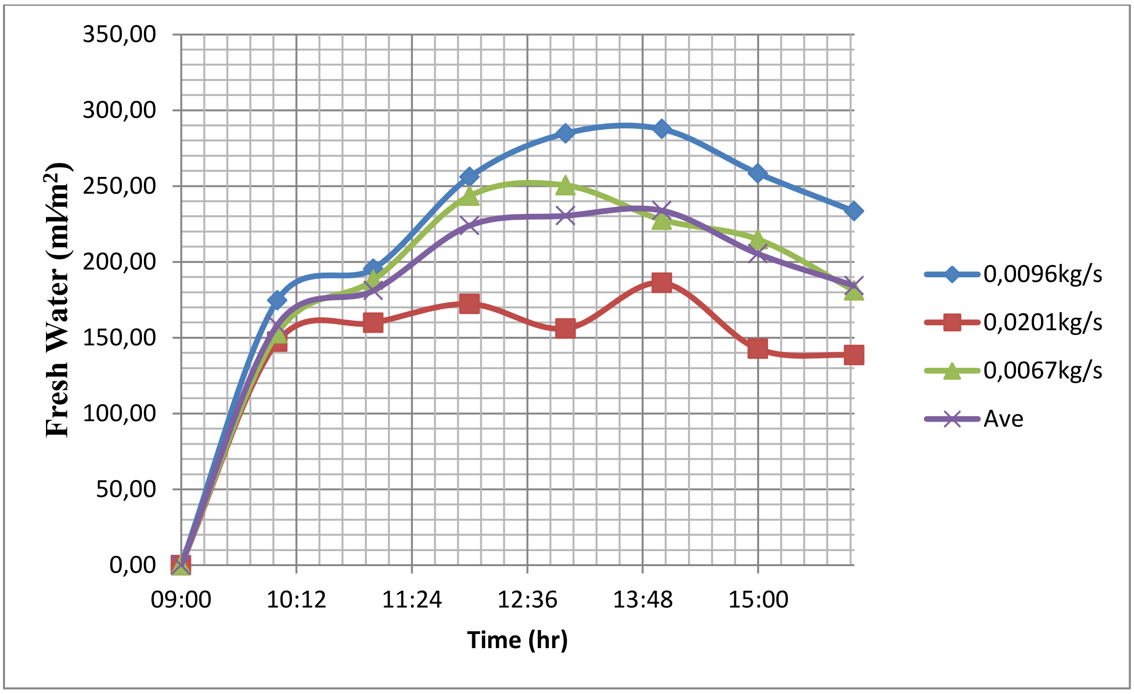
(a) Fresh water of first mass flow rate (0,00963 kg/s)



(b) Fresh water of second mass flow rate (0,02012 kg/s)



(c) Fresh water of third mass flow rate (0,00673 kg/s)

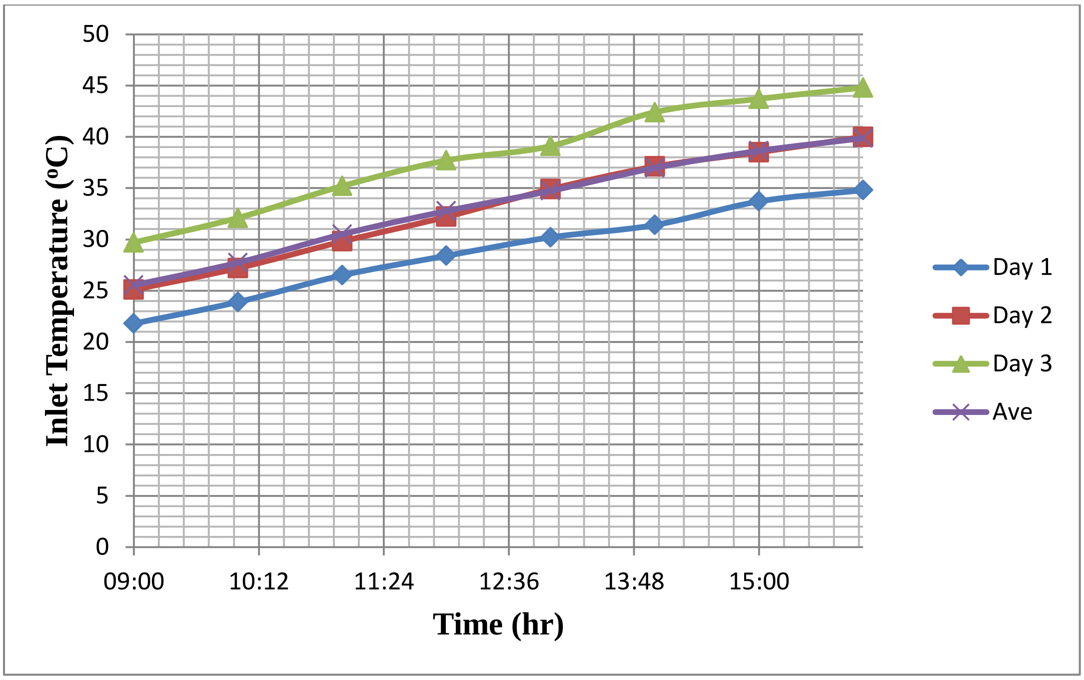


(d) Fresh water of the average mass flow rate

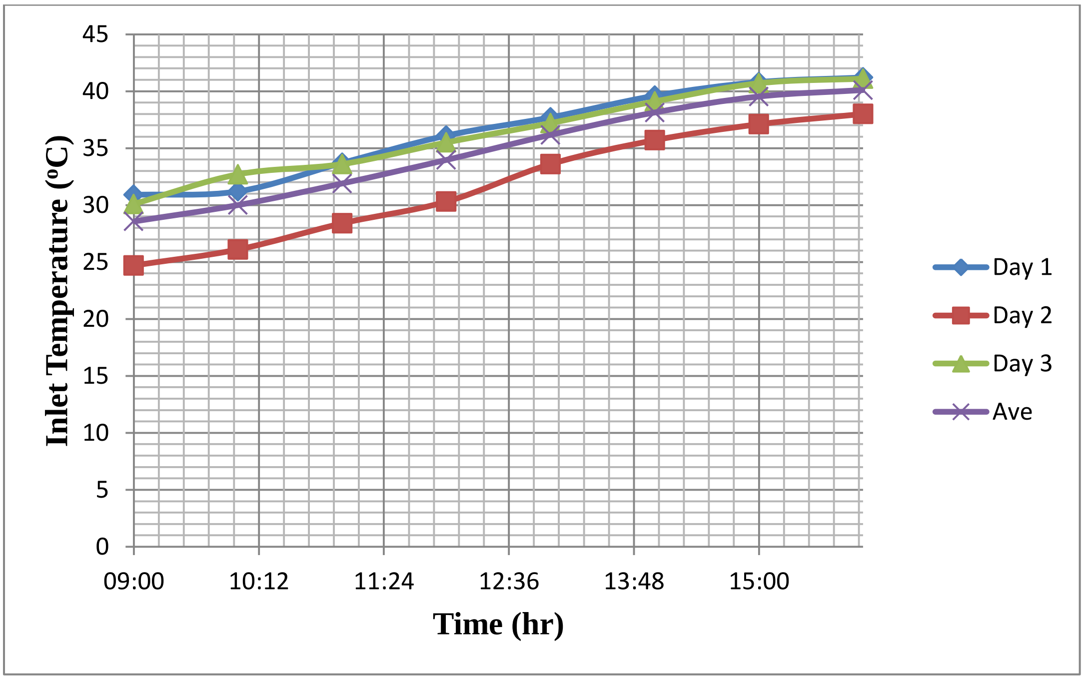
Figure 5.5: Fresh water graphs of system 1 ((a),(b),(c),(d))

5.1.2 One Storage Tank System

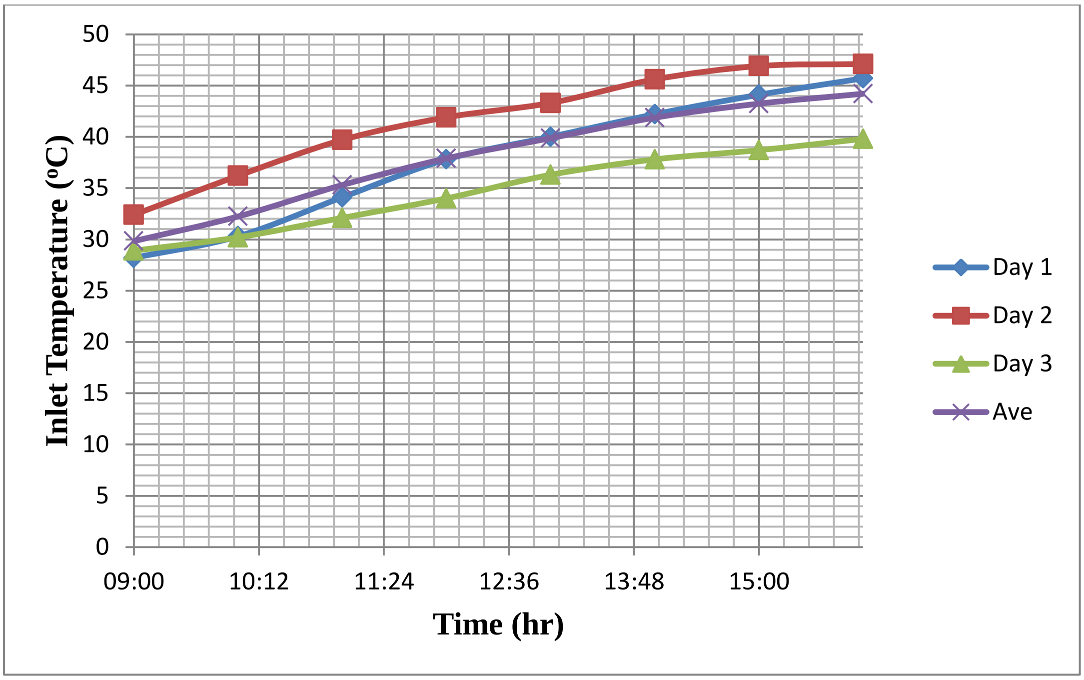
The data of one storage tank system was given in this section. Those data were taken between 17 June and 30 June which is totaly 9 days. Three mass flow rates are used for experiment. I studies each mass flow rate is examinated for three days. Those mass flow rates were 0,0297 kg/s , 0,0072 kg/s and 0,0125 kg/s respectively. In this section, the graphs shows inlet, outlet and ambient temperatures, solar radiation and fresh water produced. Two systems which are one storage and two storage tank systems, are compared in those graphs. Inlet temperature is shown in Figure 5.6. Outlet temperature of this sytem is shown in Figure 5.7. In this system outlet and inlet water temperature is higher than other system shown in Figure 5.6 and 5.7. The maximum inlet and outlet temperature is 47,1 ^{o}C and 53,7 ^{o}C. Ambient temperature is shown in Figure 5.8. This temperature usually increase with solar radiation. However, the solar radiation is decreasing when ambient temperature is increasing. The reason of this is the way of the collector. Specially when the sun goes down, the ambient temperature decreases slowly or stable but solar radiation decrease dramatically as ambient temperature Solar radiation is shown in Figure 5.9. This two graphs are related with the weather conditions. Fresh water production is increased at this system and fresh water production is shown in Figure 5.10. In this system fresh water production increases dramatically because of higher inlet temperature. Fresh water production is measured at three different mass flow rates. When the mass flow rate is slow and inlet temperature is high, the fresh water production increases. The average production of the fresh water is 2349,07 ml/m^2, 3214,81 ml/m^2 and 2935,64 ml/m^2 respectively. Shematic diagram of the one storage tank is in Appendix C.



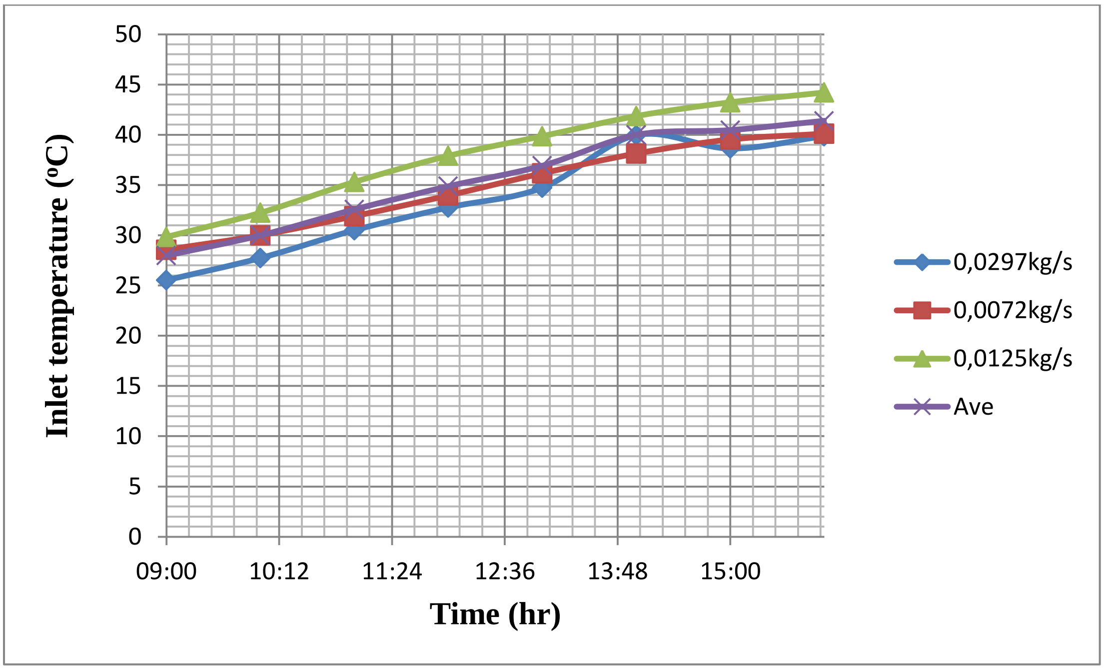
(a) Inlet temperature of the first mass flow rate (0,0297 kg/s)



(b) Inlet temperature of second mass flow rate (0,0072 kg/s)

