Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering

Graduation Project

Thermal efficiency enhancement for domestic hot water flat solar collector system

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Hebron - Palestine

February, 2015

Palestine Polytechnic University

Hebron –Palestine

College of Engineering and Technology

Mechanical Engineering Department

Project Name

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According to the project supervisor and according to the agreement of the testing committee members, this project is submit to the Department of Mechanical Engineering at College of Engineering and Technology in partial fulfillments of the requirements of the Bachelor's degree.

Supervisor Signature

…………………………..

Committee Member Signature

………………………… ………………………….. ……………………..

Department Head Signature

…………………………………

Dedication

To our parents who

Spent nights and days doing their best

To give us best …..

To all students and who

Wish to look for

The future …..

To all who love knowledge and

Looking for the new

In this world …..

To all our friends …..

Mohammad Ahmad Ghayatha ***Saeed ZeidanAlfroukh***

Acknowledgments

We could not forget our families, who stood by us, with their support, love and care for our whole lives; they were with us with their bodies and souls, believed in us and helped us to accomplish this project.

We would like to thank our amazing teachers at Palestine Polytechnic University, to whom we would carry our gratitude our whole life. Special thanks to our Supervisor Dr. MomenSughayyer.

Abstract

For water heating in domestic and commercial applications this study investigate the possibility of increasing the efficiency for the system using the same main components for capturing and transferring solar energy.

By dividing the storage capacity into many tanks that have small size to increase heat capturing, to switching the valves after obtaining the switching moment depending on the energy that each tank have it. The management strategy increasing the efficiency.

Nowadays solar-water heating system are widely used for both domestic and commercial use. The demand for hot water for domestic users usually comes during the morning while the solar radiation varies between low and high levels during the day and the year time through, this project objective is to improve heat capturing and water heating to respond to use needs and maintain comfort.

في الاونه الاخيره اصبح الاعتماد على الطاقة الشمسية في رفع درجة حرارة المياه المستخدمة في التطبيقات المنزلية وغيرها واسع الانتشار نظرا لقلة التكلفة وغيرها من ايجابيات النظام. الا ان الزيادة على استخدام الماء الساخن خاصة في فترات الصباح والتي تكون فيها كمية الاشعاع الشمسي قليلة، بالاضافة الى الايام الباردة خلال فصل الشتاء. لذلك فان هذا المشروع يهدف الى رفع وتعزيز كفاءة نظام التسخين الشمسي ليلبي الحاجة المستمره للماء الساخن، وراحة المستخدم باستخدام المكونات الاساسية لنظام التسخين الشمسي والتي تتمثل في خزان الماء الساخن، اللاقط الشمسي، وربطات الوصل بينها.

من خلال قسم خزان الماء الساخن الشائع استخدامه ذات الحجم ٢٠٠ لتر الى اربع خزانات كل خزان يحتوي على سعة تخزين ٥٠ لتر لتقليل الوقت اللازم لتسخين الماء لا سيما خلال فترات الصباح الباكر. يتم وصل وفصل هذه السعات باستخدام محابس يدوية بناءا على كمية الطاقة التي حصل عليها كل خزان. وكذلك الطاقة التي نفقدها عند وصله على الاستهلاك المنزلي يتم تحديد استراتيجيات لرفع كفاءة النظام.

Table of Content

Chapter Two Project First Phase

Chapter Three Experimental Result

Chapter four Experimental comparision between using one tank and two tanks

List of Figures

Chapter Four		
Figure No	**Title**	**Page**
Figure (4-1)	Heating 100L using conventional system	38
Figure (4-2)	ambient temperature through the previous test	39
Figure (4-3)	Solar radiation through the test	39
Figure (4-4)	Wind speed through the previous test	40
Figure (4-5)	Heating 100L by using switching strategy	42
Figure (4-6)	ambient temperature through the previous test	42
Figure (4-7)	Wind speed through the previous test	43
Figure (4-8)	Solar radiation through the test	43
Figure (4-9)	heating 100 liters using 2 ways	44
Figure (4-10)	Temperature change at storage tank A	46
Figure (4-11)	Temperature change at storage tank B	46
Figure (4-12)	The old connection	47
Figure (4-13)	Ambient temperature through the test	47
Figure (4-14)	Temperature at high level for storage tank A (□c) (heating two storage tanks together)	48
Figure (4-15)	Temperature change at storage tank B(heating two storage tanks together)	49
Figure (4-16)	The new connection	49
Figure (4-17)	ambient temperature through the test	50
Figure (4-18)	Temperature at high level for storage tank A during heating and load test	51
Figure (4-19)	Temperature at high level for storage tank B during heating and load test	51
Figure (4-20)	The new connection of hot water from tanks to domestic use	52

NOMENCLATURES

Q_{in} Amount of solar radiation received by the collector, in (W).

G_T Is the intensity of solar radiation, (W/m^2).

A_c Collector surface area in (m^2).

Q_o Rate of heat loss,(W).

U_L Overall heat transfer coefficient, in (W/K).

T_i The inlet temperature of the collector, (□C).

T_o The outlet temperature of the collector, (□C).

T_c The mean collector temperature, (□C).

T_a The ambient temperature.

Q_u Is the rate of useful energy extracted by the collector, (W).

$(mc)_c$ Thermal capacity of collector, (KJ/K.m^2).

η_c The efficiency of the collector.

$(mc_p)_f$ The mass flow rate and heat capacity for the fluid, (KJ/K).

T_f The fluid temperature (□C).

T_t Storage tank temperature (□C).

$(mc)_t$ Thermal capacity for storage tank

η_t Efficiency of storage tank

Q_t Energy losses from the storage tank

t Time

T_{si} Initial water temperature inside the storage tank, (□C).

T_{sf} Final water temperature inside the storage tank after 48 hours (□C).

UA_s The product of the surface area and heat loss coefficient of the storage tank(W/k)

MsMass of water inside the storage tank (according to the tank).

CpSpecific heat of water at constant pressure, (4.18 KJ/Kg °C).

St Time constant for storage tank.

1

CHAPTER ONE

Project overview

1.1 Project introduction
1.2 Project idea
1.3 Project objective
1.4 Project Motivation and Importance
1.5 Work Methodology
1.6 Project budget
1.7 Project plan
1.8 Project layout

Chapter one

Project overview

1.1 Project introduction

The continuous needing of humanrequirements for the energy and its transformation from one form to another, the paucity of non-renewable energy, the high cost of crude oil and it's negative environmental impact, and the people realization about this, this lead the majority of researchers to tend their researches for using the renewable energy as wind and solar energy.

The advantages of solar energy as compared with the other forms of energy is that it is clean and can be supplied without environmental pollution.

Solar energy is a largest energy resources that may be transferred to many form of energy. The using of solar energy appears from many centuries ago, so it is not modern.

One of the most important uses of solar energy is to convert it into heat energy to heat water or another working fluid. Depending on the application, one of the most important applications of using solar energy is domestic hot water system to reduce the cost of heating water by electricity,crude oil and another ways.

Solar energy radiation varies during the day but it be at minimum value at morning time at all seasons, and along the time at winter season, which summoned to find the alternative to compensate for this paucity.

Due to the lack of sun radiation the efficiency of solar system decreased to it's minimum value. Here the importance of this project appears to raise the efficiency during this period (morning period and winter).

The efficiency of solar components system raised to a very good level and the heat loss through these components decreased, which means that the need of improve this system will take another place by finding another parameters that effects the system performance.

A solar heating system can be dividedinto some major subsystems as solar collector, water storage tank, heat exchanger and control system.

This project consider two variables, the first one is static which is storage capacity which was the first project. And the second is a dynamic one which managing the water that goes to user which it is this project.

1.2 Project idea:

The main idea of this project is to investigate the possibility of increasing the efficiency for domestic hot-water solar collector system. This project will be the second phase of a previous project. The first one was oriented to determine experimentally the system main parameters. For this purpose, a prototype was built and tested to obtain system thermal capacitances, overall heat loss, time constants among other parameters. For this project, the system storage capacitance and solar collector area ratio will be varied in relation to the loading common modes, which allows to determine the best energy management strategy that helps to increase the system overall efficiency.

1.3 Project objectives:

This project aims to develop the currently in use domestic hot-water solar systems, which allows response to the continuously increasing needs of hot water.

The project specific objective is to provide a new system management strategy that allows for increasing heat capturing and usage efficiency, especially during the morning period and winter.

1.4 Project Motivation and Importance:

Development and improvement of the performance of the solar water heating system could by achieved by studying the basic factors that effects the efficiency by increasing heat capturing over time.

Therefore, in this project is mainly considered as one of the factors, which directly affect the efficiency of the system, which is heat capacities, in addition a control system will increase the efficiency.

1.5 Work Methodology:

To decrease the time that is needed to heat the water inside the storage tanks, which is about the 200 Lt, the storage tank is divided into four smaller capacities of 50 Lt each. This allows changing the storage capacitance connected to the solar collector depending on the day time and usage rate. This management strategy can be achieved using temperature sensors, flow control valves to control the system, and microcontroller. These components will open and close each storage tank according to a given values, especially when the amount of the sun radiation is low during the morning period.

1.6 Project budget:

The main requirementsare: solar flat plate collector, storage tanks, sensors, valves, piping and fittings are used to build the prototype of the system in the previous project which was the first phase.

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

Table (1.1): project budget

Component Name	**Price (NIS)**	**Quantity**	**Total cost(NIS)**
Solar flat plat collector	400	1	400
Storage tank	300	2	600
Electronic elements (solenoid valves)	20	٦	1٢0
Pipe and fitting	300	1	300
Total cost	**١٤٢٠ NIS**		

1.7 Project plan :

Project plan estimate that the time consumed for each task represented by weeks, and it summarized in the table (1.2) and table (1.3).

Table 1.2: Timing schedule of the first semester

Process	Week														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Select the idea															
Analyzing the previous project															
Collecting data and literature															
Rebuilt the prototype															
Solar heat thermal test analysis															
Writing the documentation															

Table (1.3): Timing schedule of the second semester

	Week														
Processes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Solar heat thermal tests															
Analyzing the thermal tests results															
Test the efficiency using manual valves															
Writing the documentation															

1.8 Project Layout:

This chapter presented an introduction about the reasons that catalyze the researchers to spend their time to find the optimal use of solar energy, in addition it showed the project main idea and it is main objectives, moreover the work methodology. This chapter also includes the time plan for all over the project, and the tools and equipment that are used in project and finally the total cost.

Chapter two presents an introduction about first phase of the project which included the first consideration which was the static parameter, and summarize the main works thatthe previous projecttalked, projectdescription, measuringand controlling instrumentation in the project, system modeling, previous experimental and it is results, finally the project first phase conclusion.

Chapter three will introduce the test methods for solar domestic hot water system and its condition. And also make some calculation for them as the thermosyphon phenomenon and its effect on the tank at three different level. The thermal capacity for the flat-plate solar collector, and the efficiency for the whole solar domestic hot water system.

Chapter four presents an agroup of tests, that compare between using just one tank with capacity of 50 liter or using two tanks each one with capacity of 50 liter, and shows that this system of heating water by solar more efficient than commercial one and can cover the morning demand on hot water by using switching strategy between tanks.

2

CHAPTER TWO

Project First Phase

2.1 Introduction
2.2 Project description
2.3 Measuring and controlling instrumentation in the project
2.4 System Modeling
2.5 Project First Phase Experimental Results

Chapter two

Summary of Project first phase

2.1 Introduction:

The project main idea is how to increase the efficiency for the hot water solar collector system, which divided into two consideration variables, static variable and dynamic variable. The previous project treated the static one which represented by dividing the 200 liter storage tank into four storage tanks 50 liter for each.

For this purpose the prototype of the project was built and the project describe the system from the aspect of the main system components, in addition measuring and controlling instrumentations are explained.

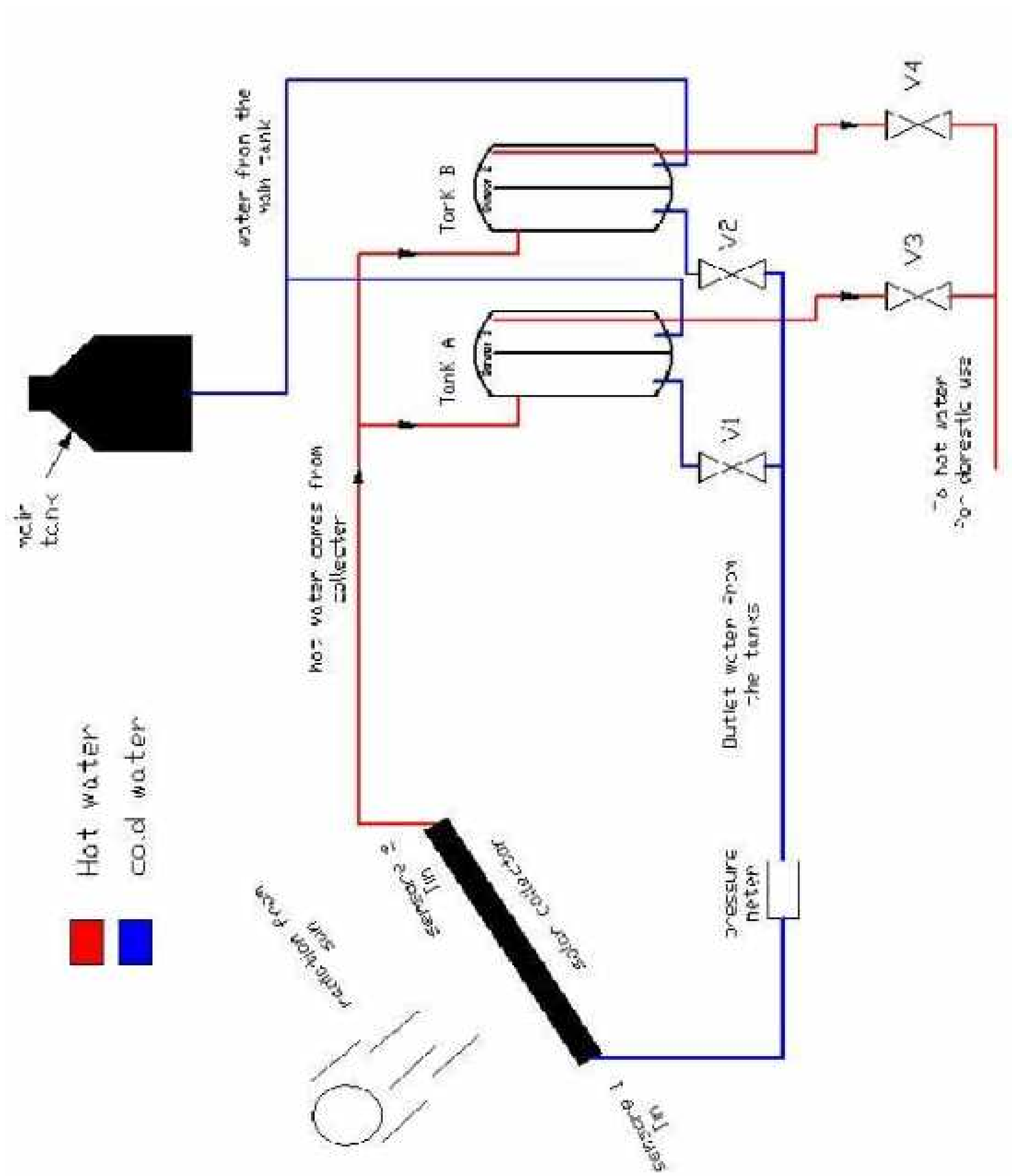
The solar domestic hot water system previous project use half of the system for experiments, which summarized in this chapter, moreover the basic equations that models the dynamic of the system, the experimentalhad been done, some of this test, thermal capacity for hot water storage tank, thermal capacity for the flat plate solar collector, the heat losses and efficiency for the whole solar domestic hot water system and the thermosyphon phenomenon and its result, this test shows that the new model system is more efficient than commercial one.

2.2 Project description:

For experiments half of the systemis used which has two hot water storage tankseach storage tanks, one flat plate solar collector, every tank consist of one temperature sensor and two valves, one is between the tank and collector and the other between the tank and domestic use, the collector has temperature sensor for the inlet water and another one for outlet water, a control panel is used to manage the system.

Each storage tank have 50 Liter capacity of water and first tank is equipped with four temperature sensors one sensor for management process, and the other three sensors are located at different levels to study the Thermosyphon phenomenon. The second tank has two temperature sensors. The prototype consists of one typical flat-plate solar collector that has an effective area of 1.62 m^2. The collector has one differential pressure measurement device and two temperature sensors: one temperature sensor on the inlet and the other on the exit of the collector. All measurements were performed using 12-bit Temperature Smart Sensor fitted in the described places. A payranometer is used to measure the irradiance over the test plane. The wind speed is measured by Anemometer model AM-4217SD. A data logger is used to record experimental data over time and in relation to sensor location either with a built in instrument or sensor or via external instruments and sensors. The data loggers used in the system are HOBO Energy Logger Pro and Squirrel Data Logger SQ2010. In addition to that four programs were to obtain and interpret data from measurement instruments; these programs are HOBOware pro program, Squirrel View, MANOMETER 5PSI and MS Excel.See figure (2.1) and (2.2)**:**

Figure(2.1): Experimental solar system with sensors locations.



Figure(2.2): layout of the system

2.3 Measuring and controlling instrumentation in the project:

2.3.1 Temperature Measurements:

The most significant aspect is to determine the temperature, during testing ten temperature measurements are desired (12 bit temperature smart sensor):

1. Fluid inlet temperature to the system (T_{cold}).
2. Fluid inlet temperature to the collector ($T_{c(in)}$).
3. Fluid outlet temperature from the collector ($T_{c(out)}$).
4. Six storage tanks temperature (T_{t2}, T_{t1} (15cm), T_{t1}(30cm), T_{t1}(45cm), T_{t1}(LM35), T_{t2}(LM35)).
5. Ambient temperature (Ta). (see figure(2.1))

Figure(2.3): 12-bit Temperature Smart Sensor

2.3.2 Irradiance Measurements:

A payranometer, used to measure the irradiance over the test plane.

Serial number: 075072

Sensitivity: 72 MV/W.m^{-2}.

Figure(2.4):payranometer

2.3.3 Pressure Measurements:

To measure the difference between static and dynamic pressure at the inlet of the collector.

- Heavy duty.
- Model HD750.

This device measures gauge and differential pressure in the range of $\pm$ 5.000 psi. The HD750 offers eleven units of measure and has a differential input that uses convenient quick – disconnect fittings.

Figure(2.5): Differential pressure manometer

2.3.4Wind speed Measurements:

Anemometer model (AM-4217SD) to measure the wind speed for the system.

Figure (2.6): Anemometer model (AM-4217SD)

2.3.5 Data logger:

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

Figure (2.7): Squirrel data logger

2.4 System Modeling:

This section introduces the modeling required to capture the systems dynamics, which will be implanted in the control systems and will define system key parameters. The model will be based on two first order differential equations that are widely used in relevant literature. The two equations are coupled as the first is for the collector dynamics and the other is for the storage tank. Both are based on heat flow governing equations. By taking the intensity of solar radiation G_T in W/m2, incident on the aperture plane of the solar collector having a collector surface area of A, in m2, then the amount of solar radiation received by the collector is:

$Q_{in} = G_T.A$ ………(2.1)

As the collector absorbs heat its temperature is getting higher, which increase heat loss to the surrounding.

The rate of heat loss Q_o depends on the collector overall heat transfer coefficient U_L and the collector temperature, and is given by:

$Q_O = U_L \,.\, A_c(T_C\text{-}T_a)$ ………(2.2)

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

$Q_u = Q_{in} – Q_o = (G_T \,.\, A_c) – (U_L \,.\, A_c\, (T_c – T_a))$[6] ………(2.3)

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

$Q_u = (mc)_c \,.\, (T_i – T_o)$ ………(2.4)

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

Solar plate internal heat change rate:

$(mc)_c \frac{dT_c}{dt} = A_c[G_T - U_l(T_c - T_a)] - \eta_c(\dot{m}c_p)_f(T_c - T_f)$ [6] ……… (2.5)

Where T_c is the mean collector temperature, $(mc)_c$ is the mass and the heat capacity of collector, A_c is the area of collector, G_T is the solar radiation comes from the sun, U_L is the overall heat loss coefficient, T_a is the ambient temperature, η_c is the efficiency of collector, $(mc_p)_f$ is the mass flow rate and heat capacity for the fluid, and T_f is the fluid temperature.

Storage tank internal heat change rate with η_t to account for heat exchange efficiency and pipes losses is given by:

$$(mc)_t \frac{dT_t}{dt} = \eta_t (\dot{m}c_p)_f (T_c - T_t) - Q_t$$ [6] ………(2.6)

Where T_t is the tank temperature, $(mc)_t$ is the mass and the heat capacity of storage tank, and Q_t is the heat demand.

2.5 Previous Experiments:

Many tests have been done in the first phase to be sure that the solar domestic hot water system more efficient than conventional one that currently used.

During the period of test the sun radiation must be not less than 17000 KJ/m^2.day.

The thermal efficiency test has been done between 11:00 am – 13:00 pm to avoid long time testing, which reduces the errors due to heat transfer over time. The collector assembly was placed in a degree that the falling sun radiation is perpendicular in the noon period.

The wind speed and direction was measured over a level equal half the collector height, and the wind speed was below 4.5 m/s. the ambient temperature was less than 30°c during the test period.

A) Hot water storage tank tests:

1) storage tank heat loss test:

The test used to determine the storage heat loss coefficient (UAs), where the storage is charged to a temperature above 50 °c, and allowed to cool for about 48 hours.