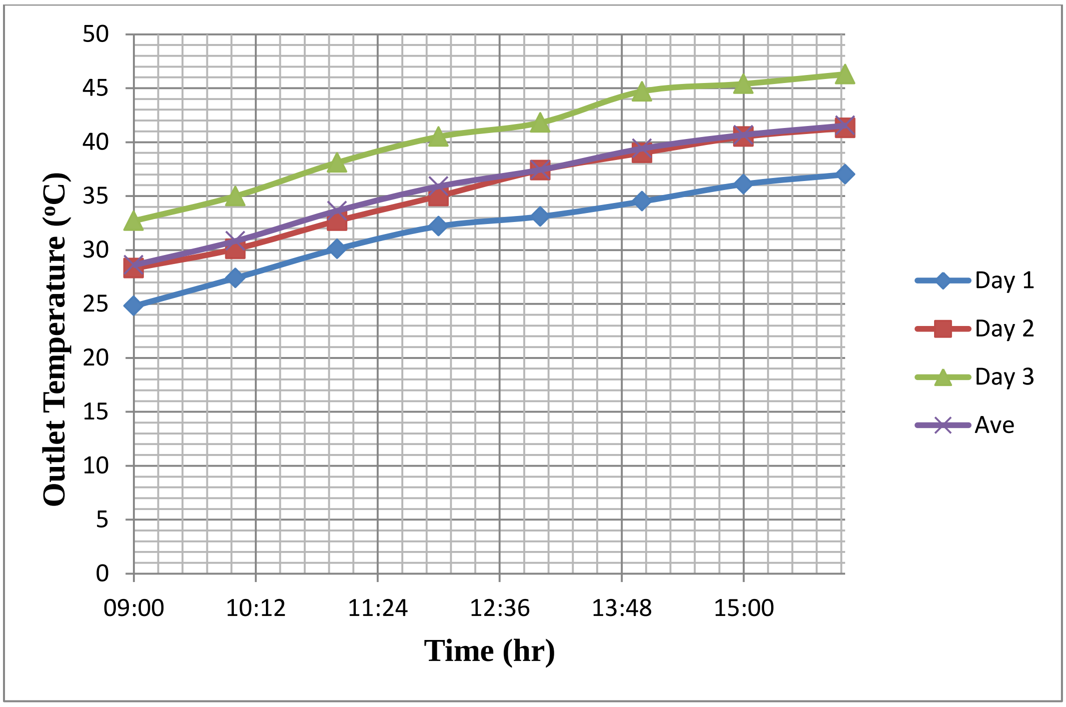


(c) Inlet temperature of the third mass flow rate (0,0125 kg/s)

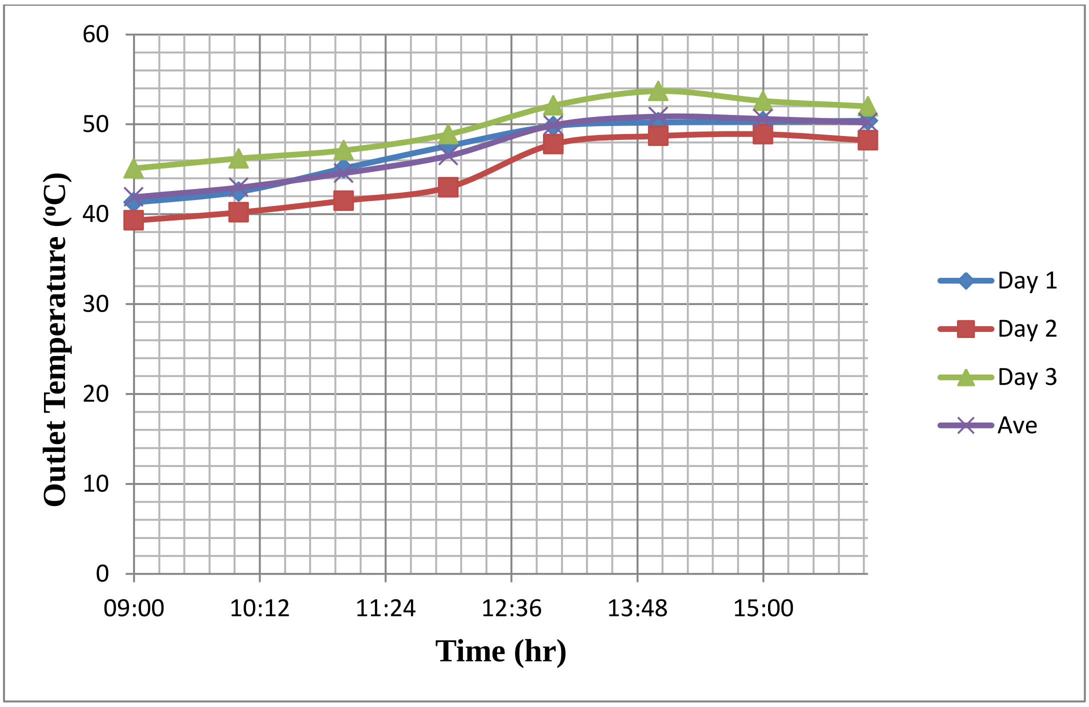


(d) Inlet temperature of the average of the mass flow rates

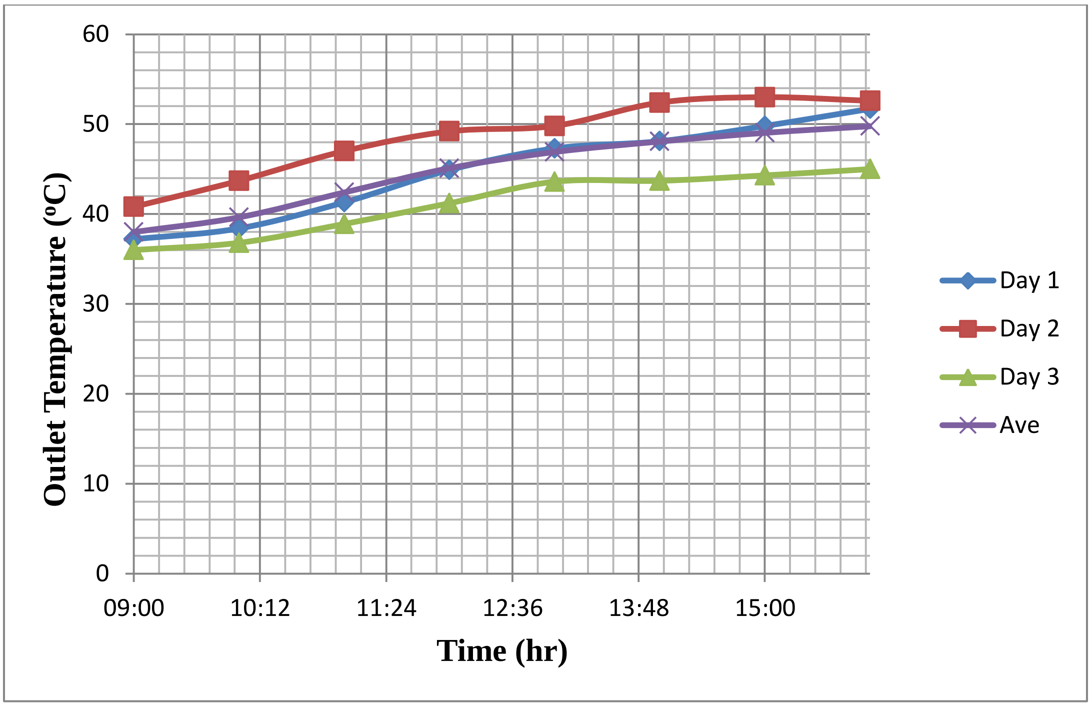
Figure 5.6: Inlet temperature graphs of system 2 ((a),(b),(c),(d))



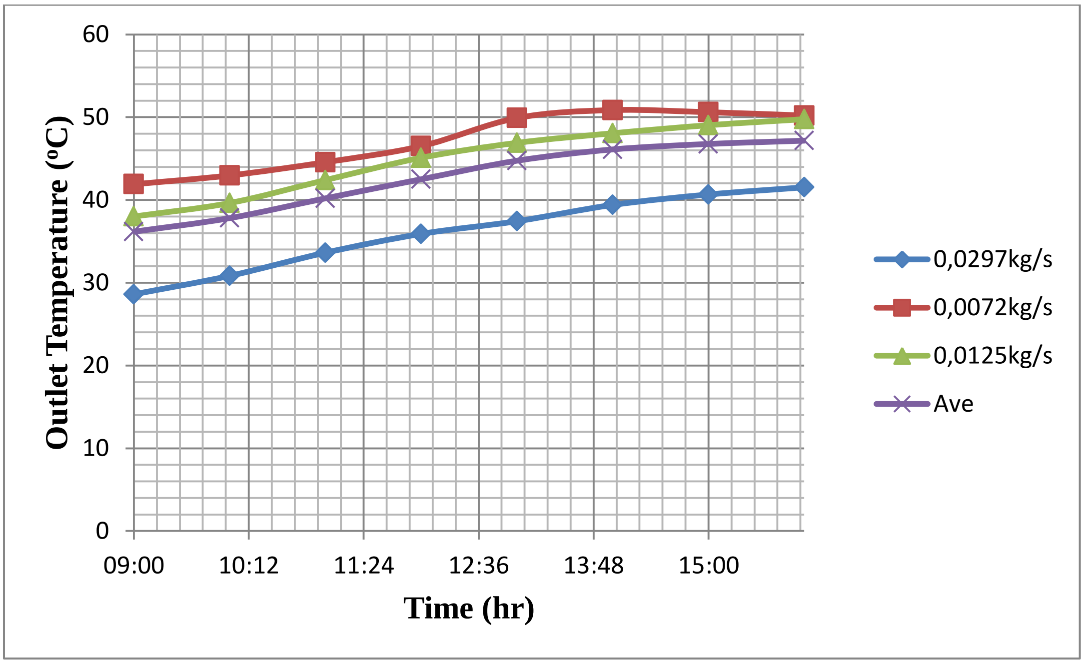
(a) Outlet temperature of the first mass flow rate (0,0297 kg/s)



(b) Outlet of the second mass flow rate (0,0072 kg/s)

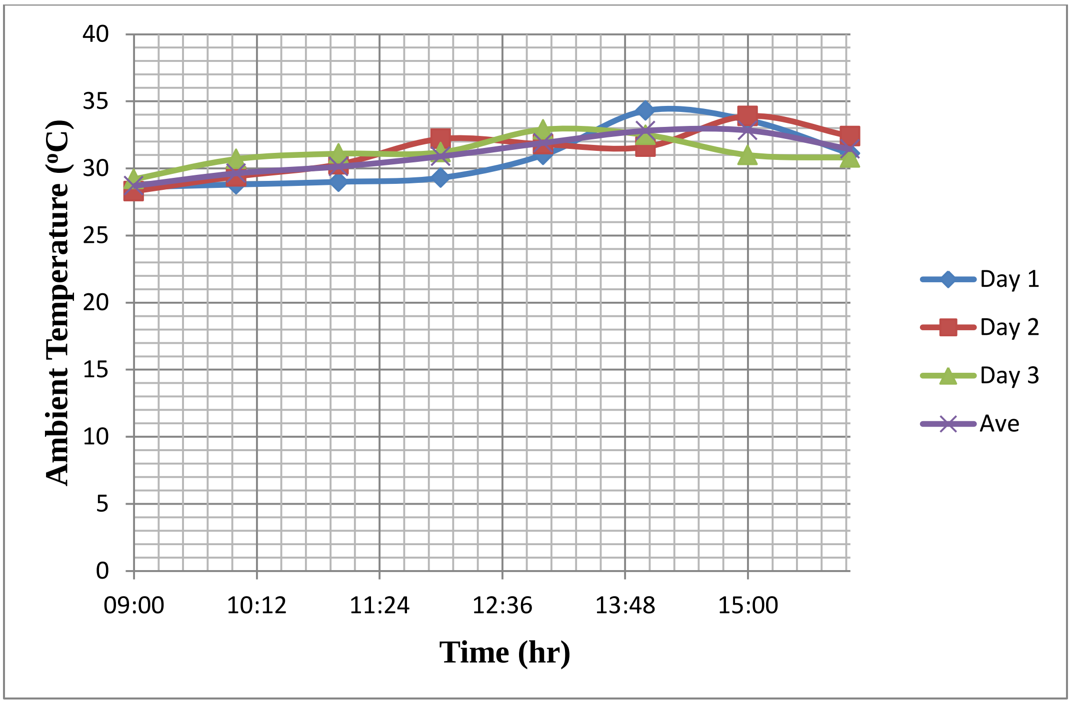


(c) Outlet temperature of the third mass flow rate (0,0125 kg/s)

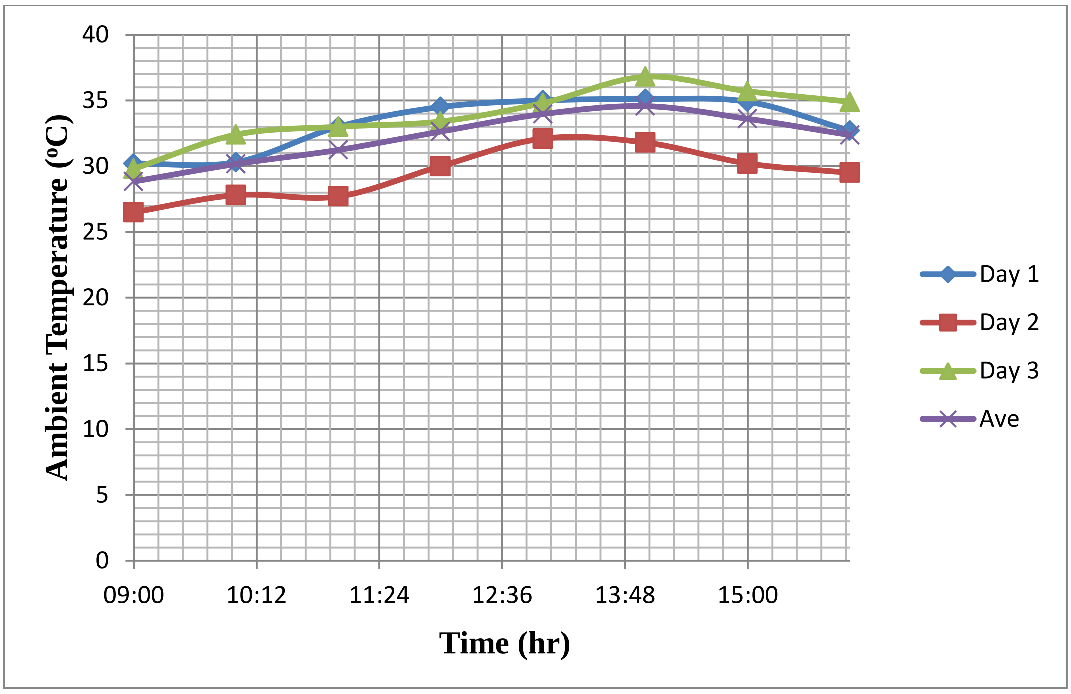


(d) Outlet temperature of the average of the mass flow rates

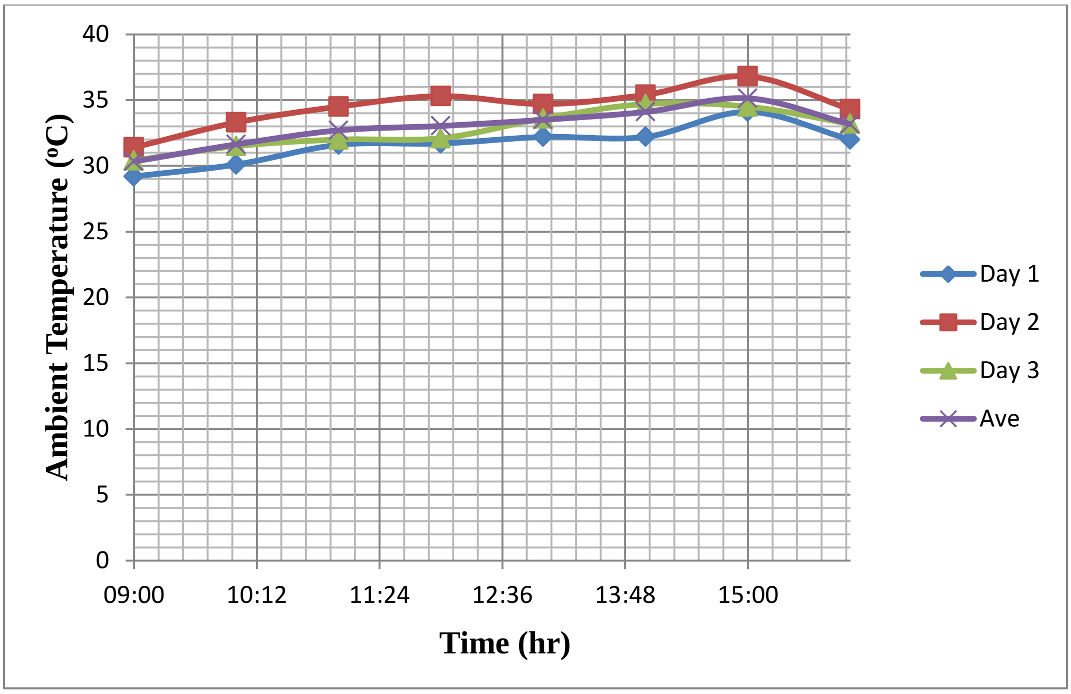
Figure 5.7: Outlet temperature graphs of system 2 ((a),(b),(c),(d))