The equation for the heat loss coefficient of the storage tank is follows:

$$UA_s = \frac{-1}{t} M_s C_p \ln\left[1 - \frac{(T_{sf} - T_{si})}{(T_a - T_{si})}\right] \text{[6]} \qquad \text{………(2.7)}$$

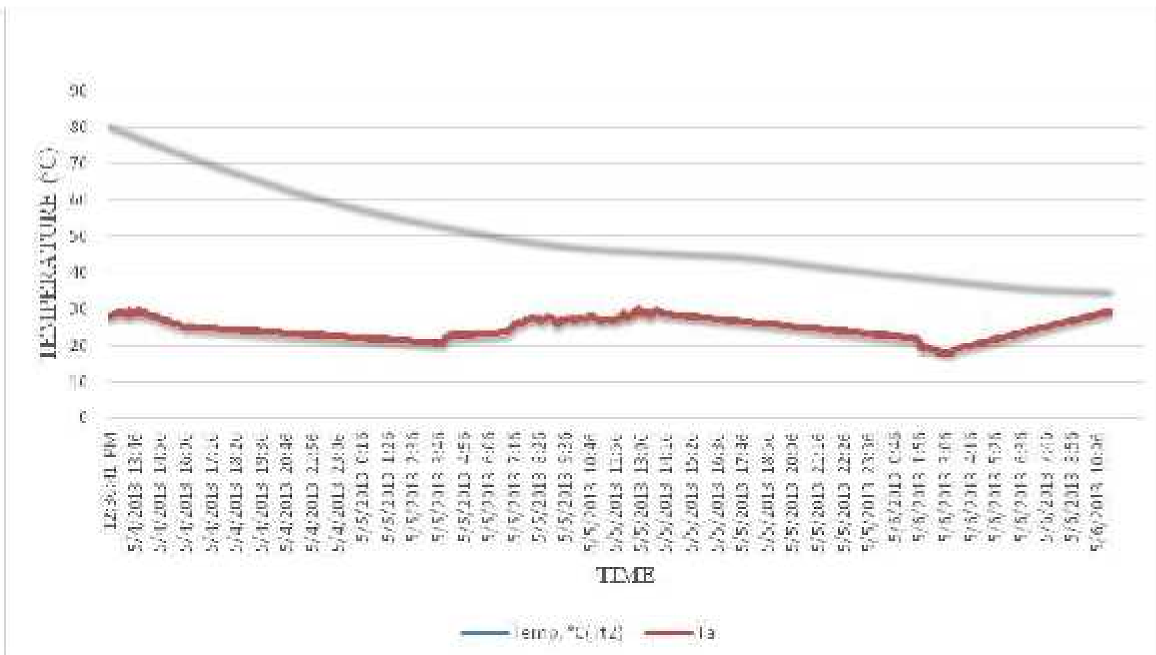


Figure (2.8): storage tank temperature[6]

2) Thermal capacity for hot water storage tank test to calculate the thermal capacity (mc_p) for the 50 liter tank.

Figure (2.9): Time constant data for storage tank[6]

3) Temperature at different level in storage tank: this test aim for studying the heat transferprocess which help to increase the heat capacity.

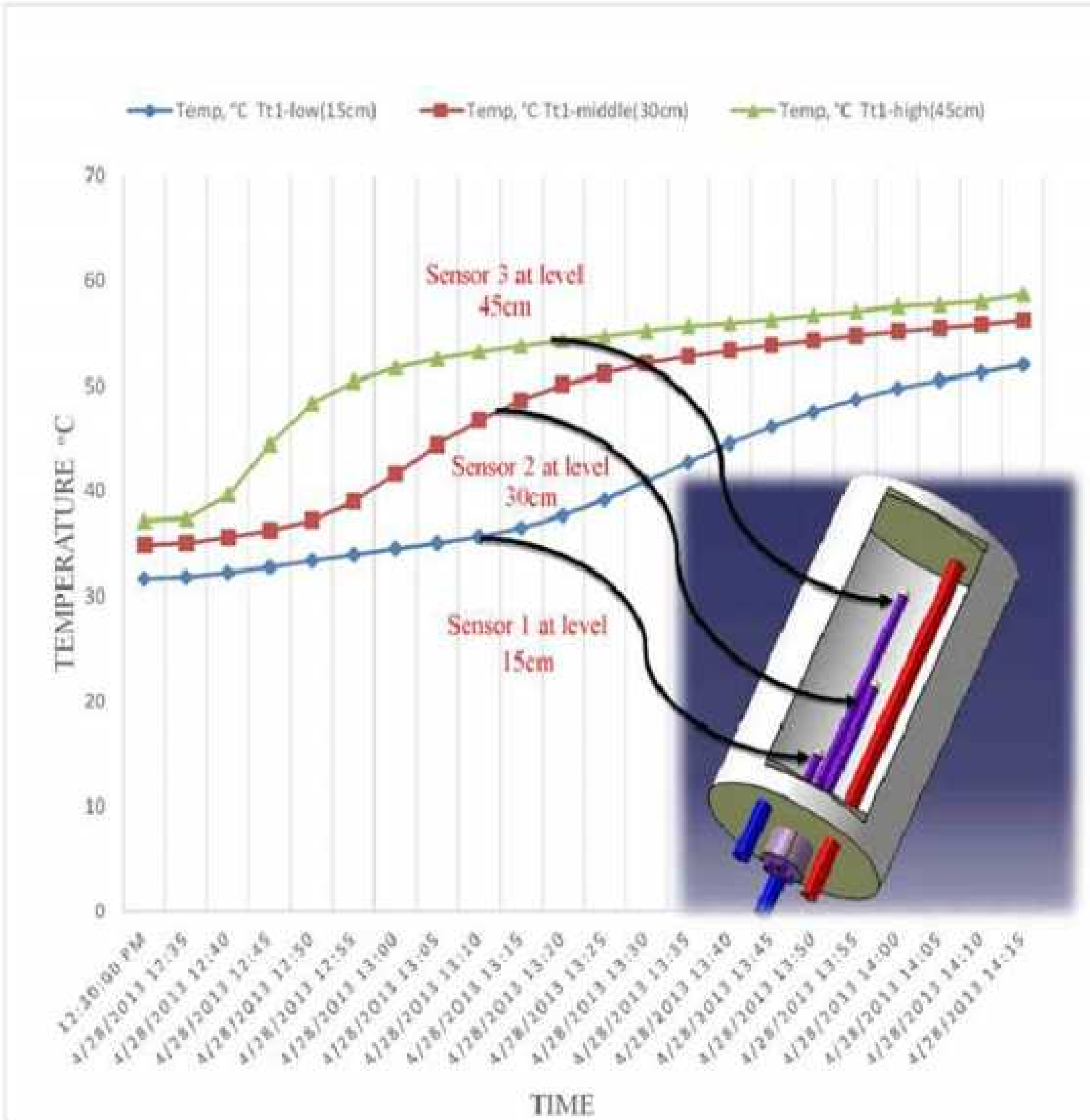


Figure (2.10): Change in temperature at three different levels[6]

B) Flat plate solar collector tests:

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

$\eta = \eta_0 - UT^*$ ……… (2.8)

$T^* = (T_c - T_a)/G_t$ ……… (2.9)

T* is the reduced temperature different.

T_c mean plate operating temperature,°C.

$T_C = (T_{in} + T_{out})/2$ ………(2.10)

Energy of collector:

The energy output of the collector is calculated as:

$Q_{in} = \dot{m} c_p (T_{out} - T_{in})$ ……… (2.11)

Also,

$Q_o = U_L . A(T_c - T_a)$ [6] ……… (2.12)

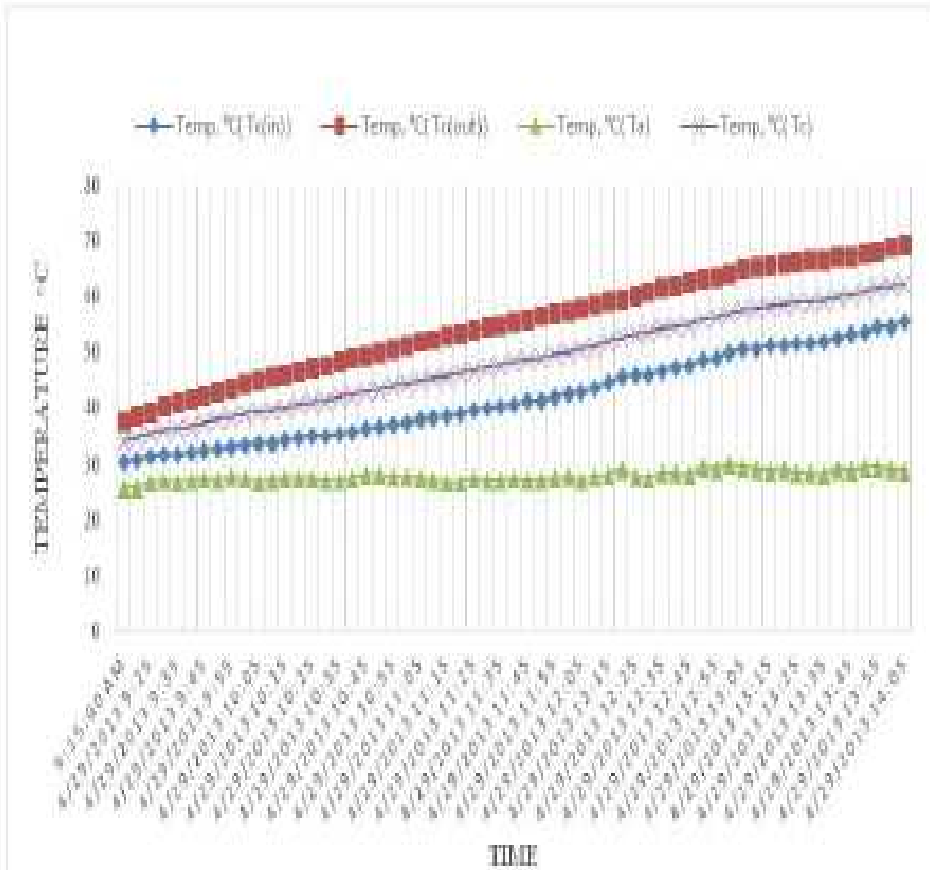
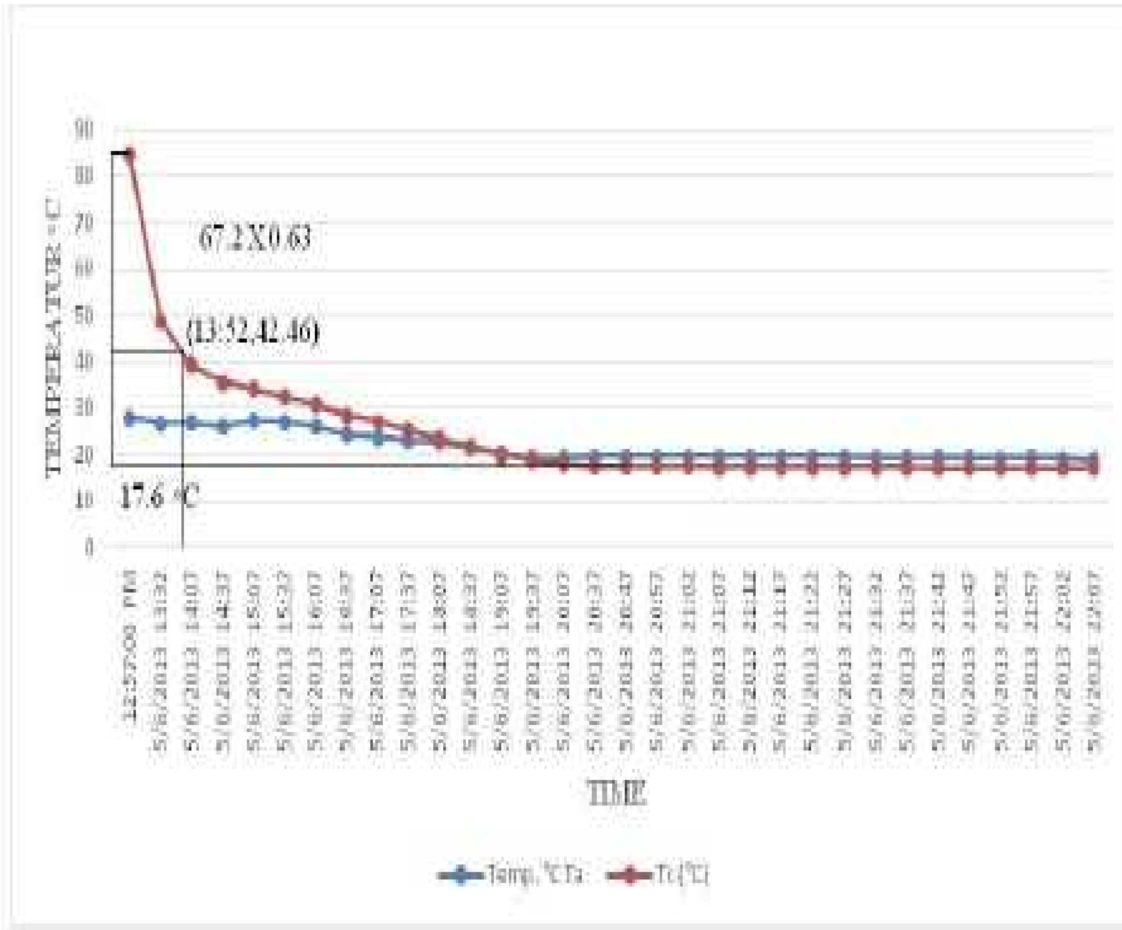


Figure (2.11): Collector temperature[6]

Thermal capacity for the collector test:

This test is prepared to calculate the thermal capacity $(mc_p)c$ for the flat-plate solar collector. The procedure that done in this test is charged the water inside the collector by sun radiation up to 85 °c, and allowed to cool by covering the collector.



Figure(2.12): Temperature of step input with time[6]

Solar domestic hot water system with management:

Figure(2.12) shows the change in water temperature inside one 50 liter storage tank in the morning period at 7:00 am, so by 30 minutes the water temperature reach 50°c that the consumer can use this hot water in multi tasks instead of using the electrical heating that cost a lot of money.

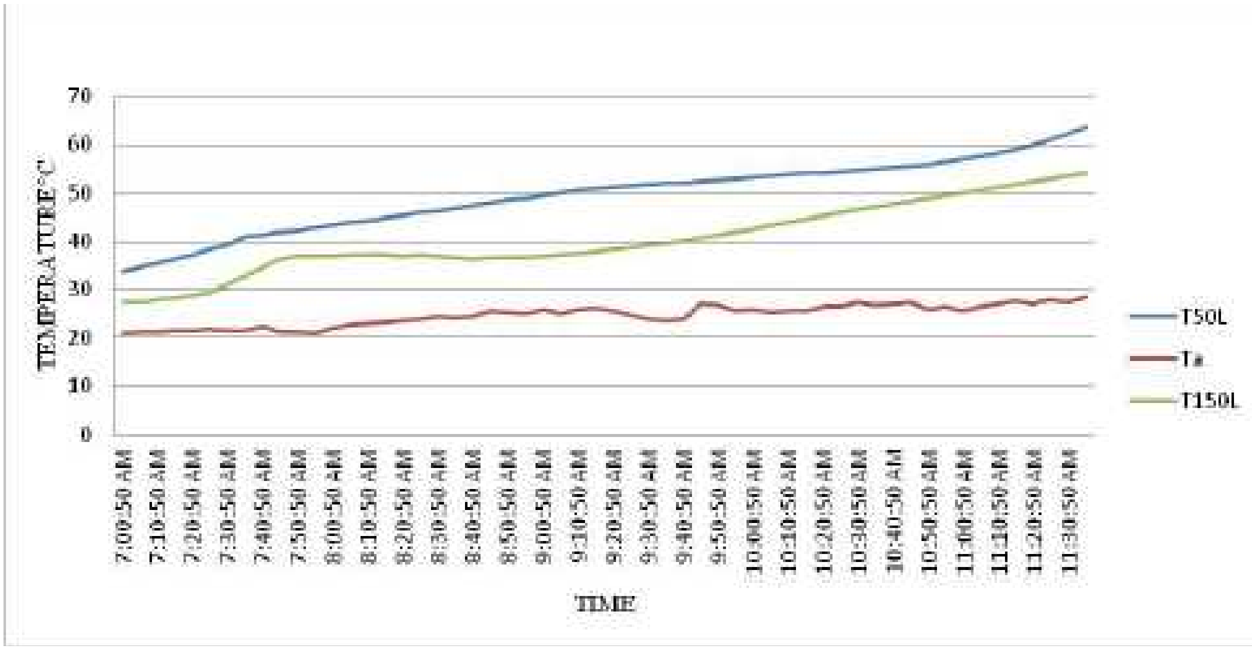


Figure (2.13): SDHW system (for 50 liter tank)[6]

3

CHAPTER THREE

Experimental Result

3.1 Introduction
3.2 Testing overview
3.3 Hot water storage tank tests
3.4 Flat-plate solar collector tests
3.5 system overall efficiency

CHAPTER THREE

Experimental Result

3.1 Introduction:

This chapter will introduce the test methods for new type solar domestic hot water system and its operating conditions, which is built for this purpose in the university. In addition, some calculations will be made for the thermosyphon phenomenon and its effect on the tank at three different levels. The thermal capacity for the flat-plate solar collector and the efficiency for the whole solar domestic hot water system, these tests show that the system used in this project is more efficient than the commercial system that currently used.

The adopted strategy is to manage and control each tank alone aims to raise the efficiency of the system by finding the suitable time to open or close the valves related to weather conditions, day time period and user demand, focusing on the morning period when the radiation of the sun is at minimum value, on other hand the project aims to reduce the consumption of electricity that used to heat the water by electrical heating element, and reduce the fuel if it used instead the electricity.

3.2 Testing overview:

- The collector must be assembly in a place free from any unwanted reflected radiation over the collector.
- The thermal efficiency test must be done between 11:00 am - 13:00 pm. And the collector should assembly in a degree that the falling sun radiation over the collector be perpendicular in the noon period.
- The wind direction must be known and the wind speed should be measured over a level equal half the collector height, and the wind speed must not more than 4.5 m/s.
- The ambient temperature should be not more than 30° C at the test period.

3.3 Hot water storage tank tests:

Temperature at different level in storage tank:

The main goal for this test is to investigate the heat transfer process which help to increase the heat capacity. Figure (3.1) shows the change in temperature at three different levels inside the tank.

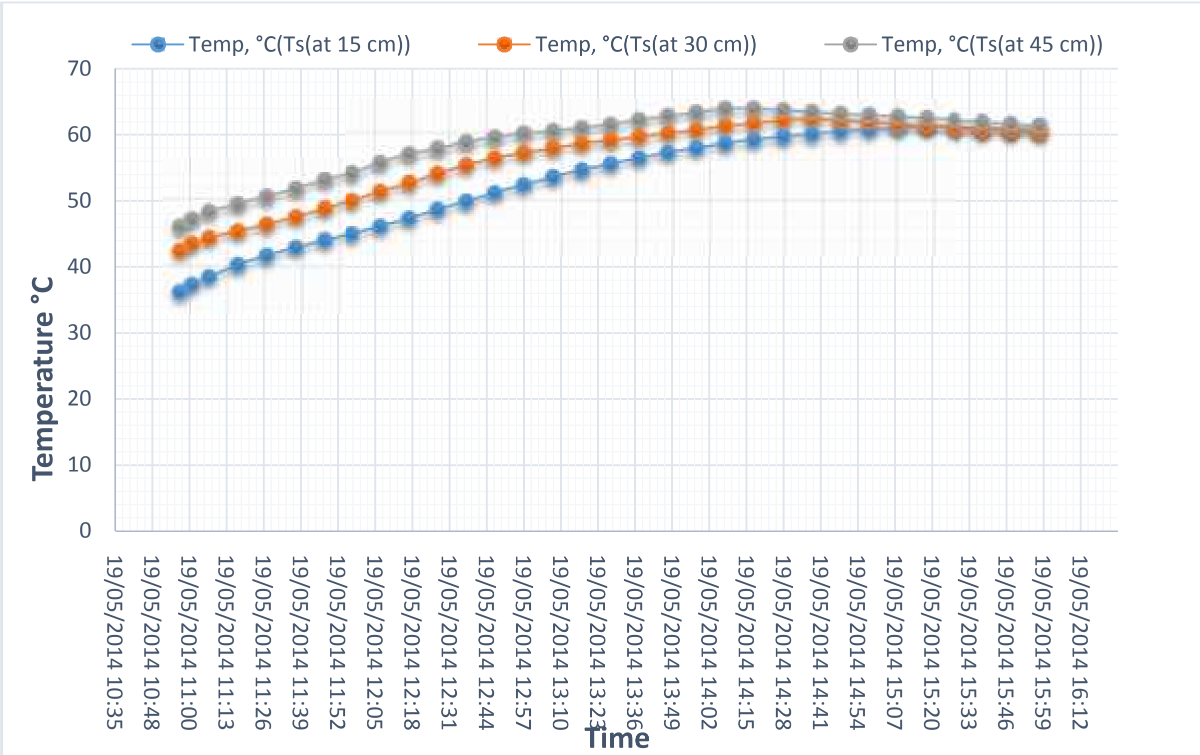
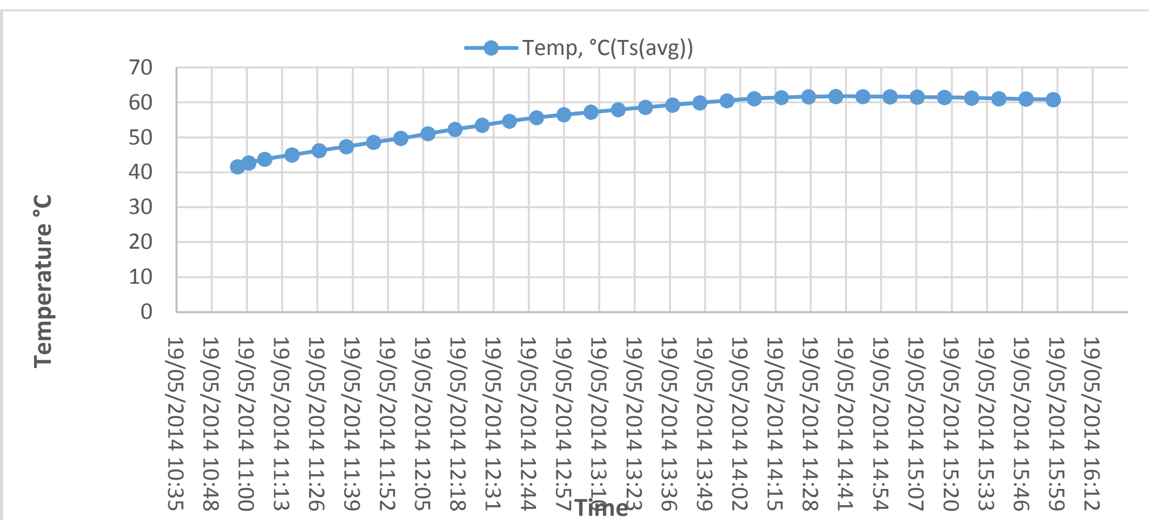


Figure (3.1): the temperature change at three different level



Figure(3.2): Average temperature at storage tank

3.4 Flat-plate solar collector tests:

Thermal capacity for the collector test:

To calculate the thermal capacity$(mC_p)_c$for the flat-plat solar collector, this test can be used. After charged the water inside the collector by sun radiation up to 55°C, and allowed to cool by covering the flat collector. During changing, there is a point must be taken into account, no water add to or extracted from the system the measurement is performed every 10 minutes, after finishing this test (seetable A2) has been generated.