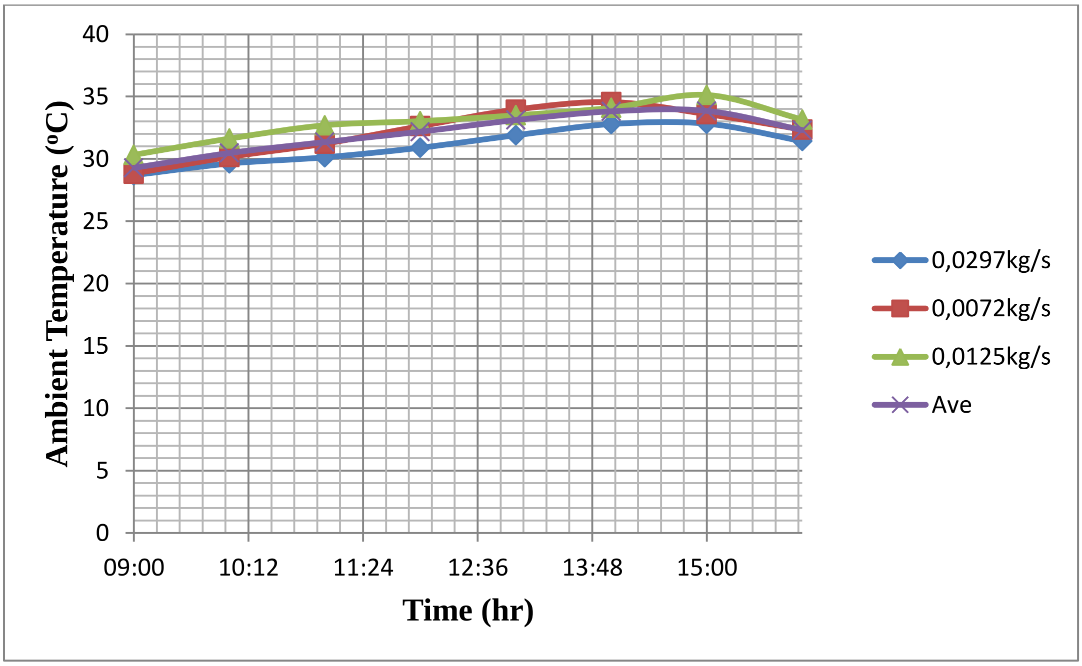
(a) Ambient temperature of first mass flow rate (0,0297 kg/s)



(b) Ambient temperature of second mass flow rate (0,0072 kg/s)

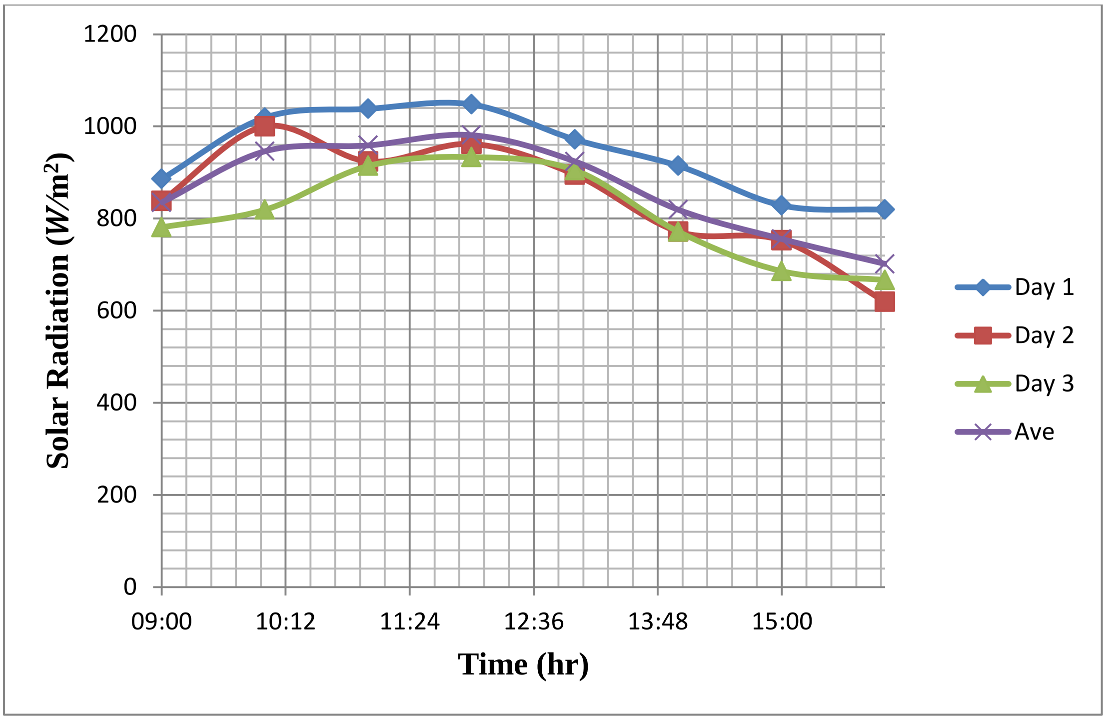


(c) Ambient temperature of third mass flow rate (0,0125 kg/s)

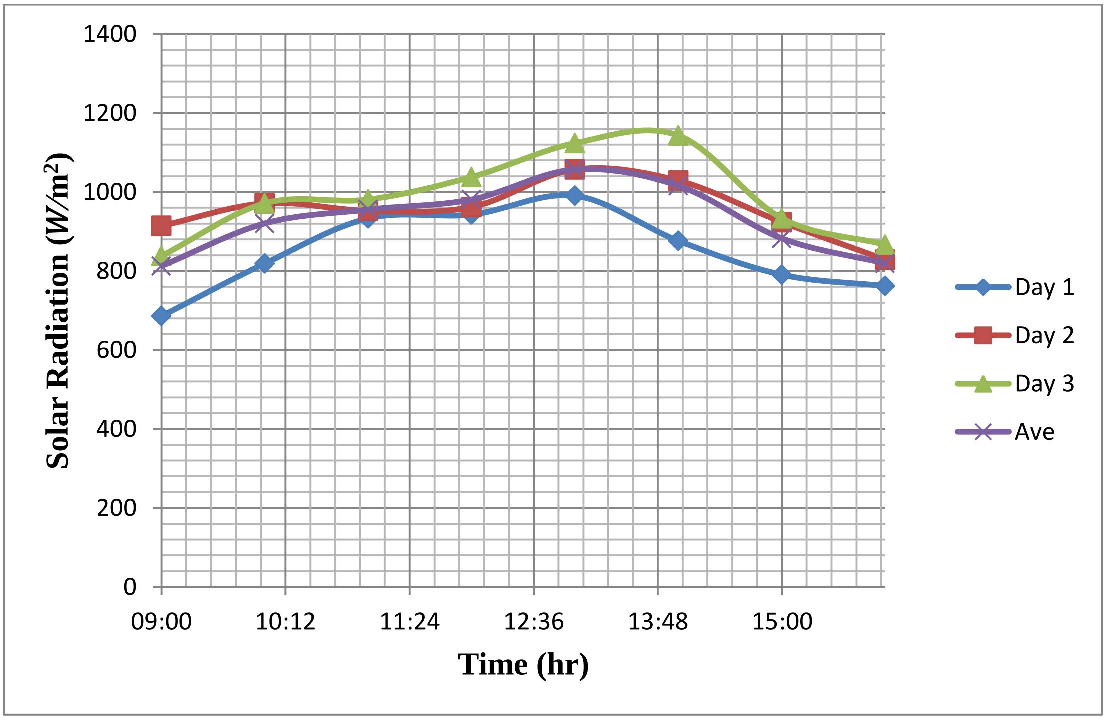


(d) Ambient temperature of average of the mass flow rates

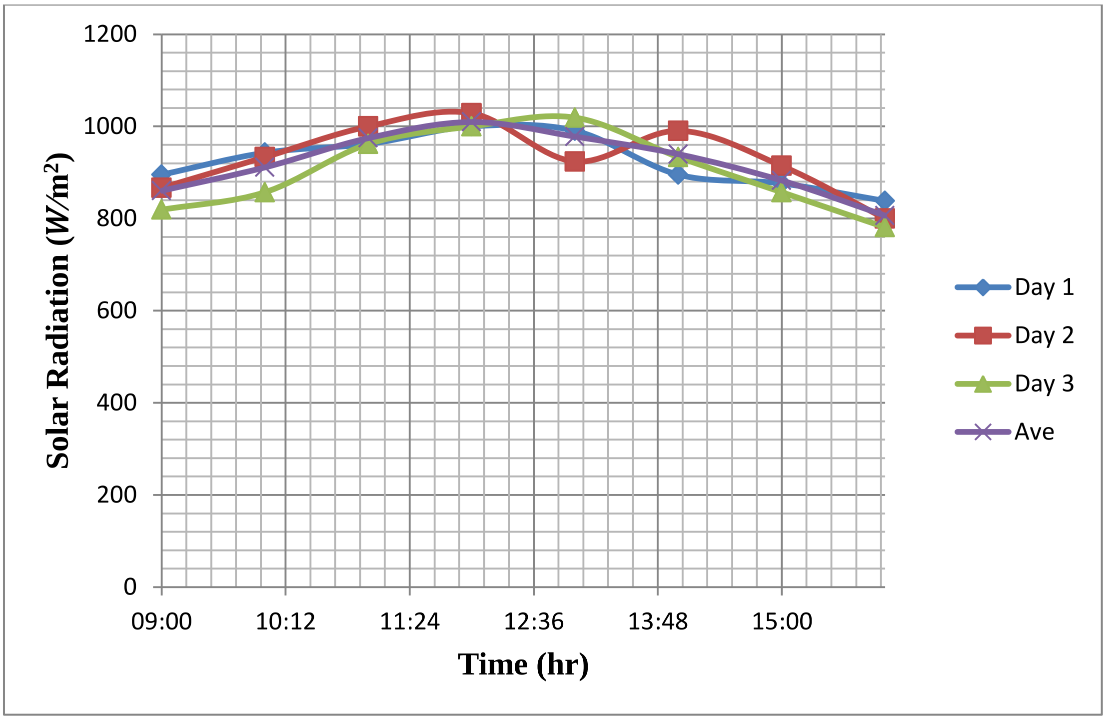
Figure 5.8: Ambient temperature graphs of system 2 ((a),(b),(c),(d))



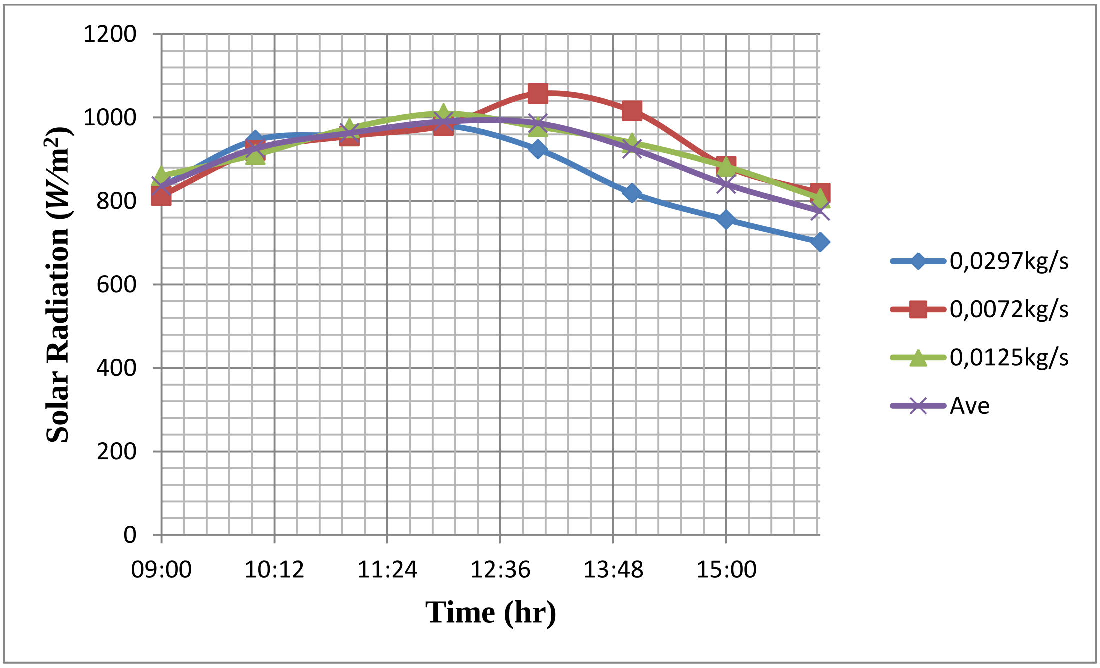
(a) Solar radiation of the first mass flow rate (0,0297 kg/s)



(b)Solar raditaion of the second mass flow rate (0,0072 kg/s)