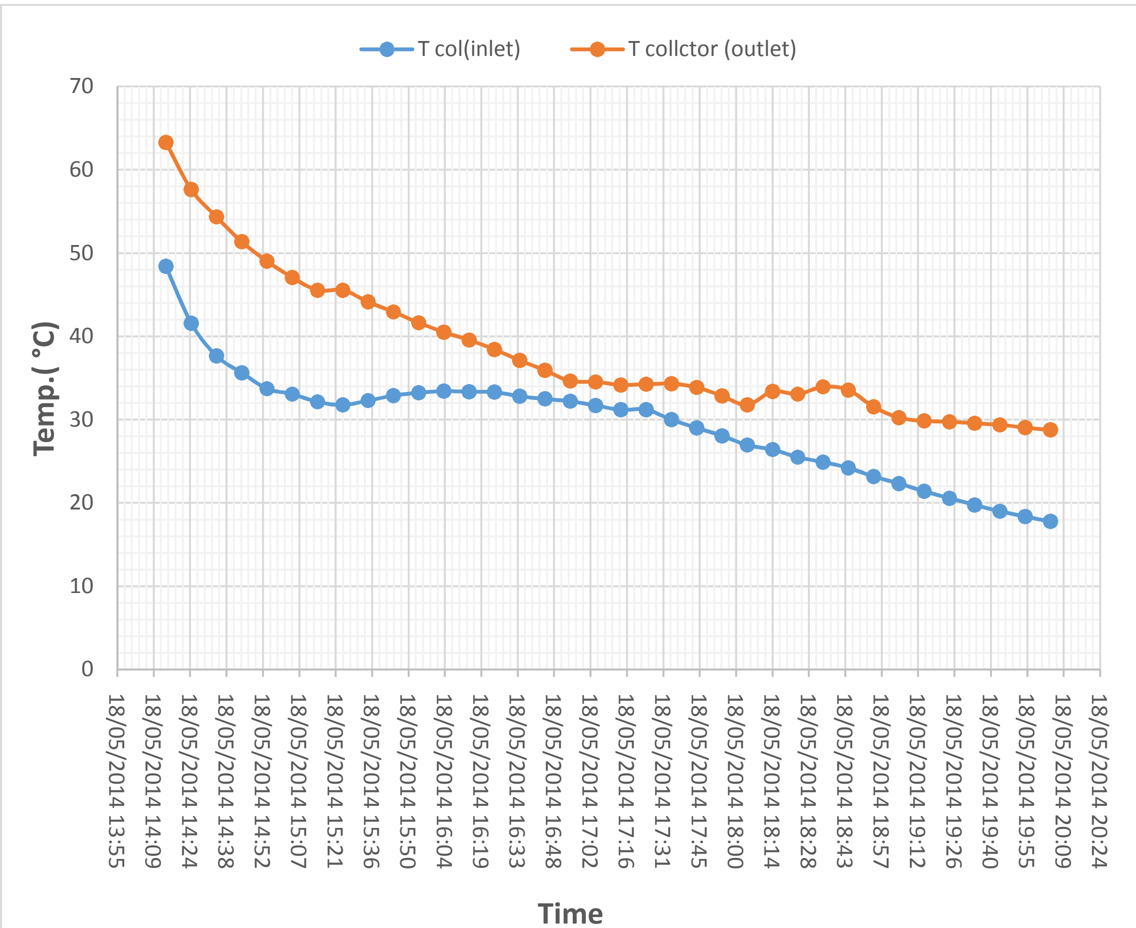


Figure (3.3): thermal capacity for the collector test

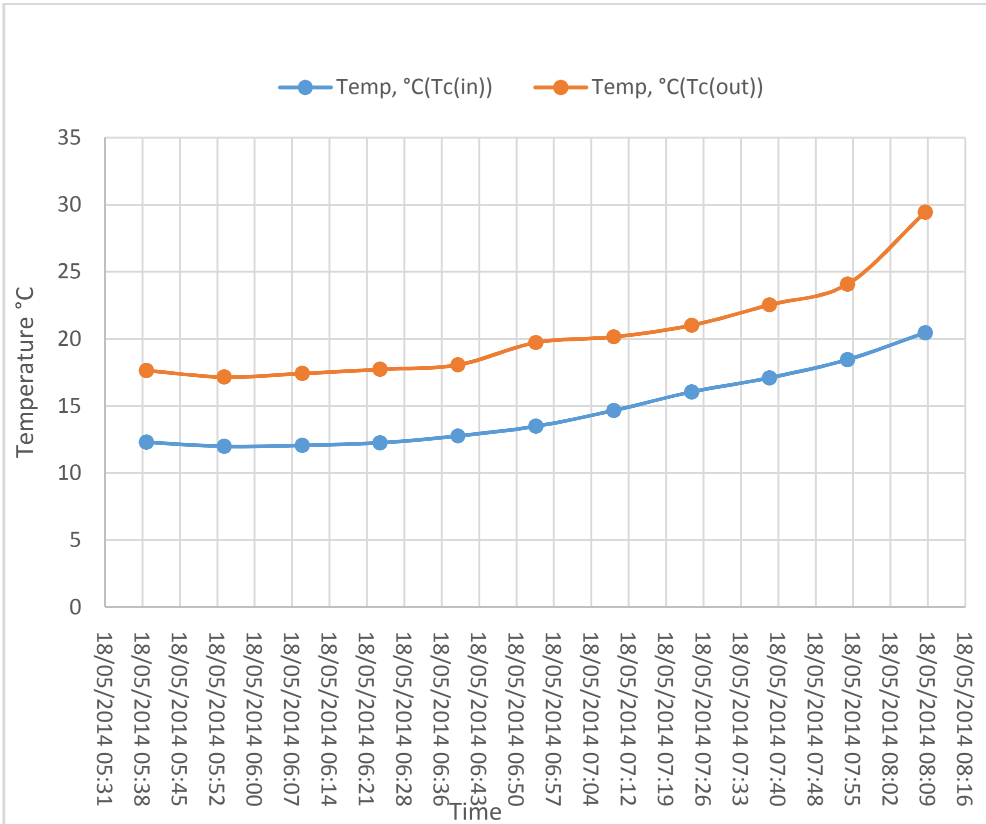


Figure (3.4): Change in inlet and outlet temperature of the collector

(see table A3)

3.5 system overall efficiency:

To create a new model of solar domestic hot water that has a control panel which control the system, the overall efficiency of the system without management must be calculated, the efficiency of the system changes as the ratio between the temperature of the collector and the temperature of the storage tank changes. The efficiency decrease as this ratio tend to be more close to one.

So the overall efficiency of the solar domestic hot water system can be obtained by this test which measure the temperature of the storage tank at three levels and find the average temperature to be the storage tank temperature. The collector temperature founded by measuring the inlet and outlet temperature of the collector. Then by this two temperatures the ratio can by calculated in order to show that how the efficiency of the system changes. Table Aℇ and figure (3.5) has been generated after finishing this test.

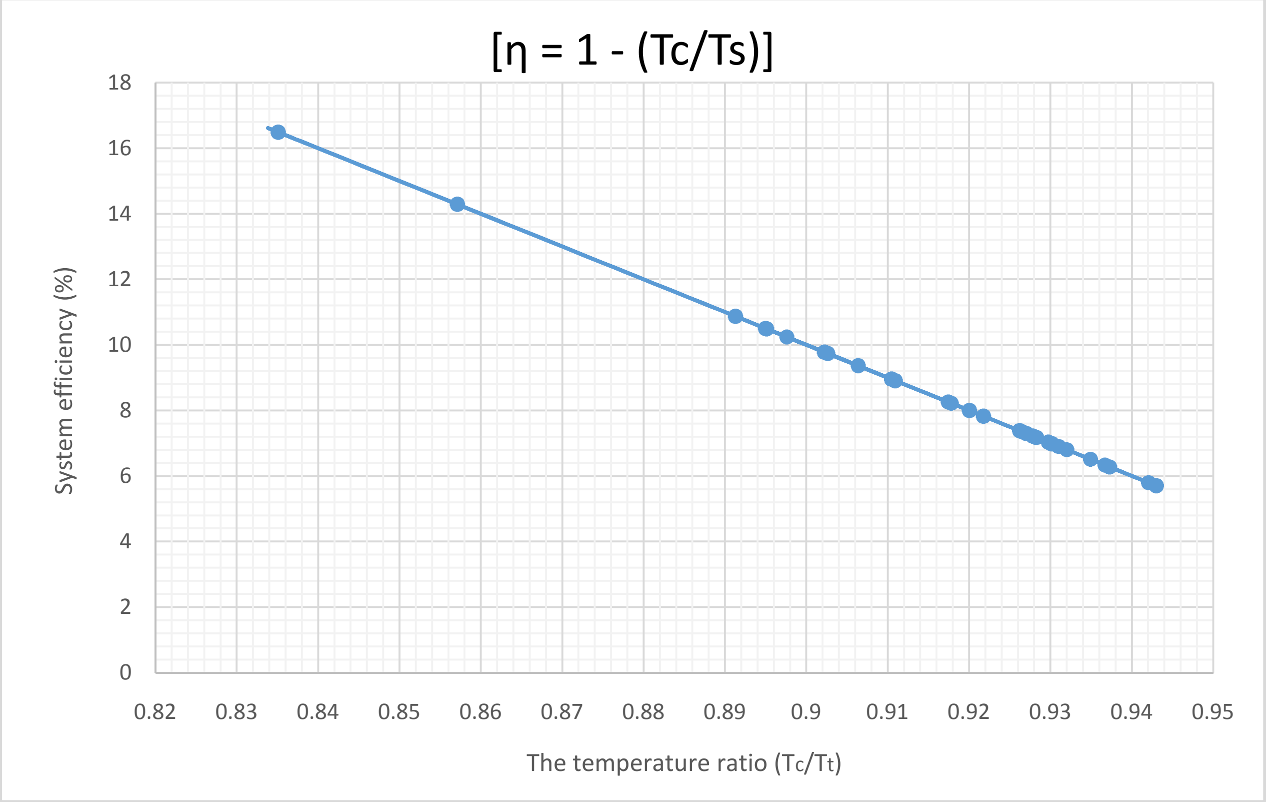


Figure (3.5): system overall efficiency

After this test, the curve of the efficiency allowed to predict the track of a new curve of the efficiency that should the system take after the management strategy created, to reach this target a very long time and effort must expend and a lot of tests a long different period of time with different conditions must be done. The figure (3.6) shows the new curve of efficiency which predicted.