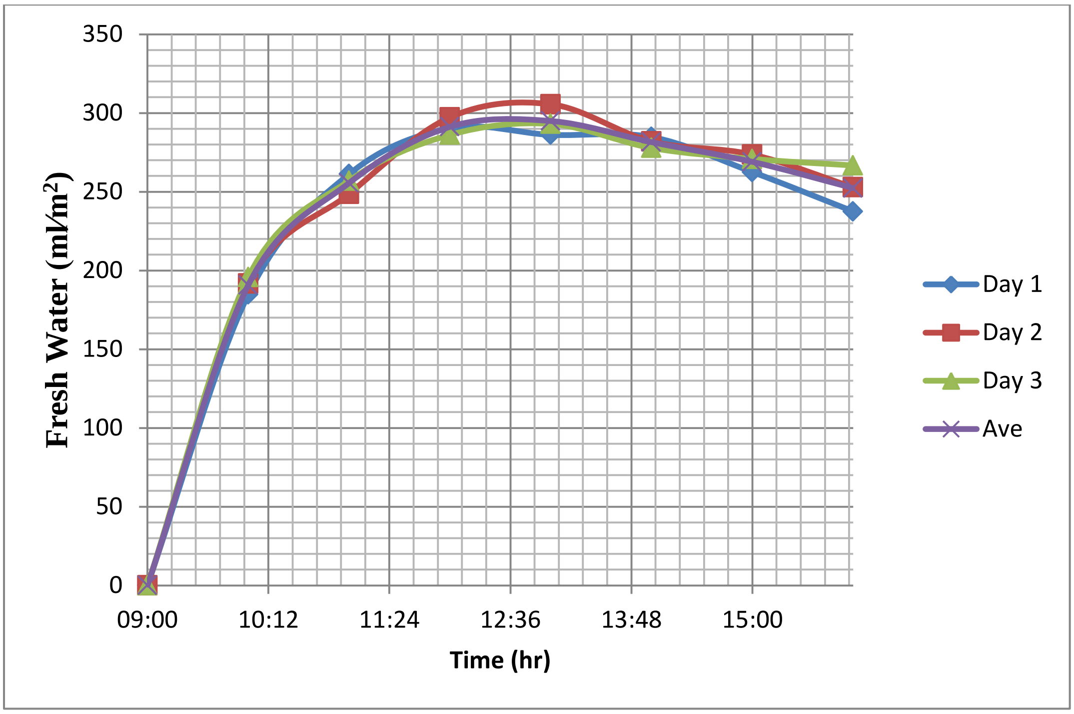


(c) Solar radiation of the third mass flow rate (0,0125 kg/s)

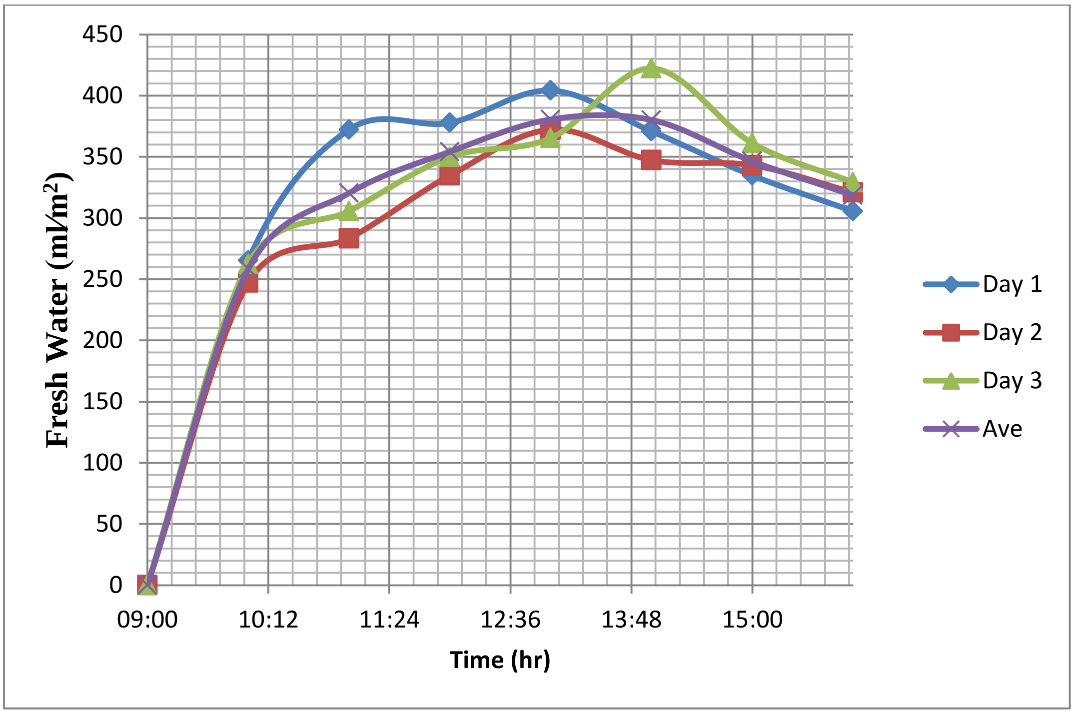


(d) Solar radiation of the average of the mass flow rates

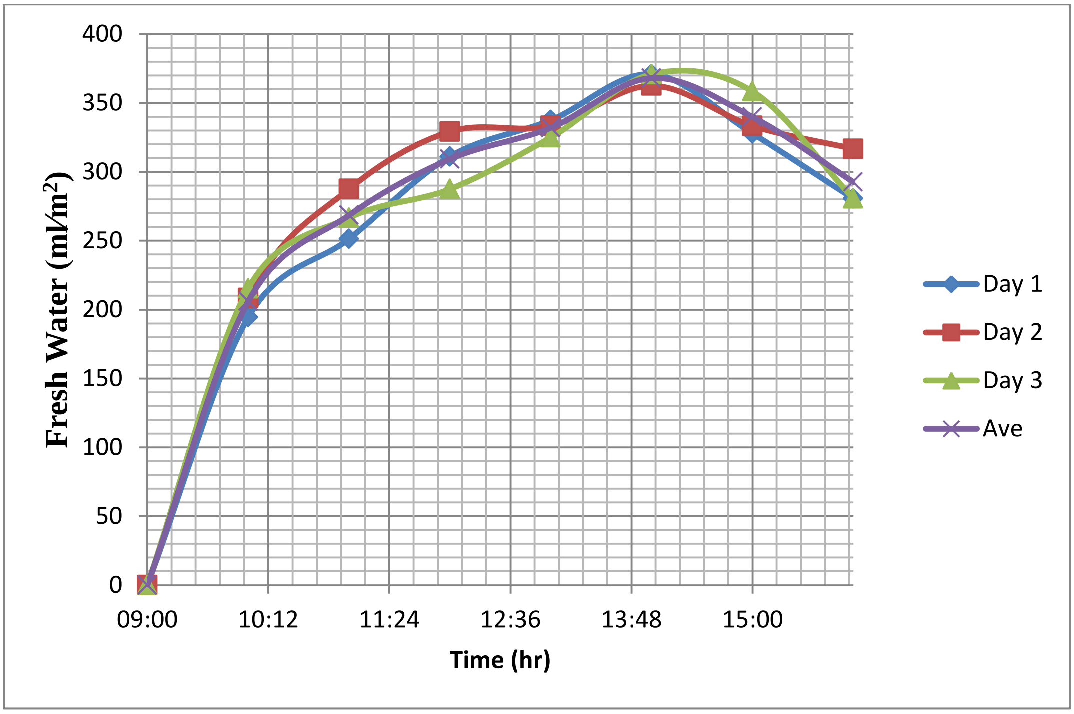
Figure 5.9: Solar radiation graphs of system 2 ((a),(b),(c),(d))



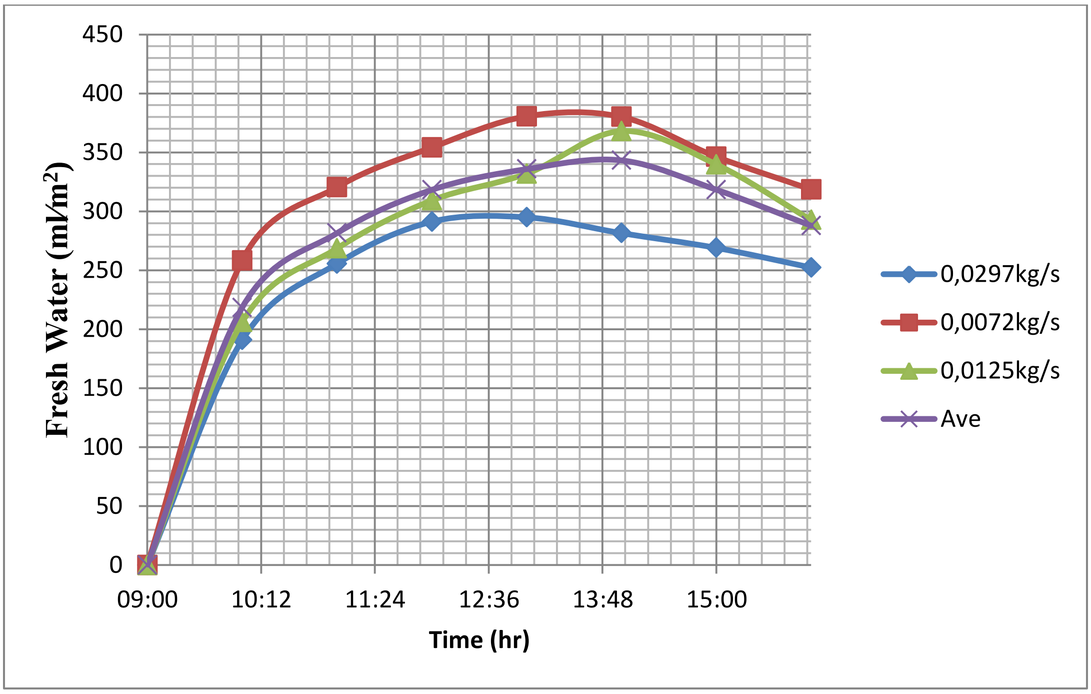
(a) Fresh water of first mass flow rate (0,0297 kg/s)



(b) Fresh water of second mass flow rate (0,0072 kg/s)



(c) Fresh water of third mass flow rate (0,0125 kg/s)



(d) Fresh water of the average mass flow rate

Figure 5.10: Fresh water graphs of system 2 ((a),(b),(c),(d))

5.2 Experimental Result

In this section result of the thesis presented. A tap water of the Mağusa was desalinate at inclined solar water heater and desalination system. Tap water of the Mağusa is desalinate before seperation for the house. Because of this reason the system desalinate the water which is desalinate before from municipality of the Mağusa. Parameter such as the ph of the tap water and clean water and TDS of the tape water and clean water is in Table 5.1.

Table 5.1: Parameter of the waters

Parameter	pH	TDS (mg/l)
Tap Water	8,2	430
System Water	7,5	2

Those values were measured at office of Ministry of Agriculture in Türkmenköy with a pH meter. Photos of the machine and recorded data by this machine are in Appendix A. TDS values of two water is below than 500 mg/l. Therefore this two water were accepted clean water. The system water TDS is very low because the system desalinates the clean water and the TDS value is decreased until 0 mg/l.

pH value is unit of measure which show the acidic and basic value of the water. The measure of pH value of the water is between 1 and 14. When the pH value is 7, the water is neutral. If the pH values below 7 the water is acidic wheras if the pH value is higher than 7 the water is basic. According to the Turkish Standarts, pH values of the drinking water is between 4,5 and 9,5. However the human blood needs pH value which are between 7.3 and 7.5. Beacuse of this reason, the most acceptable drinking water must be basic and the pH value is 7,5. (Uras, 2012).

The efficiency of the systems were calculated. For every hour the efficiency of the system recorded into on excel file. Firstly, two storage tank system was calculated. The inlet and outlet temperatures were used and the fresh water production was used for energy calculation. Every hour from 9:00 to 16:00 the data were recorded. For every day, and every mass flow rate the average efficiency is calculated for the two systems. The first system has lower efficiency than other system which is one storage tank. The average efficiency of the two storage tank is 66,43 % at a mass flow rate 0,00963 kg/s , 58,91 % at a mass flow rate 0,02012 kg/s and 70,58 % at a mass flow rate 0,00673 kg/s. Figure 5.11 shows the average efficiency of the mass flow rates for two storage tank.

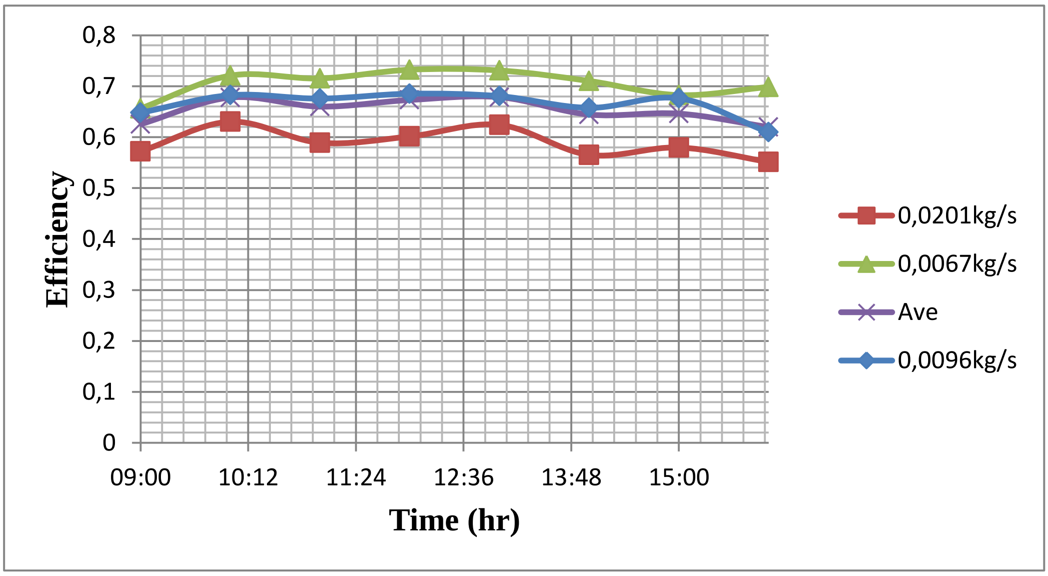


Figure 5.11: Efficiency graph of the two storage tank system

One storage tank system is more efficient than two storage tank system. Because one storage tank system has one tank and the hot water which is heated in solar collector, goes to the water tank so the water temperature is increased in storage tank. Therefore, the inlet temperature of the system start to incerase. The average efficiency of the two storage tank is 69,36 % at mass flow rate 0,0297 kg/s, 75,44 % at mass flow rate 0,0072 kg/s and 71,75 % at mass flow rate 0,0125 kg/s. Figure 5.12 shows the average efficiency of the mass flow rates for one storage tank.