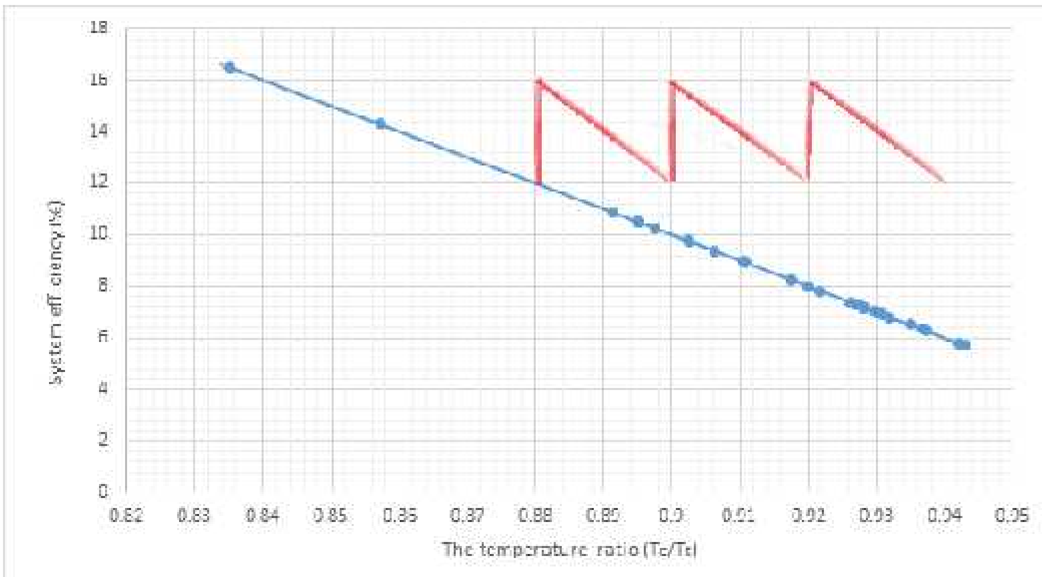


Figure (3.6): The predict curve of efficiency for new modal system

4

CHAPTER FOUR

Experimental comparison between using one tank and two tanks

Chapter four

Experimental comparison between using one tank and two tanks

4.1 Introduction:

This chapter will introduce many tests and conditions for some tests that represent no load, without domestic consumption, and others with system under the load, there is a flow to the domestic use, all tests done after cooling the collector to the same initial conditions.

The primary goal for these tests is to compare between using the collector to capture the energy for 50 liter storage tank or for 100 liter two storage tank each one 50 liter.

Increasing the energy capturing and user comfort must take place by switching the valves, which are fitted as shown in figure (2.2) to separate and connect the required tank.

The tests simulate the real use for the system, and take into account the main factor of dynamic behavior which is the domestic heat load.

4.2 Heating100 liters(conventional system):

The test is carried out to monitor the change of temperature when 100 liters connected with sun radiation collector, which means that the system were used was the conventional one.(using two tanks instead a tank with 100 liters capacity).

Before this test, the collector must be cooled completely by covering it by a white cover before one day as a reason of the beginning time.

Note: The test began at 11:00 am.

Furthermore, the water inside the two storage tanks must be cooled to the initial temperature – the initial temperature is about 15 °c, it is the temperature of the water that comes from the roof tanks for cold water.

The change in temperature value that have been adapted is the average of the temperature changes at three levels inside storage tank A:

- The first level at 15 cm high from the bottom of the 50 liter storage tank.
- The second level at 30 cm high from the bottom of the 50 liter storage tank.
- The third level at 45 cm high from the bottom of the 50 liter storage tank.

To take into account the differences in the temperature within the same storage tank, the system during the test must not be loaded, which means there is no domestic consumption.

The system took about 40 minutes from the beginning of the test until the temperature reached to 41°c – the suitable temperature for human use.

Figure (4.1) shows the experimentally result obtained for heating the two storage tanks together, and figure (4.2) show the ambient temperature through the test. (See table B1).

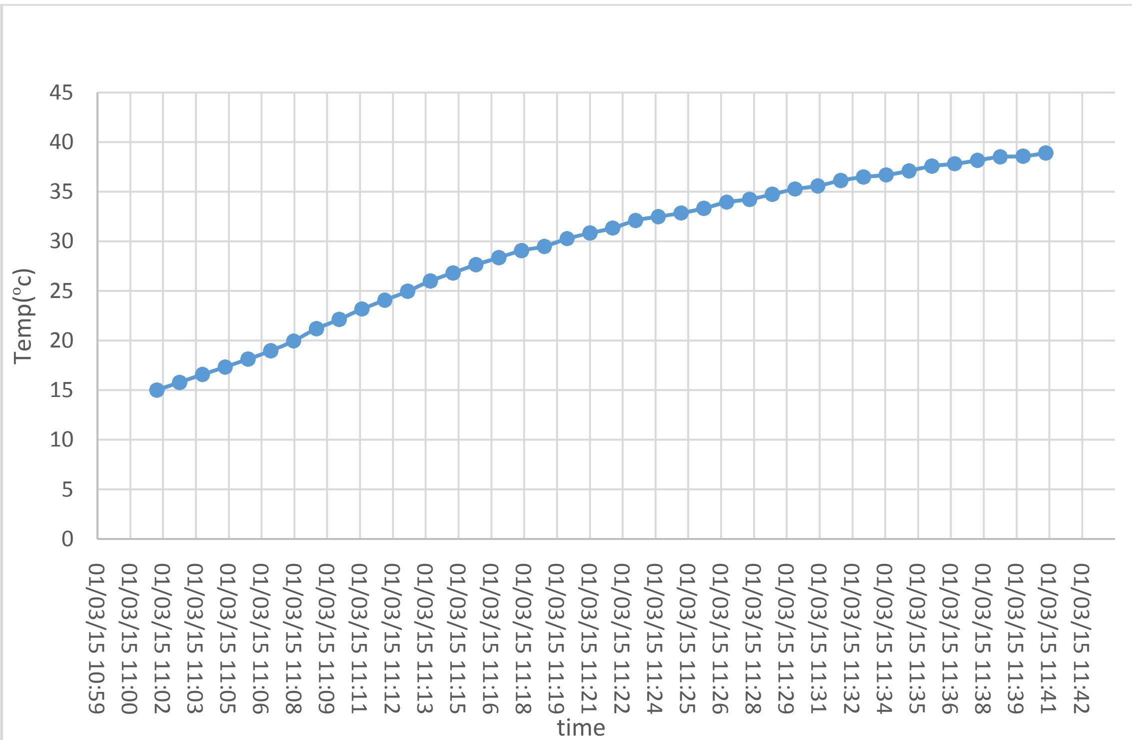
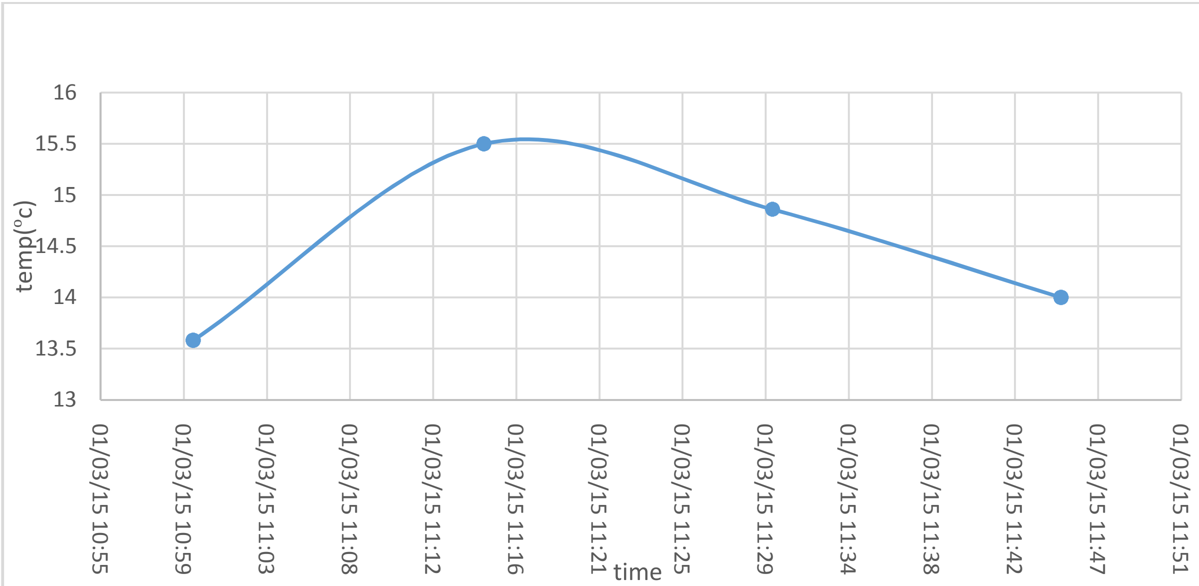


Figure (4.1): Heating 100 liters using conventional system.

The primary conditions which are the ambient temperature, the speed of wind, and the sun radiation were attached after the previous test and the following one to show that these conditions are close to each others.



Figure(4.2):ambient temperature through the test

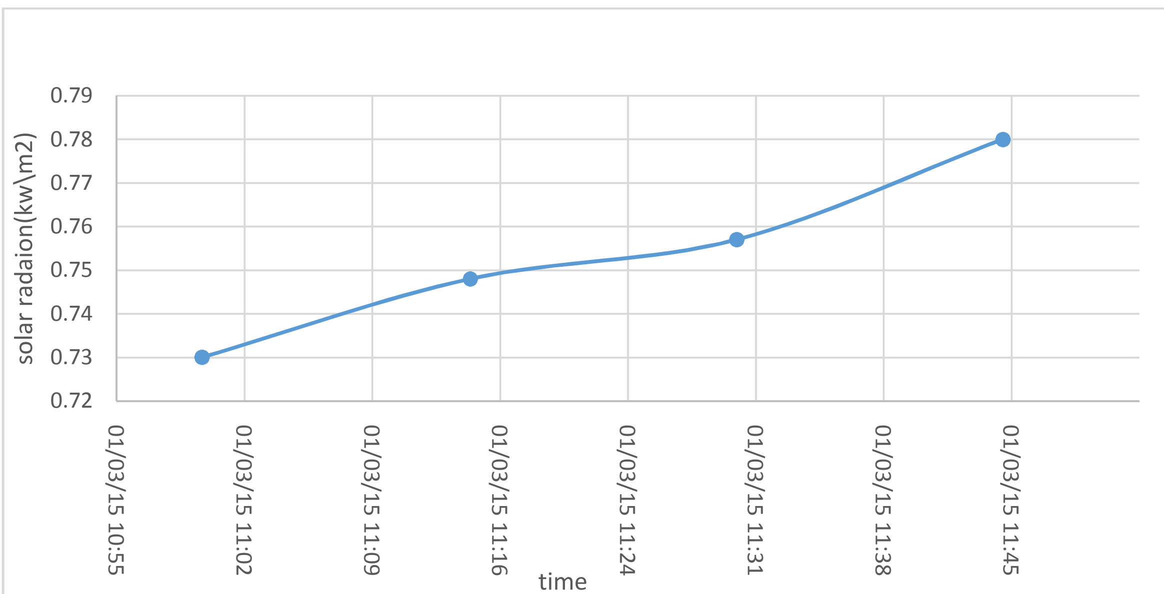


Figure (4.3): Solar radiation through the test

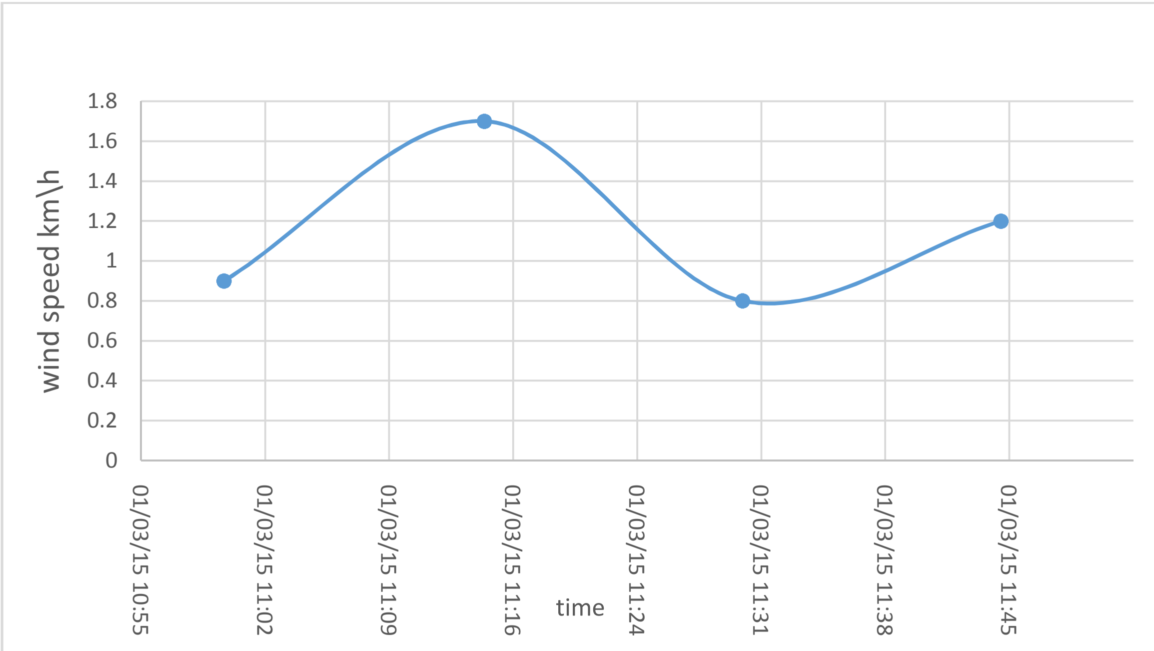


Figure (4.4):wind speed through the test

4.3 Heating 100 liters by using switching strategy:

Depending on the main objective which is to investigate the heat capturing efficiency improvements. The switching strategy used to heat 100 liters by heating every 50 liters alone. A valve between the domestic use and the storage tank which will be separated from the system and the other valve between the same storage tank and the collector. This will restrict water recycling on a single tank.

After 20 minutes the temperature at the first tank reached 40□c, then the first tank was separated and the second one was connected to the collector, which needed the same period to reach the same temperature.

The same actions that has been applied in the previous test:

1. Collector must be cooled by covering it before long time.
2. Storage tank must be cooled if it is contain a heated water, must be replaced by a new water from the main roof tank with initial temperature near to the previous initial temperature depend on it.
3. The same three levels to monitor the change of temperature to obtain the average.

The system take about 40 minutes from the beginning of the test until the temperature reached to 41°c,the suitable temperature for human use.

Making sure that the system is not loaded (no domestic consumption), it is noted that by connecting one storage tank with collector reduce the time which be needed to reach the same temperature by connecting two storage tanks to 40 °c under the same conditions, this result enhanced the idea of this project. The heat capturing can be improved by switching between storage tanks and collector from one hand and between storage tanks and domestic use from another hand. See figure (4.5) and See tableB2.

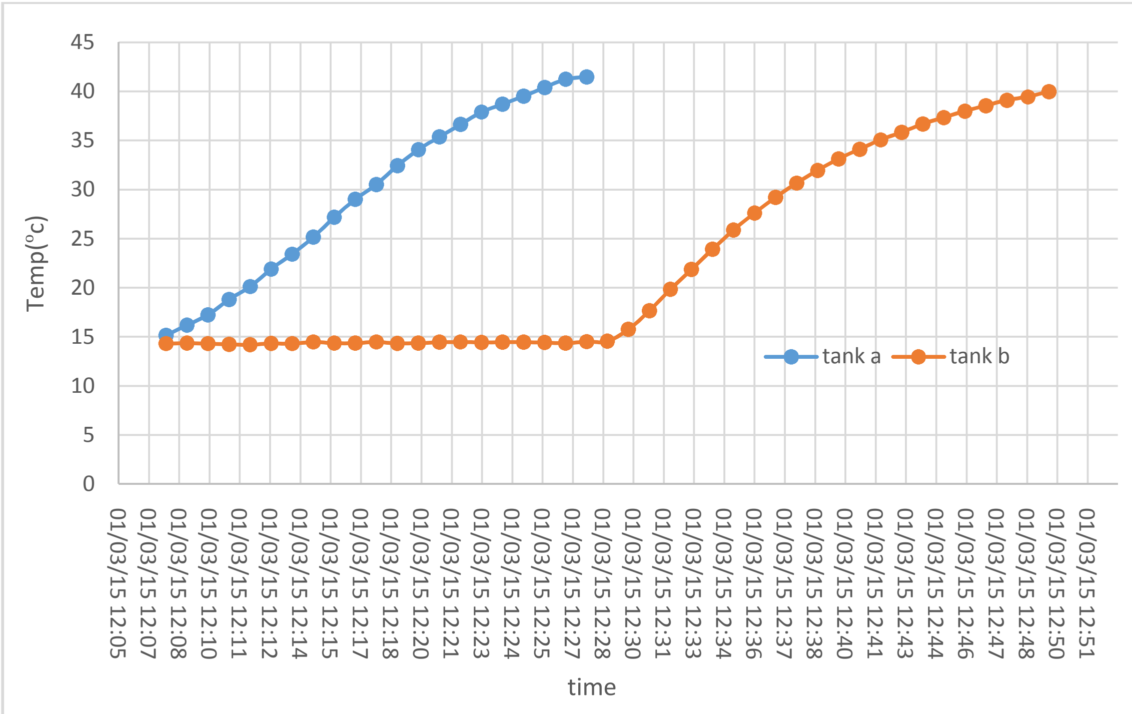
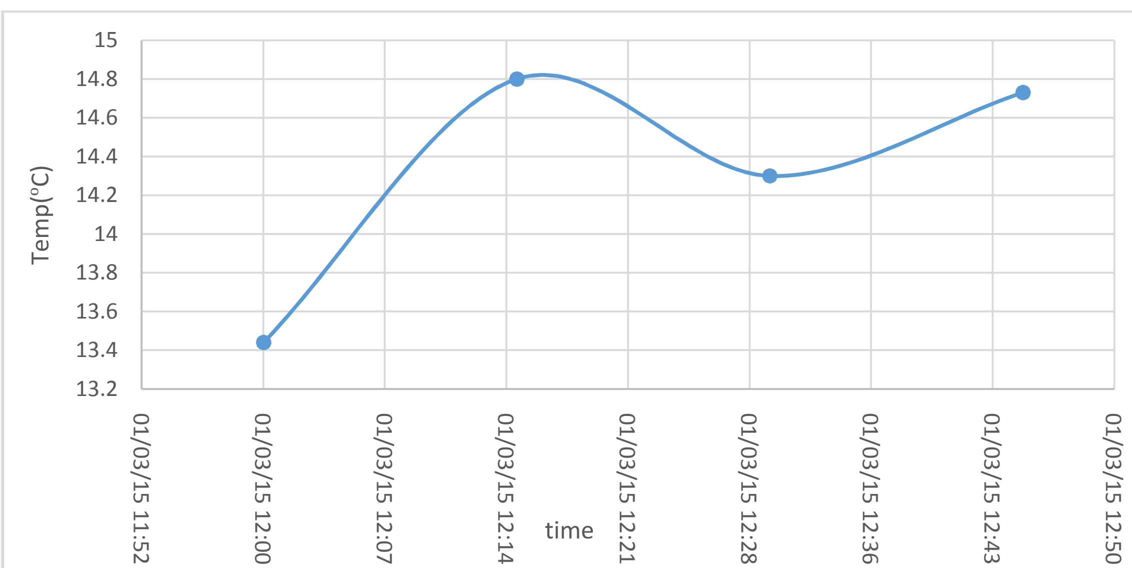