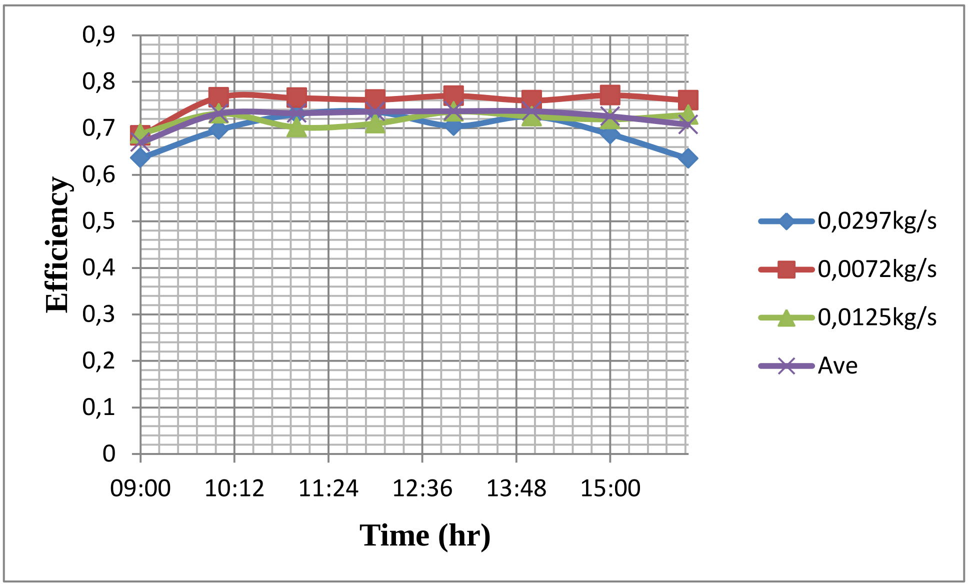


Figure 5.12: Efficiency graph of the one storage tank system

All calculations and data are included in Appendix B.

5.3 Economic Analysis

The experimental system used is almost twice of the prototype system. The price of the material used is lower than the real system. However when the mass production started, the price should be aproximately same with this production. Also after this production, some materials or welding types should be changed for low cost production. The parts used during construction of the panel and cost of these parts are shown in Table 5.2.

Table 5.2: Cost of the system

Item	Size	Amount	Unit Cost (TL/Part)	Total Cost (TL)
1,5 mm Sheet Metal	1m*2m	1	65	65
1 mm Sheet Metal	1m*2m	1	45	45
Bronze Connecting Union	25 mm	2	7,5	15
T Pipe Connector	25 mm	2	1,5	3
Pipe Connector	25 mm	6	1,5	9
Soldered	---	----	---	120
Glass Wool	1m*1m	1	25	25
Glass	1m*0,8m	1	20	20
Black Paint	100gr	1	10	10
Silicone	---	1	5	5
Plastic Pipe	3m	1	6	6
Labor Cost	---	---	---	100
TOTAL COST				423

5.4 Payback Period Analysis

At this section, the payback period of the system was calculated. As seen from Table 5.2, the cost of collector is 423TL. If the collector was built at original size, the price would be 846TL. This 846TL is the investment money of the system. The monthly general inflation rate is aproximately 0,6%. The system produces both hot water and fresh water. The fresh water production is 2 lt per day on average. Also it heats the water up to 50°C on average. The price of the electricity which is saved by heating the water with solar energy, and fresh water is calculated below. Table 5.4 shows the payback period of the system while using this data.

5.4.1 Fresh Water Calculation

System produces on average 2 liters fresh water per day. This average covers winter and summer weather conditions. Because in winter season the fresh water production decreases. However in the weather conditons in summer, the fresh water production is nearly 3,5 liter for one day. If the system was produced at original size this will incerase two times which is 4 liters per day. Today, in North Cyprus one liter of fresh water is 0,65 TL in the market in July 2014. The fresh water calculation is shown below.

$$Daily\ Cost = \left(0.65\ {}^{TL}/_{lt}\right)(4\ lt) = 2{,}6\ TL$$

$$for\ monthly\ cost = 2{,}6\ TL * 30\ day = 78\ TL$$

5.4.2 Heater Element Calculation

Cold and hot water consumption increases as compared to the old systems. For all that, hot water price is expensive than cold water. Therefore, people do not use hot water everytime. For instance, washing machine, dishwasher works with cold water. The standard heater element power is 3000 W. If solar energy wasn't used in this project, this 3000 W heater element would be used for heating the water. System heats the water up to 60^{o}C on average. Therefore, the desired temperature was calculated as 60^{o}C. Table 5.3 shows the hot water requirement for one person per day.

Table 5.3: Hot water requirement (Köktürk)

REQUIREMENT TYPES	60˚C HOT WATER CONSUMPTION [lt]
Cleaning of Morning	6
Breakfast Dishes	1
Morning Care	2
Cleaning of Noon	1
Hand Washing (for lunch)	1
Lunch Dishes	3
Afternoon Cleaning	2
Prepare Dinner	1
Hand Washing (for dinner)	1
Dinner DİShes	3
Cleaning of Night	6
Take a Shower	30
TOTAL	57

Table 5.3 shows, one family which has 4 people, that 228 lt hot water for one day is needed. From this information, the needed time for heating the water up to 60°C, is calculated. The average inlet water is accepted to be 20°C. This means 40°C is needed for reaching the desired water temperature. This is helpful for calculating the price of the electricity per day. The electricity price of the North Cyprus is very high which is 0,5 TL/kWh.

Standard Heater Element = 3000 Watts

Price of electricity in North Cyprus in July 2014 = 0.5 TL/ kWh

Desired Temperature = 60°C

$$Heating\ Power = \frac{m \cdot C_p \ \cdot \Delta T}{time} = 3000\ Watt$$

$$= \frac{(150\ kg)\left(4186\ {}^{J}\!/_{kg\ \cdot\ ℃}\right)(60 - 20℃)}{time}$$

$$time = \frac{(150\ kg)\left(4186\ {}^{J}\!/_{kg\ \cdot\ ℃}\right)(60 - 20℃)}{3000\ watts}$$

$$time = 2\ hours\ and\ 19\ minutes\ to\ reach\ 60\ ℃$$

$$Daily\ Cost = \left(0.5\ {}^{TL}\!/_{kW\ \cdot\ h}\right)(3\ kW)(2.32\ h) = 3{,}48\ TL$$

$$for\ monthly\ cost = 3{,}48\ TL * 30\ day = 105\ TL$$

Table 5.4: Payback Period Analysis

Month	Net Cash Flows	Cash Outflow	Fresh Water Price	Electricity Price	Cash Income
0	-846	-846	78	105	0
1	851,07	0	78,46	105,63	184,09
2	670,98	0	78,93	106,26	185,19
3	491,63	0	79,4	106,89	186,29
4	307,17	0	79,88	107,53	187,41
5	120,47	0	80,35	108,17	188,52
6	-68,04	0	80,8	108,81	189,61

As seen from Table 5.3, The payback period is calculated for 6 months. There is no maintenance and other outflows price. The montly general inflation rate is accepted to be 0,6%. Therefore, every month this inflation rate is calculated. The system will be used more than 5 years. It means the collector saves more money.

Chapter 6

DISCUSSION

In this study, two system were tested. One of them was with two storage tank and other system was with one storage tank. One storage tank system is more efficient than other system. Because two storage tank system has cold inlet water. That system has second hot water storage tank and there is no circulation. However at one storage tank, system has circulation and the temperature of the inlet water increases, when the storage tank temperature increases. For two water storage tank, the average water inlet temperature is 22,63 ^{o}C. In one storage tank, the average inlet temperature is 35,51 ^{o}C. Because of this reason system efficiency increased at one storage tank system. Figure 6.1 compares the average efficieny of the systems.

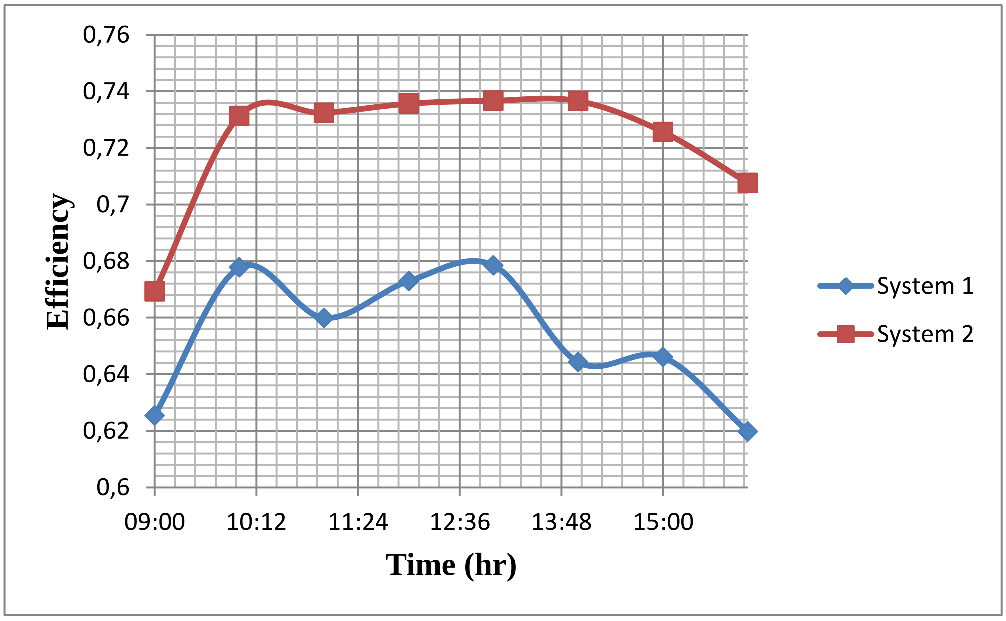


Figure 6.1: Average efficiency of the two systems

The fresh water production is increased at one storage tank system because of the inlet temperature. Two storage tank system produces aproximately 2134,1 ml/m^2 fresh water at one day whereas at one storage tank system, the average fresh water is 2833.17 ml/m^2 at one day. Fresh water production is related with mass flow rate. If mass flow rate is slow the production of the fresh water is increased. Also mass flow rate affects the efficieny of the systems.

The efficiency of the system incerases with reducing the mass flow rate of the water. If the upper part has some metal points, mass flow rate of the water will reduce and system efficiency increases and it produces more fresh water.

Chapter 7

CONCLUSION

The use of the solar collector has grown to huge amount due to the increase in population and misproper use. Pollution and the economical needs being another factors, since there is no negative effects for using this devise; solar collector is not against enviroment and in the same time is not costly. The world have water scarity problem and fuel problem. Expecially in Cyprus, all of the houses almost use the solar collector for heating the water. They save money from electricity price or fuel price. However, people who live in Cyprus, don't use solar energy for fresh water. They give more money to companies for drinking or using water for cooking. This project, may be a model fort he solution of water problem of Cyprus. The housescan produce their own fresh water at inclined solar water desalination and water heater system. They also save money from this project when they start to use.

In this project, inclined solar water desalination and water heater system is applied together. System works with aproximately 72% efficiency. Project was designed as sandwich type solar collector. One 1 mm galvanized sheet metal is used for the absorber. This material also affects the heat transfer of the solar collector. If the thickness of the material is low, the efficiency of the material would incerase. But light material which the thickness is very low, has damaged because of the tap water.

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APPENDICES

Appendix A: Photographs

Appendix A1: Spot welded to the absorber

Appendix A2: Bronze welded to the connection union

Appendix A3: Parts are soldered

Appendix A4: After soldered

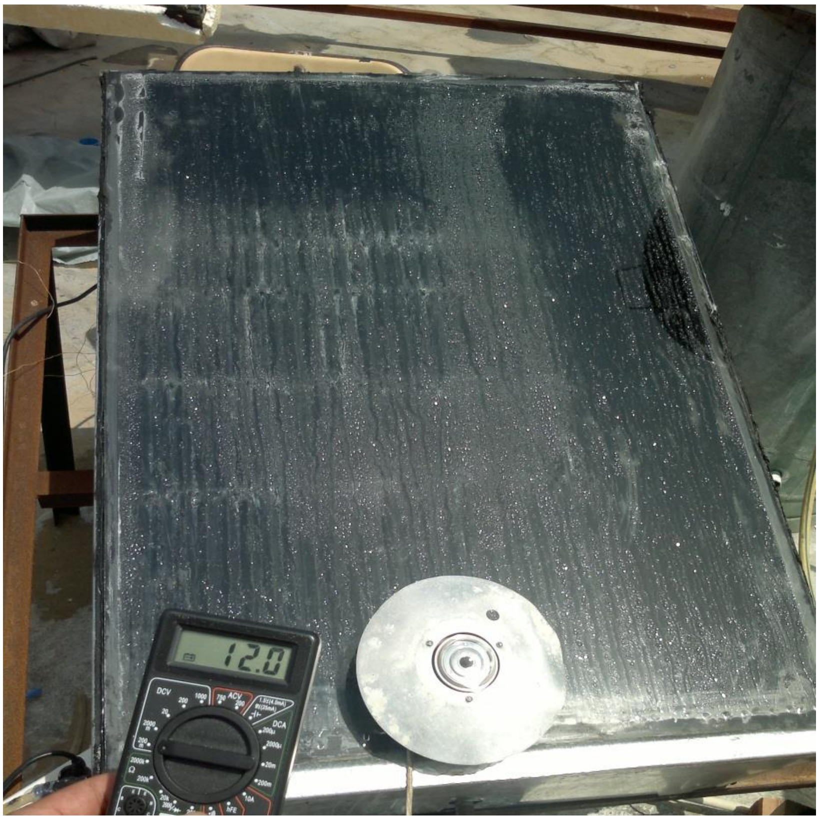
Appendix A5: Box and absorber connected

Appendix A6: Attached to the fresh water channel with bronze welding

Appendix A7: After painting the collector

Appendix A8: Leakages are blocked with silicone

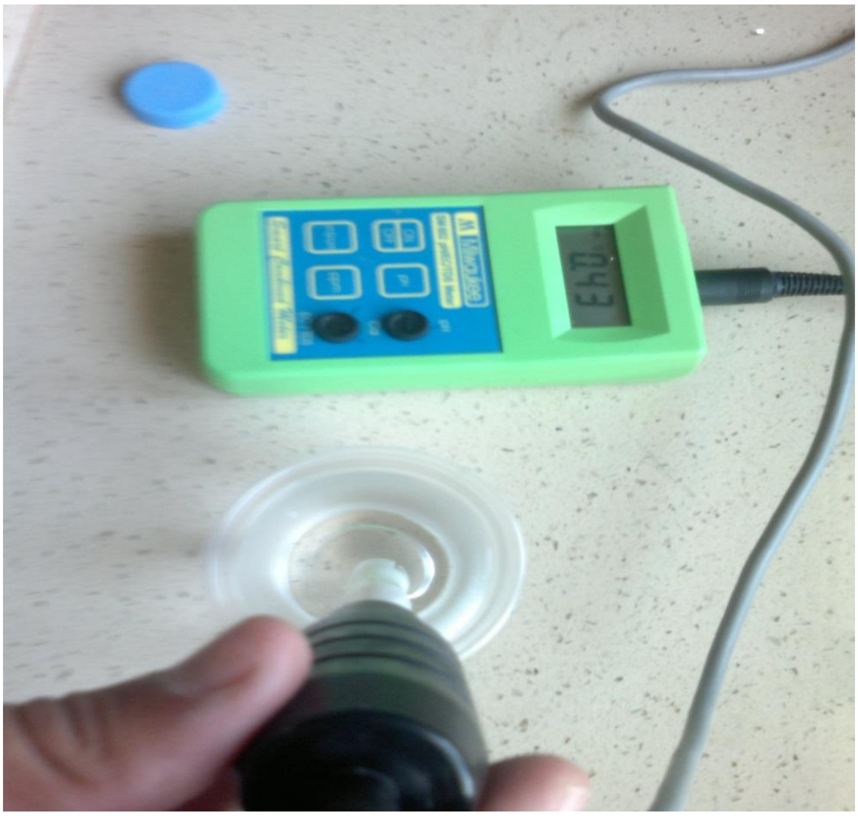
Appendix A9: System Set-up



Appendix A10: Solar ray measured

Appendix A11: TDS value of system water

Appendix A12: pH value of system water



Appendix A13: TDS value of tap water

Appendix A14: pH value of tap water

APPENDIX B: Data Analysis

$\dot{m}$=0,009634 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	17,2	26,3	24	8,6	0	4,1855	2257,1	0,72	0	9,1	509,63458	0	819,0476	0,622228
10:00	19,8	28,8	26,1	9,8	127	4,1855	2257,1	0,72	3,52778E-05	9	504,0342	110,5909	933,3333	0,658527
11:00	21,5	29,6	28	9,6	152	4,1855	2257,1	0,72	4,22222E-05	8,1	453,63078	132,3608	914,2857	0,640928
12:00	22,7	31,6	29,6	10,6	197	4,1855	2257,1	0,72	5,47222E-05	8,9	498,43382	171,5466	1009,524	0,66366
13:00	24,8	33,9	30,5	10,8	209	4,1855	2257,1	0,72	5,80556E-05	9,1	509,63458	181,9961	1028,571	0,672419
14:00	25,3	34,3	31	11	216	4,1855	2257,1	0,72	0,00006	9	504,0342	188,0917	1047,619	0,660666
15:00	25,1	33,2	29,9	10,2	184	4,1855	2257,1	0,72	5,11111E-05	8,1	453,63078	160,2262	971,4286	0,631912
16:00	24,5	32,1	27,9	9,9	167	4,1855	2257,1	0,72	4,63889E-05	7,6	425,62888	145,4227	942,8571	0,605661
Average Efficiency														0,6445

Time	FW (ml)	FW (ml/m^2)
09:00	0	0
10:00	127	176,3889
11:00	152	211,1111
12:00	197	273,6111
13:00	209	290,2778
14:00	216	300
15:00	184	255,5556
16:00	167	231,9444
Daily total	1252	1738,889

Appendix B1: First day datas of the system 1 (30,05,2014)

$\dot{m}$=0,009634 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	16,6	26,2	28,3	8,4	0	4,1855	2257,1	0,72	0	9,6	537,6365	0	800	0,672046
10:00	17,2	25,7	29,4	8,6	116	4,1855	2257,1	0,72	3,22E-05	8,5	476,0323	101,0122	819,0476	0,704531
11:00	18,9	20,1	30,3	2,6	108	4,1855	2257,1	0,72	0,00003	1,2	67,20456	94,04583	247,619	0,651204
12:00	19,3	28,7	32,2	10,5	137	4,1855	2257,1	0,72	3,81E-05	9,4	526,4357	119,2989	1000	0,645735
13:00	21,5	30,3	31,8	10,2	184	4,1855	2257,1	0,72	5,11E-05	8,8	492,8334	160,2262	971,4286	0,672267
14:00	23,4	30,9	31,6	9,7	198	4,1855	2257,1	0,72	0,000055	7,5	420,0285	172,4174	923,8095	0,641307
15:00	24,8	35,1	33,9	11	190	4,1855	2257,1	0,72	5,28E-05	10,3	576,8391	165,451	1047,619	0,70855
16:00	23,7	31,6	32,4	9,5	159	4,1855	2257,1	0,72	4,42E-05	7,9	442,43	138,4564	904,7619	0,642032
Average Efficiency														0,667209

Time	FW (ml)	FW (ml/m^2)
09:00	525	729,1667
10:00	126	175
11:00	108	150
12:00	167	231,9444
13:00	194	269,4444
14:00	198	275
15:00	205	284,7222
16:00	169	234,7222
Daily total	1692	2350

Appendix B2: Second day datas of the system 1 (02,06,2014)

$\dot{m}$=0,009634 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	16,7	26,2	21,2	8,6	0	4,1855	2257,1	0,72	0	9,5	532,0361	0	819,0476	0,649579
10:00	17,1	28,2	24,3	11,2	124	4,1855	2257,1	0,72	3,44E-05	11,1	621,6422	107,9785	1066,667	0,684019
11:00	22	34,1	27,6	11,7	162	4,1855	2257,1	0,72	0,000045	12,1	677,646	141,0688	1114,286	0,734744
12:00	24,1	36,9	29,1	12,4	189	4,1855	2257,1	0,72	5,25E-05	12,8	716,8486	164,5802	1180,952	0,746371
13:00	24,9	35,7	29,2	11,9	212	4,1855	2257,1	0,72	5,89E-05	10,8	604,841	184,6085	1133,333	0,696573
14:00	25,8	34,1	30,7	10,1	207	4,1855	2257,1	0,72	5,75E-05	8,3	464,8315	180,2545	961,9048	0,670634
15:00	25,6	31,4	30,3	7,2	169	4,1855	2257,1	0,72	4,69E-05	5,8	324,822	147,1643	685,7143	0,688313
16:00	24,1	28	29,8	6,5	162	4,1855	2257,1	0,72	0,000045	3,9	218,4148	141,0688	619,0476	0,580704
Average Efficiency														0,681367

Time	FW (ml)	FW (ml/m^2)
09:00	575	798,6111
10:00	124	172,2222
11:00	162	225
12:00	189	262,5
13:00	212	294,4444
14:00	207	287,5
15:00	169	234,7222
16:00	168	233,3333
Daily total	1806	2508,333

Appendix B3: Third day datas of the system 1 (03,06,2014)

$\dot{m}$=0,020121 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	16,9	20,3	26,2	6,9	0	4,1855	2257,1	0,72	0	3,4	397,683322	0	657,1429	0,60517
10:00	18,2	21,7	27,6	8,4	91	4,1855	2257,1	0,72	2,52778E-05	3,5	409,37989	79,24232	800	0,610778
11:00	20	24,5	27,5	10	116	4,1855	2257,1	0,72	3,22222E-05	4,5	526,345573	101,0122	952,381	0,658726
12:00	21,9	24,1	28,4	6,7	124	4,1855	2257,1	0,72	3,44444E-05	2,2	257,324503	107,9785	638,0952	0,57249
13:00	23,7	28,8	31,3	11,4	127	4,1855	2257,1	0,72	3,52778E-05	5,1	596,524983	110,5909	1085,714	0,651291
14:00	24,2	28,7	31,6	10,8	135	4,1855	2257,1	0,72	0,0000375	4,5	526,345573	117,5573	1028,571	0,626017
15:00	24,1	27,2	29,9	7,8	98	4,1855	2257,1	0,72	2,72222E-05	3,1	362,593617	85,33789	742,8571	0,602985
16:00	23,5	26	28,7	7,6	112	4,1855	2257,1	0,72	3,11111E-05	2,5	292,414207	97,52901	723,8095	0,538737
Average Efficiency														0,608274

Time	FW (ml)	FW (ml/m^2)
09:00	590	819,4444
10:00	91	126,3889
11:00	116	161,1111
12:00	124	172,2222
13:00	127	176,3889
14:00	135	187,5
15:00	98	136,1111
16:00	112	155,5556
Daily total	1393	1934,722

Appendix B4: First day datas of the system 1 (04,06,2014)

$\dot{m}$=0,020121 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg * °C)$	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	18,9	22,7	26,8	8,5	0	4,1855	2257,1	0,72	0	3,8	444,4696	0	809,5238	0,549051
10:00	19,7	24,5	27,3	10,6	105	4,1855	2257,1	0,72	2,92E-05	4,8	561,4353	91,43345	1009,524	0,64671
11:00	21,1	25,1	29,1	10,3	125	4,1855	2257,1	0,72	3,47E-05	4	467,8627	108,8493	980,9524	0,58791
12:00	23,9	28,2	33,5	11,1	142	4,1855	2257,1	0,72	3,94E-05	4,3	502,9524	123,6529	1057,143	0,592735
13:00	24,2	26,5	28,2	6,8	113	4,1855	2257,1	0,72	3,14E-05	2,3	269,0211	98,39981	647,619	0,567341
14:00	25,4	28,9	30,5	10,4	133	4,1855	2257,1	0,72	3,69E-05	3,5	409,3799	115,8157	990,4762	0,530246
15:00	24	25,2	28,7	4,8	102	4,1855	2257,1	0,72	2,83E-05	1,2	140,3588	88,82106	457,1429	0,501331
16:00	22,2	23,7	26,2	4,6	98	4,1855	2257,1	0,72	2,72E-05	1,5	175,4485	85,33789	438,0952	0,595273
Average Efficiency														0,571325

Time	FW (ml)	FW (ml/m^2)
09:00	540	750
10:00	105	145,8333
11:00	125	173,6111
12:00	142	197,2222
13:00	113	156,9444
14:00	133	184,7222
15:00	102	141,6667
16:00	98	136,1111
Daily total	1358	1886,111

Appendix B5: Second day datas of the system 1 (05,06,2014)

$\dot{m}$=0,020121 (kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	18,7	23	26,7	9,4	0	4,1855	2257,1	0,72	0	4,3	502,9524	0	895,2381	0,561809
10:00	20,4	24,7	27,6	10,1	122	4,1855	2257,1	0,72	3,39E-05	4,3	502,9524	106,237	961,9048	0,633316
11:00	21,9	24,6	27,9	8,2	104	4,1855	2257,1	0,72	2,89E-05	2,7	315,8073	90,56265	780,9524	0,520352
12:00	22,4	25,2	29,1	6,9	106	4,1855	2257,1	0,72	2,94E-05	2,8	327,5039	92,30424	657,1429	0,638838
13:00	23	25,1	29,8	5,3	97	4,1855	2257,1	0,72	2,69E-05	2,1	245,6279	84,46709	504,7619	0,653962
14:00	24,5	28,2	28,7	10,7	134	4,1855	2257,1	0,72	3,72E-05	3,7	432,773	116,6865	1019,048	0,539189
15:00	24	26,4	26,8	6,2	108	4,1855	2257,1	0,72	0,00003	2,4	280,7176	94,04583	590,4762	0,63468
16:00	22,8	24	25,2	4,4	89	4,1855	2257,1	0,72	2,47E-05	1,2	140,3588	77,50073	419,0476	0,519892
Average Efficiency														0,587755

Time	FW (ml)	FW (ml/m^2)
09:00	560	777,7778
10:00	122	169,4444
11:00	104	144,4444
12:00	106	147,2222
13:00	97	134,7222
14:00	134	186,1111
15:00	108	150
16:00	89	123,6111
Daily total	1320	1833,333

Appendix B6: Third day datas of the system 1 (06,06,2014)

$\dot{m}$=0,006739(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	19,8	32,5	27,8	7,8	0	4,1855	2257,1	0,72	0	12,7	497,49036	0	742,8571	0,669699
10:00	21	36,2	28,1	9,8	102	4,1855	2257,1	0,72	2,83333E-05	15,2	595,421533	88,82106	933,3333	0,733117
11:00	23,1	38	28,7	10,2	128	4,1855	2257,1	0,72	3,55556E-05	14,9	583,669793	111,4617	971,4286	0,715577
12:00	24,6	40,7	29,8	10,9	156	4,1855	2257,1	0,72	4,33333E-05	16,1	630,676756	135,844	1038,095	0,738392
13:00	26,7	43,5	30,8	11,4	181	4,1855	2257,1	0,72	5,02778E-05	16,8	658,097484	157,6139	1085,714	0,751313
14:00	26,2	40,2	30,9	9,5	142	4,1855	2257,1	0,72	3,94444E-05	14	548,41457	123,6529	904,7619	0,742811
15:00	25,8	37,2	32,1	8,5	136	4,1855	2257,1	0,72	3,77778E-05	11,4	446,56615	118,4281	809,5238	0,697934
16:00	24,9	34,7	31,2	7,6	117	4,1855	2257,1	0,72	0,0000325	9,8	383,890199	101,883	723,8095	0,671134
Average Efficiency														0,714997

Time	FW (ml)	FW (ml/m^2)
09:00	608	844,4444
10:00	102	141,6667
11:00	128	177,7778
12:00	156	216,6667
13:00	181	251,3889
14:00	142	197,2222
15:00	136	188,8889
16:00	117	162,5
Daily total	1570	2180,556

Appendix B7: First day datas of the system 1 (09,06,2014)

$\dot{m}$=0,006739(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	19,9	30,8	26,8	7,2	0	4,1855	2257,1	0,72	0	11	430,8972	0	685,7143	0,628392
10:00	21,1	33,5	27,3	8,6	118	4,1855	2257,1	0,72	3,28E-05	12,4	485,7386	102,7538	819,0476	0,718508
11:00	23,6	38,4	29,1	10,5	136	4,1855	2257,1	0,72	3,78E-05	14,8	579,7525	118,4281	1000	0,698181
12:00	25,4	41,2	33,5	11,6	175	4,1855	2257,1	0,72	4,86E-05	15,8	618,925	152,3891	1104,762	0,698172
13:00	26,8	43,7	28,2	11,8	182	4,1855	2257,1	0,72	5,06E-05	16,9	662,0147	158,4846	1123,81	0,730105
14:00	26,1	40,3	30,5	10,7	188	4,1855	2257,1	0,72	5,22E-05	14,2	556,2491	163,7094	1019,048	0,706501
15:00	24,6	36,2	28,7	8,9	148	4,1855	2257,1	0,72	4,11E-05	11,6	454,4006	128,8776	847,619	0,688137
16:00	23,2	31,8	26,2	6,6	121	4,1855	2257,1	0,72	3,36E-05	8,6	336,8832	105,3662	628,5714	0,703579
Average Efficiency														0,696447

Time	FW (ml)	FW (ml/m^2)
09:00	640	888,8889
10:00	118	163,8889
11:00	136	188,8889
12:00	175	243,0556
13:00	182	252,7778
14:00	188	261,1111
15:00	148	205,5556
16:00	121	168,0556
Daily total	1708	2372,222

Appendix B8: Second day datas of the system 1 (10,06,2014)

$\dot{m}$=0,006739(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	19,8	30,4	27,8	6,5	0	4,1855	2257,1	0,72	0	10,6	415,2282	0	619,0476	0,670753
10:00	21,6	36,6	30,4	10,1	110	4,1855	2257,1	0,72	3,06E-05	15	587,587	95,78742	961,9048	0,710439
11:00	23,2	39,8	31,2	11,1	142	4,1855	2257,1	0,72	3,94E-05	16,6	650,263	123,6529	1057,143	0,732083
12:00	25,4	45,1	32,3	13	195	4,1855	2257,1	0,72	5,42E-05	19,7	771,6976	169,805	1238,095	0,760444
13:00	25,8	40	32,1	10,5	178	4,1855	2257,1	0,72	4,94E-05	14,2	556,2491	155,0015	1000	0,711251
14:00	25,4	37,7	30,9	9,6	162	4,1855	2257,1	0,72	0,000045	12,3	481,8214	141,0688	914,2857	0,681286
15:00	25,7	38,1	31,4	10,2	180	4,1855	2257,1	0,72	0,00005	12,4	485,7386	156,7431	971,4286	0,661378
16:00	24,1	35,6	30,2	8,5	153	4,1855	2257,1	0,72	4,25E-05	11,5	450,4834	133,2316	809,5238	0,72106
Average Efficiency														0,706087

Time	FW (ml)	FW (ml/m^2)
09:00	610	847,2222
10:00	110	152,7778
11:00	142	197,2222
12:00	195	270,8333
13:00	178	247,2222
14:00	162	225
15:00	180	250
16:00	153	212,5
Daily total	1730	2402,778

Appendix B9: Third day datas of the system 1 (11,06,2014)

$\dot{m}$=0,0297(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	21,8	24,8	28,6	9,3	0	4,1855	2257,1	0,72	0	3	517,955625	0	885,7143	0,584789
10:00	23,9	27,4	28,8	10,7	133	4,1855	2257,1	0,72	3,69444E-05	3,5	604,281563	115,8157	1019,048	0,706638
11:00	26,5	30,1	29	10,9	188	4,1855	2257,1	0,72	5,22222E-05	3,6	621,54675	163,7094	1038,095	0,756439
12:00	28,4	32,2	29,3	11	209	4,1855	2257,1	0,72	5,80556E-05	3,8	656,077125	181,9961	1047,619	0,799979
13:00	30,2	33,1	31	10,2	206	4,1855	2257,1	0,72	5,72222E-05	2,9	500,690438	179,3837	971,4286	0,700076
14:00	31,4	34,5	34,3	9,6	205	4,1855	2257,1	0,72	5,69444E-05	3,1	535,220813	178,5129	914,2857	0,780646
15:00	33,7	36,1	33,6	8,7	189	4,1855	2257,1	0,72	0,0000525	2,4	414,3645	164,5802	828,5714	0,698726
16:00	34,8	37	31,1	8,6	171	4,1855	2257,1	0,72	0,0000475	2,2	379,834125	148,9059	819,0476	0,645555
Average Efficiency														0,709106

Time	FW (ml)	FW (ml/m^2)
09:00	0	0
10:00	133	184,7222
11:00	188	261,1111
12:00	209	290,2778
13:00	206	286,1111
14:00	205	284,7222
15:00	189	262,5
16:00	171	237,5
Daily total	1301	1806,944

Appendix B10: First day datas of the system 2 (17,06,2014)

$\dot{m}$=0,0297(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	25,1	28,3	28,3	8,8	0	4,1855	2257,1	0,72	0	3,2	552,486	0	838,0952	0,659216
10:00	27,2	30,1	29,4	10,5	138	4,1855	2257,1	0,72	3,83E-05	2,9	500,6904	120,1697	1000	0,62086
11:00	29,8	32,7	30,3	9,7	179	4,1855	2257,1	0,72	4,97E-05	2,9	500,6904	155,8723	923,8095	0,710712
12:00	32,2	35	32,2	10,1	214	4,1855	2257,1	0,72	5,94E-05	2,8	483,4253	186,3501	961,9048	0,696301
13:00	34,9	37,4	31,8	9,4	220	4,1855	2257,1	0,72	6,11E-05	2,5	431,6297	191,5748	895,2381	0,696133
14:00	37,1	39	31,6	8,1	203	4,1855	2257,1	0,72	5,64E-05	1,9	328,0386	176,7713	771,4286	0,654383
15:00	38,5	40,5	33,9	7,9	197	4,1855	2257,1	0,72	5,47E-05	2	345,3038	171,5466	752,381	0,686953
16:00	40	41,3	32,4	6,5	182	4,1855	2257,1	0,72	5,06E-05	1,3	224,4474	158,4846	619,0476	0,618583
Average Efficiency														0,667893

Time	FW (ml)	FW (ml/m^2)
09:00	570	791,6667
10:00	138	191,6667
11:00	179	248,6111
12:00	214	297,2222
13:00	220	305,5556
14:00	203	281,9444
15:00	197	273,6111
16:00	182	252,7778
Daily total	1903	2643,056

Appendix B11: Second day datas of the system 2 (18,06,2014)

$\dot{m}$=0,0297(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	29,7	32,7	29,2	8,2	0	4,1855	2257,1	0,72	0	3	517,9556	0	780,9524	0,663236
10:00	32,1	35	30,7	8,6	141	4,1855	2257,1	0,72	3,92E-05	2,9	500,6904	122,7821	819,0476	0,761216
11:00	35,2	38,1	31,1	9,6	185	4,1855	2257,1	0,72	5,14E-05	2,9	500,6904	161,097	914,2857	0,72383
12:00	37,7	40,5	31,2	9,8	206	4,1855	2257,1	0,72	5,72E-05	2,8	483,4253	179,3837	933,3333	0,710152
13:00	39,1	41,8	32,9	9,5	211	4,1855	2257,1	0,72	5,86E-05	2,7	466,1601	183,7377	904,7619	0,718308
14:00	42,4	44,7	32,5	8,1	200	4,1855	2257,1	0,72	5,56E-05	2,3	397,0993	174,159	771,4286	0,74052
15:00	43,7	45,4	31	7,2	195	4,1855	2257,1	0,72	5,42E-05	1,7	293,5082	169,805	685,7143	0,675665
16:00	44,8	46,3	30,8	7	192	4,1855	2257,1	0,72	5,33E-05	1,5	258,9778	167,1926	666,6667	0,639256
Average Efficiency														0,704023

Time	FW (ml)	FW (ml/m^2)
09:00	540	750
10:00	141	195,8333
11:00	185	256,9444
12:00	206	286,1111
13:00	211	293,0556
14:00	200	277,7778
15:00	195	270,8333
16:00	192	266,6667
Daily total	1870	2597,222

Appendix B12: Third day datas of the system 2 (19,06,2014)

$\dot{m}$=0,0072(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	30,9	41,3	30,2	7,2	0	4,1855	2257,1	0,72	0	10,4	435,292	0	685,7143	0,634801
10:00	31,2	42,5	30,3	8,6	191	4,1855	2257,1	0,72	5,30556E-05	11,3	472,9615	166,3218	819,0476	0,78052
11:00	33,7	45,1	33	9,8	268	4,1855	2257,1	0,72	7,44444E-05	11,4	477,147	233,373	933,3333	0,761271
12:00	36,1	47,6	34,5	9,9	272	4,1855	2257,1	0,72	7,55556E-05	11,5	481,3325	236,8562	942,8571	0,761715
13:00	37,7	49,8	35	10,4	291	4,1855	2257,1	0,72	8,08333E-05	12,1	506,4455	253,4013	990,4762	0,767153
14:00	39,6	50,2	35,1	9,2	267	4,1855	2257,1	0,72	7,41667E-05	10,6	443,663	232,5022	876,1905	0,77171
15:00	40,8	50,3	34,9	8,3	241	4,1855	2257,1	0,72	6,69444E-05	9,5	397,6225	209,8615	790,4762	0,768504
16:00	41,2	50,4	32,7	8	220	4,1855	2257,1	0,72	6,11111E-05	9,2	385,066	191,5748	761,9048	0,756841
Average Efficiency														0,750315

Time	FW (ml)	FW (ml/m^2)
09:00	600	833,3333
10:00	191	265,2778
11:00	268	372,2222
12:00	272	377,7778
13:00	291	404,1667
14:00	267	370,8333
15:00	241	334,7222
16:00	220	305,5556
Daily total	2350	3263,889

Appendix B13: First day datas of the system 2 (20,06,2014)

$\dot{m}$=0,0072(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	24,7	39,3	26,5	9,6	0	4,1855	2257,1	0,72	0	14,6	611,083	0	914,2857	0,668372
10:00	26,1	40,2	27,8	10,2	178	4,1855	2257,1	0,72	4,94E-05	14,1	590,1555	155,0015	971,4286	0,767073
11:00	28,4	41,5	27,7	10	204	4,1855	2257,1	0,72	5,67E-05	13,1	548,3005	177,6421	952,381	0,76224
12:00	30,3	43	30	10,1	241	4,1855	2257,1	0,72	6,69E-05	12,7	531,5585	209,8615	961,9048	0,770783
13:00	33,6	47,8	32,1	11,1	268	4,1855	2257,1	0,72	7,44E-05	14,2	594,341	233,373	1057,143	0,782973
14:00	35,7	48,7	31,8	10,8	250	4,1855	2257,1	0,72	6,94E-05	13	544,115	217,6987	1028,571	0,740652
15:00	37,1	48,9	30,2	9,7	247	4,1855	2257,1	0,72	6,86E-05	11,8	493,889	215,0863	923,8095	0,767447
16:00	38	48,2	29,5	8,7	231	4,1855	2257,1	0,72	6,42E-05	10,2	426,921	201,1536	828,5714	0,758021
Average Efficiency														0,752195

Time	FW (ml)	FW (ml/m^2)
09:00	620	861,1111
10:00	178	247,2222
11:00	204	283,3333
12:00	241	334,7222
13:00	268	372,2222
14:00	250	347,2222
15:00	247	343,0556
16:00	231	320,8333
Daily total	2239	3109,722

Appendix B14: Second day datas of the system 2 (23,06,2014)

$\dot{m}$=0,0072(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg*$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	30,1	45,1	29,8	8,8	0	4,1855	2257,1	0,72	0	15	627,825	0	838,0952	0,749109
10:00	32,7	46,2	32,4	10,2	189	4,1855	2257,1	0,72	5,25E-05	13,5	565,0425	164,5802	971,4286	0,751082
11:00	33,6	47,1	33	10,3	220	4,1855	2257,1	0,72	6,11E-05	13,5	565,0425	191,5748	980,9524	0,771309
12:00	35,5	48,9	33,4	10,9	252	4,1855	2257,1	0,72	0,00007	13,4	560,857	219,4403	1038,095	0,751663
13:00	37,2	52,1	34,8	11,8	263	4,1855	2257,1	0,72	7,31E-05	14,9	623,6395	229,019	1123,81	0,758722
14:00	39,1	53,7	36,8	12	304	4,1855	2257,1	0,72	8,44E-05	14,6	611,083	264,7216	1142,857	0,766329
15:00	40,7	52,6	35,7	9,8	260	4,1855	2257,1	0,72	7,22E-05	11,9	498,0745	226,4066	933,3333	0,77623
16:00	41,1	52	34,9	9,1	237	4,1855	2257,1	0,72	6,58E-05	10,9	456,2195	206,3784	866,6667	0,764536
Average Efficiency														0,761122

Time	FW (ml)	FW (ml/m^2)
09:00	630	875
10:00	189	262,5
11:00	220	305,5556
12:00	252	350
13:00	263	365,2778
14:00	304	422,2222
15:00	260	361,1111
16:00	237	329,1667
Daily total	2355	3270,833

Appendix B15: Third day datas of the system 2 (25,06,2014)

$\dot{m}$=0,0125(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	28,2	37,2	29,2	9,4	0	4,1855	2257,1	0,72	0	9	653,984375	0	895,2381	0,730514
10:00	30,3	38,4	30,1	9,9	140	4,1855	2257,1	0,72	3,88889E-05	8,1	588,585938	121,9113	942,8571	0,753558
11:00	34,1	41,3	31,6	10,1	181	4,1855	2257,1	0,72	5,02778E-05	7,2	523,1875	157,6139	961,9048	0,707764
12:00	37,8	44,9	31,7	10,5	224	4,1855	2257,1	0,72	6,22222E-05	7,1	515,921007	195,058	1000	0,710979
13:00	40	47,3	32,2	10,4	243	4,1855	2257,1	0,72	0,0000675	7,3	530,453993	211,6031	990,4762	0,749192
14:00	42,2	48,1	32,2	9,4	267	4,1855	2257,1	0,72	7,41667E-05	5,9	428,72309	232,5022	895,2381	0,738603
15:00	44,1	49,8	34,1	9,2	236	4,1855	2257,1	0,72	6,55556E-05	5,7	414,190104	205,5076	876,1905	0,707264
16:00	45,7	51,7	32	8,8	202	4,1855	2257,1	0,72	5,61111E-05	6	435,989583	175,9005	838,0952	0,730096
Average Efficiency														0,728496

Time	FW (ml)	FW (ml/m^2)
09:00	580	805,5556
10:00	140	194,4444
11:00	181	251,3889
12:00	224	311,1111
13:00	243	337,5
14:00	267	370,8333
15:00	236	327,7778
16:00	202	280,5556
Daily total	2073	2879,167

Appendix B16: First day datas of the system 2 (26,06,2014)

$\dot{m}$=0,0125(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	32,4	40,8	31,4	9,1	0	4,1855	2257,1	0,72	0	8,4	610,3854	0	866,6667	0,704291
10:00	36,2	43,7	33,3	9,8	150	4,1855	2257,1	0,72	4,17E-05	7,5	544,987	130,6192	933,3333	0,723864
11:00	39,7	47	34,5	10,5	207	4,1855	2257,1	0,72	5,75E-05	7,3	530,454	180,2545	1000	0,710709
12:00	41,9	49,2	35,3	10,8	237	4,1855	2257,1	0,72	6,58E-05	7,3	530,454	206,3784	1028,571	0,716365
13:00	43,3	49,8	34,7	9,7	240	4,1855	2257,1	0,72	6,67E-05	6,5	472,322	208,9907	923,8095	0,737504
14:00	45,6	52,4	35,4	10,4	261	4,1855	2257,1	0,72	7,25E-05	6,8	494,1215	227,2774	990,4762	0,728335
15:00	46,9	53	36,8	9,6	240	4,1855	2257,1	0,72	6,67E-05	6,1	443,2561	208,9907	914,2857	0,713395
16:00	47,1	52,6	34,3	8,4	228	4,1855	2257,1	0,72	6,33E-05	5,5	399,6571	198,5412	800	0,747748
Average Efficiency														0,722776

Time	FW (ml)	FW (ml/m^2)
09:00	610	847,2222
10:00	150	208,3333
11:00	207	287,5
12:00	237	329,1667
13:00	240	333,3333
14:00	261	362,5
15:00	240	333,3333
16:00	228	316,6667
Daily total	2173	3018,056

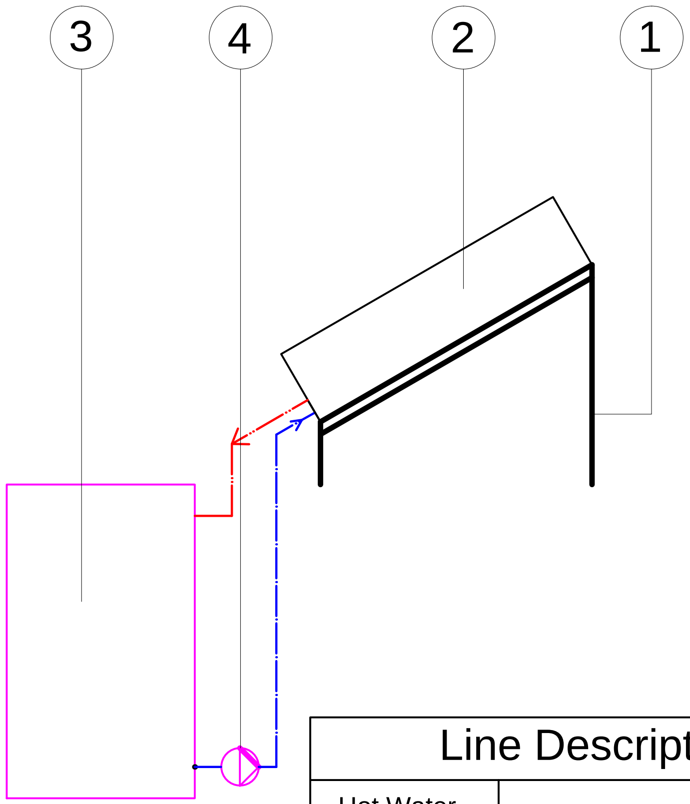
Appendix B17: Second day datas of the system 2 (27,06,2014)

$\dot{m}$=0,0125(kg/s)														
Time	T_{in} (°C)	T_{out} (°C)	T_{amb} (°C)	P	FW (ml)	C_p $(kj/kg *$°C)	h_{fg} (kj/kg)	A_s (m^2)	$\dot{m}$ of FW (kg/s)	ΔT (°C)	q_c (W/m^2)	q_d (W/m^2)	q_{rad} (W/m^2)	efficiency
09:00	28,9	36	30,4	8,6	0	4,1855	2257,1	0,72	0	7,1	515,921	0	819,0476	0,629904
10:00	30,2	36,8	31,5	9	155	4,1855	2257,1	0,72	4,31E-05	6,6	479,5885	134,9732	857,1429	0,716989
11:00	32,1	38,9	32	10,1	192	4,1855	2257,1	0,72	5,33E-05	6,8	494,1215	167,1926	961,9048	0,687505
12:00	34	41,2	32,1	10,5	207	4,1855	2257,1	0,72	5,75E-05	7,2	523,1875	180,2545	1000	0,703442
13:00	36,3	43,6	33,6	10,7	234	4,1855	2257,1	0,72	0,000065	7,3	530,454	203,766	1019,048	0,720496
14:00	37,8	43,7	34,7	9,8	267	4,1855	2257,1	0,72	7,42E-05	5,9	428,7231	232,5022	933,3333	0,708456
15:00	38,7	44,3	34,5	9	258	4,1855	2257,1	0,72	7,17E-05	5,6	406,9236	224,665	857,1429	0,736853
16:00	39,8	45	33,2	8,2	202	4,1855	2257,1	0,72	5,61E-05	5,2	377,8576	175,9005	780,9524	0,709081
Average Efficiency														0,701591

Time	FW (ml)	FW (ml/m^2)
09:00	580	805,5556
10:00	155	215,2778
11:00	192	266,6667
12:00	207	287,5
13:00	234	325
14:00	267	370,8333
15:00	258	358,3333
16:00	202	280,5556
Daily total	2095	2909,722

Appendix B18: Third day datas of the system 2 (30,06,2014)

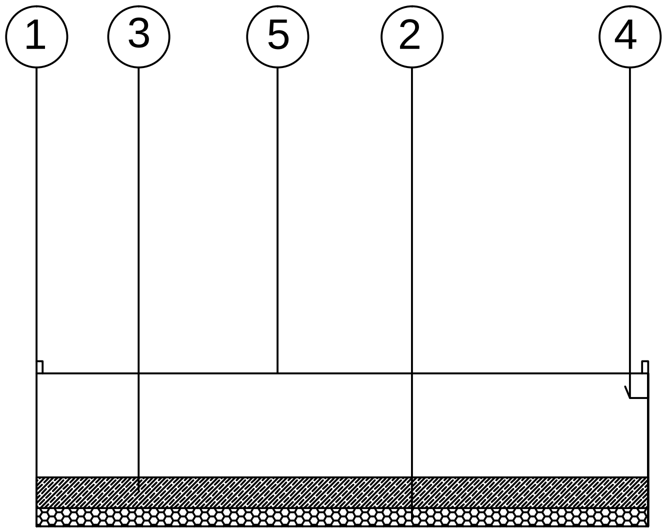
Appendix C: Drawings



Line Description	
Hot Water	
Cold Water	

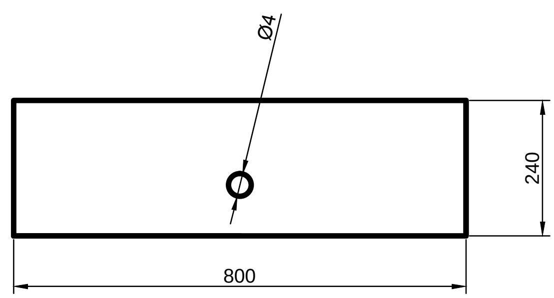
Number	Name	Material	Description
4	Pump	Plastic	1 m^3 / s
3	Water Tank	Steel	150 lt
2	Solar Collector	Sheet Metal	1050mm x 800mm
1	Stand	Steel	height is 1000mm

	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:20	One Storage Tank System		DWG.NO 1



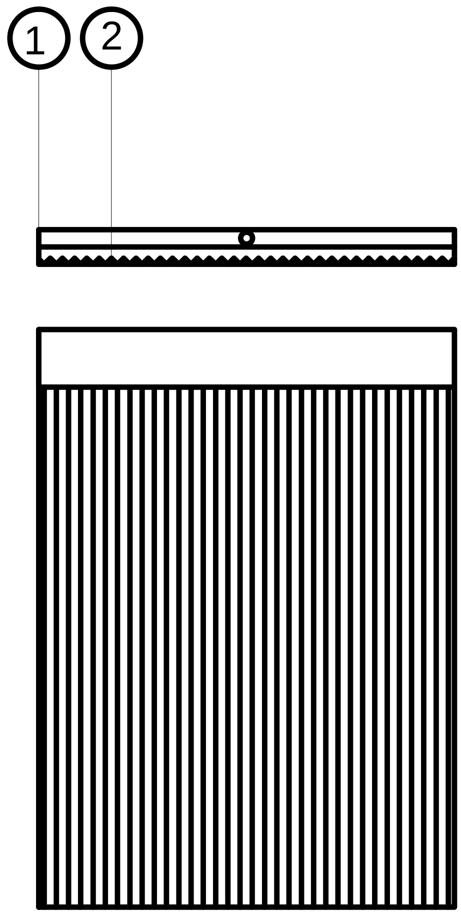
5	Glass Cover	Glass	1050mmx800mm t:3mm
4	Collector	Sheet Metal	300mmx300mm t:1,5mm
3	Absorber	Sheet Metal	1000mmx750mm t:30mm
2	Insulation	Glass Wool	1050mmx800mm t:50mm
1	Frame	Sheet Metal	1050mmx800mm t:240mm
Number	Name	Material	Description

	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:10	Solar Collector		DWG.NO 1.2



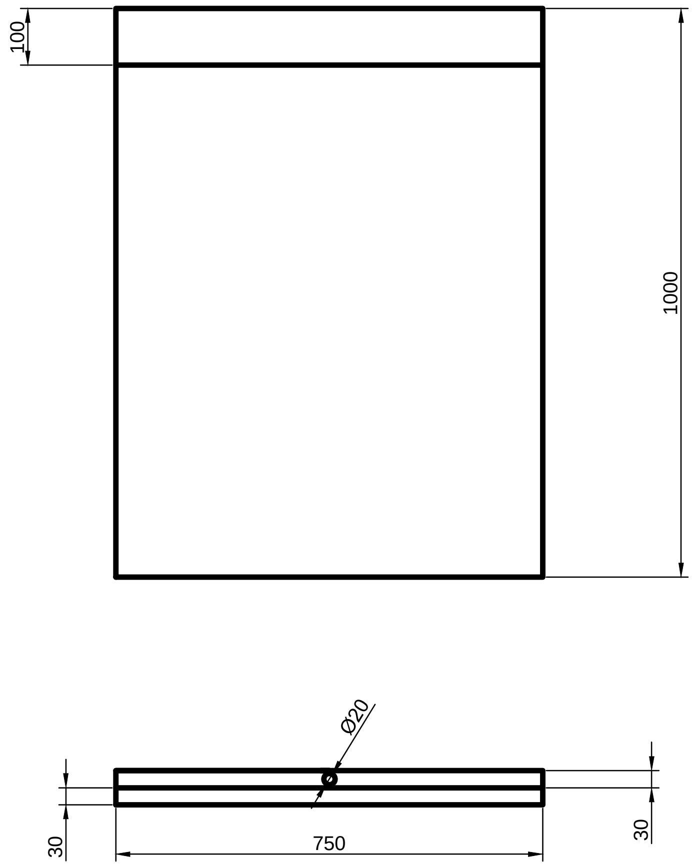
(Depth=1050 mm)

	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:10	Frame		DWG.NO 1.2.1

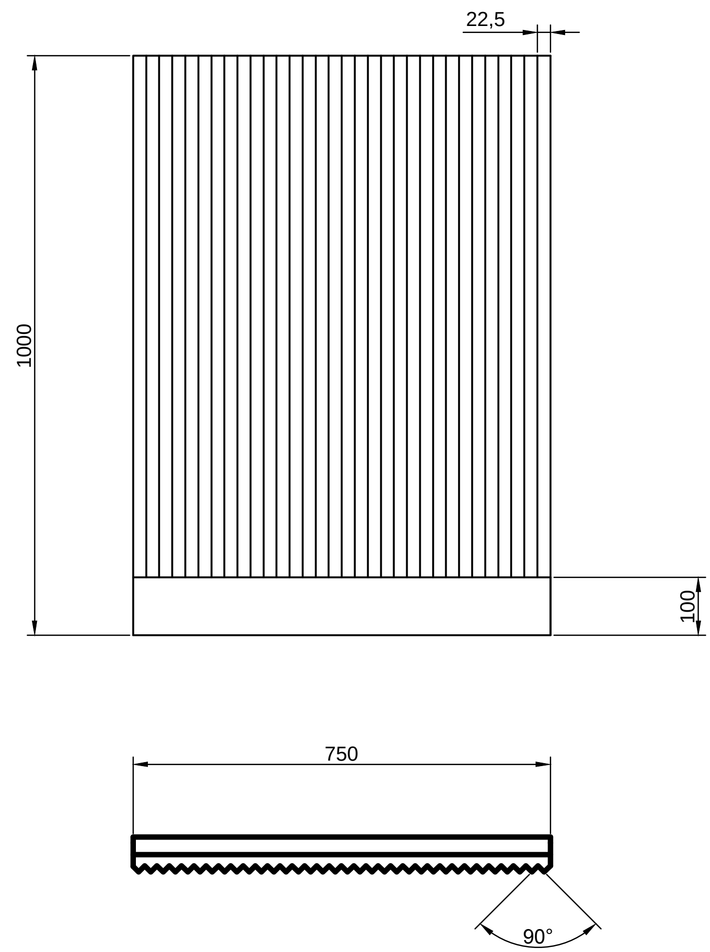


2	Upper Part	Sheet Metal	Produced
1	Below Part	Sheet Metal	Produced
Number	Name	Material	Description

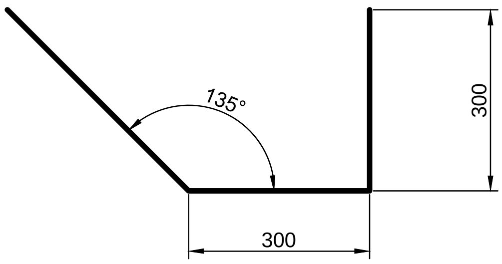
	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:10	Absorber		DWG.NO 1.2.2



	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:10	Below Part		DWG.NO 1.2.2.1

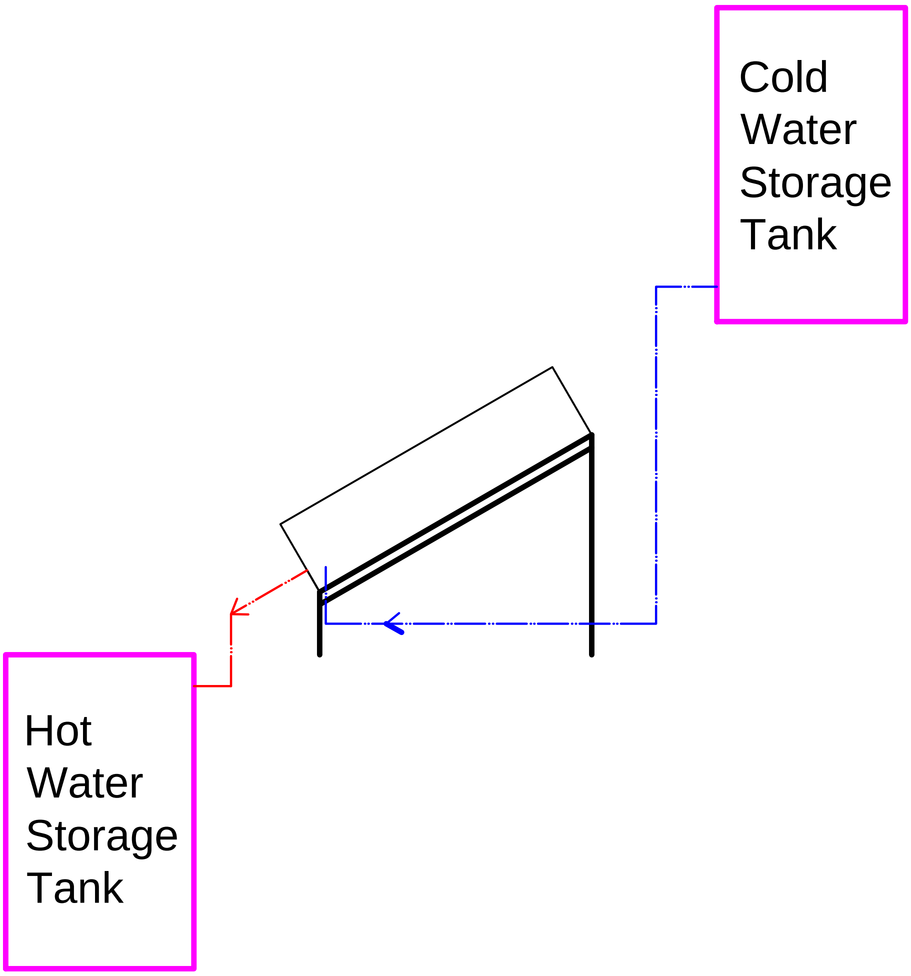


	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:10	Upper Part		DWG.NO 1.2.2.2



(Thickness=800 mm)

	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:1	Collector		DWG.NO 1.2.4



Line Description	
Hot Water	
Cold Water	

	NAME	DATE	EMU
DWGBY	ME	14JUNE	
CHK BY	CK	4 JULY	
Scale 1:20	Two Storage Tank System		DWG.NO 2