Figure (4.5): Heating 100 liters by using switching strategy



Figure(4.6):ambient temperature through the test

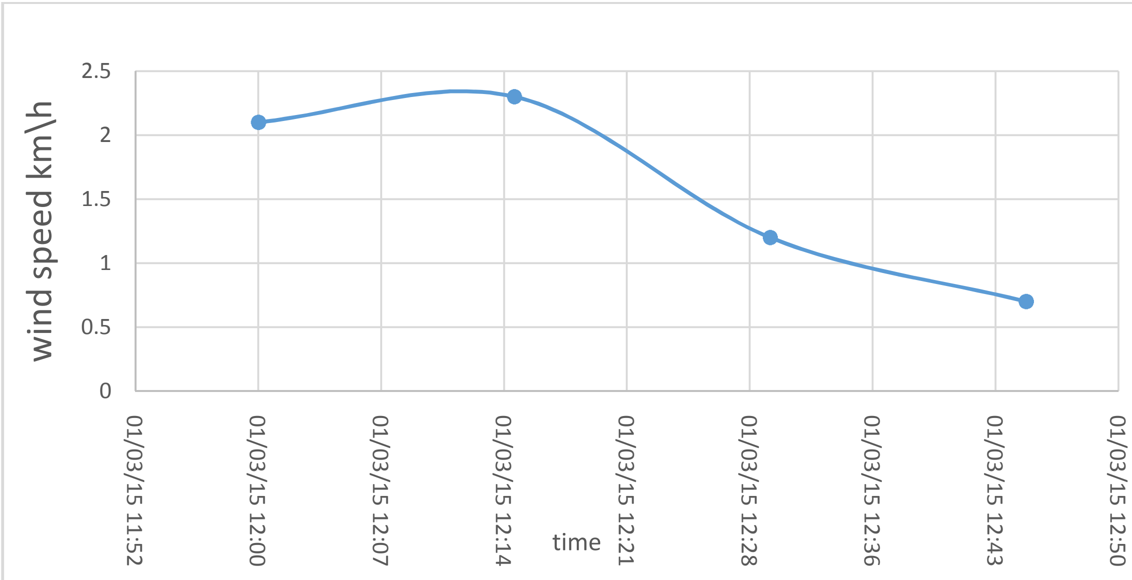


Figure (4.7):wind speed through the test

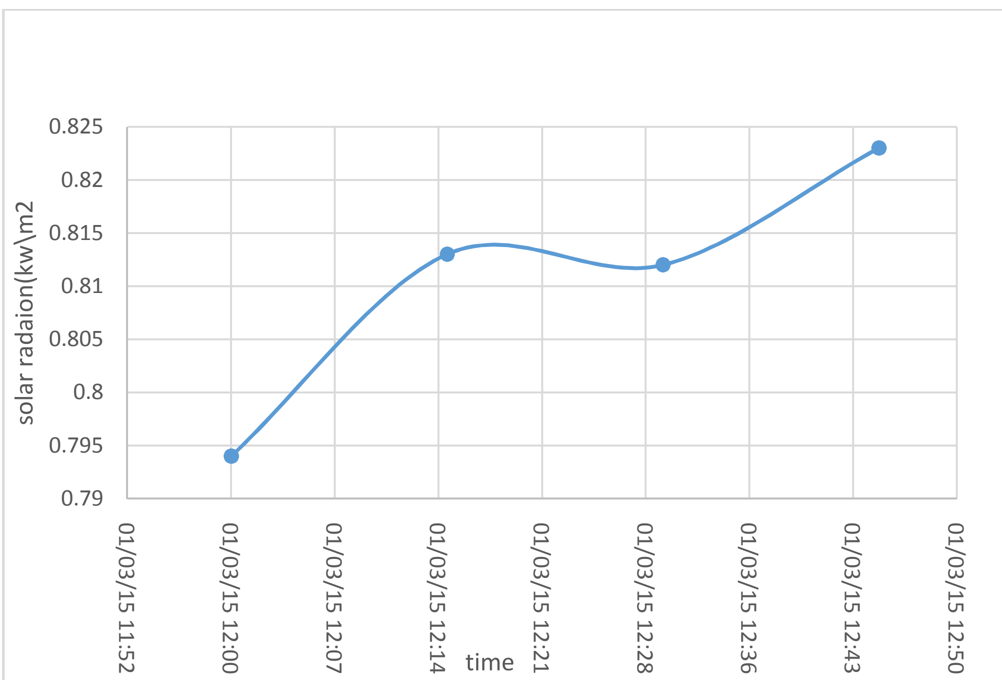


Figure (4.8): Solar radiation through the test

After ignoring the differences between the tests conditions for the two curves (fig (4.1) and fig (4.5))were drawn at the same figure to become more obvious, and to clarify the difference between the time which needed to raise the temperature to 40 □c for two tanks and the time needed to raise the temperature to the same temperature for one tank.

Figure (4.5) shows that the users after 20 minutes from the beginning of heating process could use a water with 43□c temperature if the system used is the new one with switching strategy (orange line for first 50 liters tank), while the system heating the second 50 liters tank in the second period, but if the conventional one is used the temperature at this moment is about 30□c (after 20 minutes) with 13 □c degrees difference.

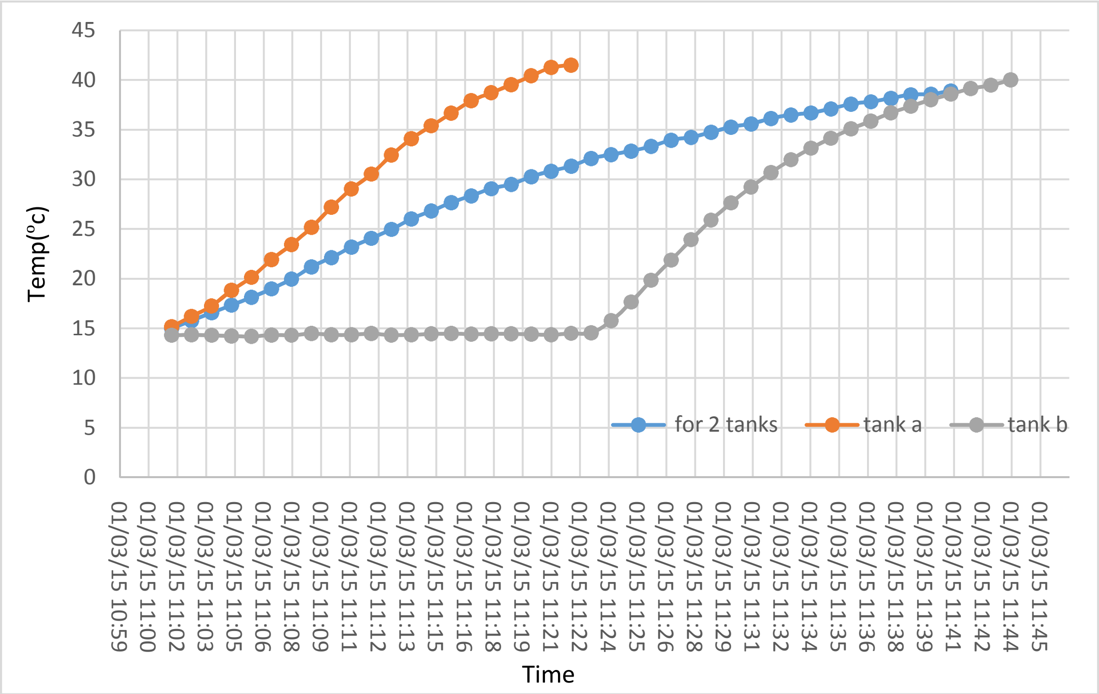


Figure (4.9):heating 100 liters using 2 ways

4.4 Change in temperature for two storage tanks each one have a sensor at high level:

In this test, to be more accurate a sensor was fitted inside storage tank A at high level (45 cm), and another sensor fitted at storage tank B at the same level. The sensors fitted at this level to measure the temperature of the water which goes to users, because the water that goes to the users taken from a pipe fitted at level equal to the level of the pipe that bring the hot water from the collector (the highest water temperature inside the system).

Notice that temperature inside storage tank A start to increase exponentially (figure 4.10) while the temperature inside storage tank B remained constant (figure 4.11), which is the initial temperature, and after the temperature of the water inside storage tank A reached to about 40 ° C the temperature inside the storage tank B started to increase exponentially, the valves are totally opened through the test.

This result shows that the storage tank B at the first period which storage tank A take to reach the temperature 40 ° C is out of the system dominance; from this result we can conclude that there is a problem in the connection prevent the temperature of the water inside the tank B to increase parallel with tank A; as a solution the connection changed to be similar to the figure as shown (see table B3 and B4 and see figure (4.12)).

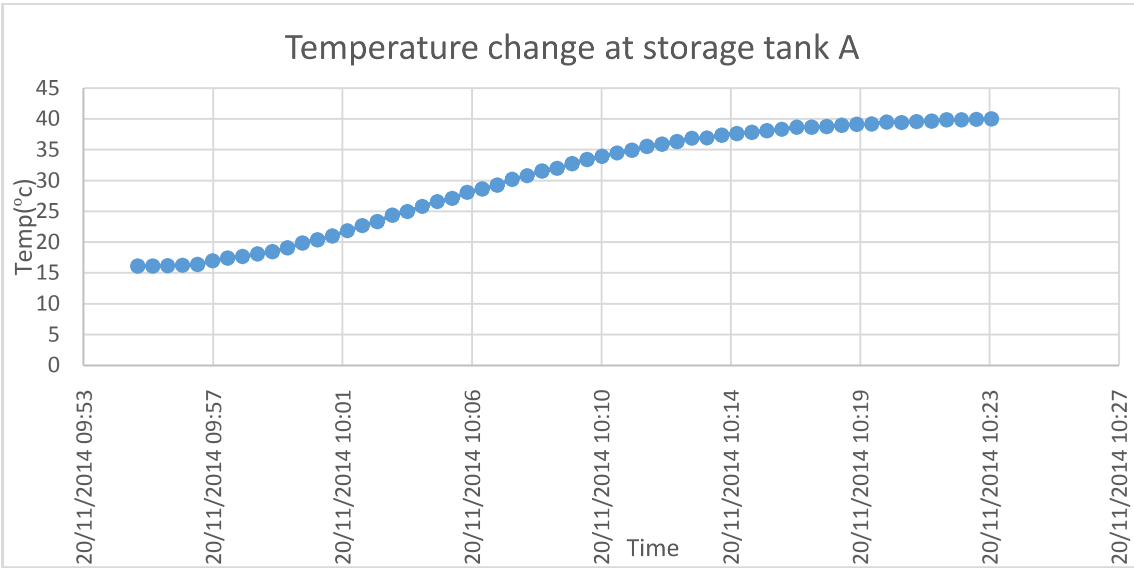


Figure (4.10): Temperature change at storage tank A

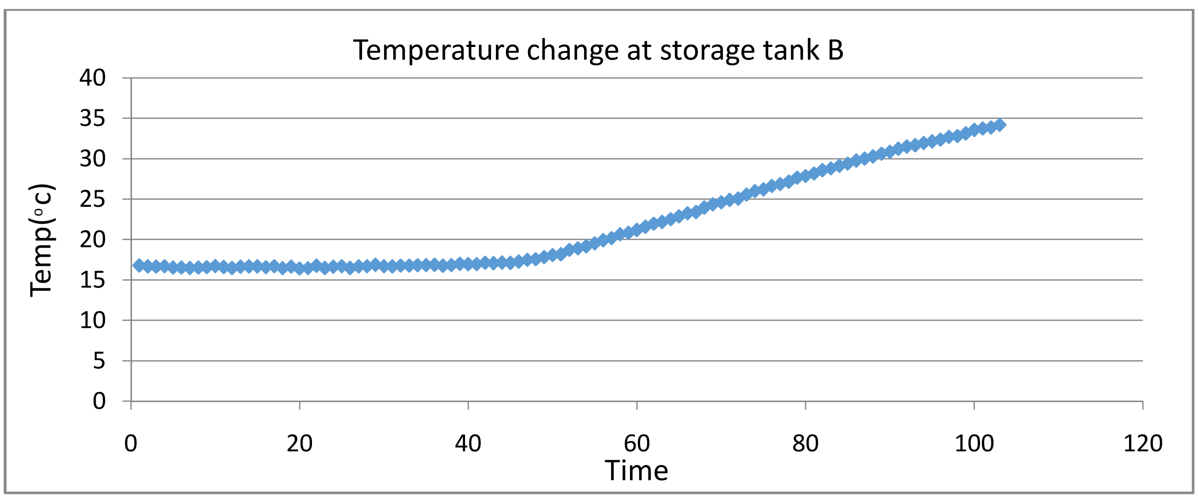


Figure (4.11): Temperature change at storage tank B

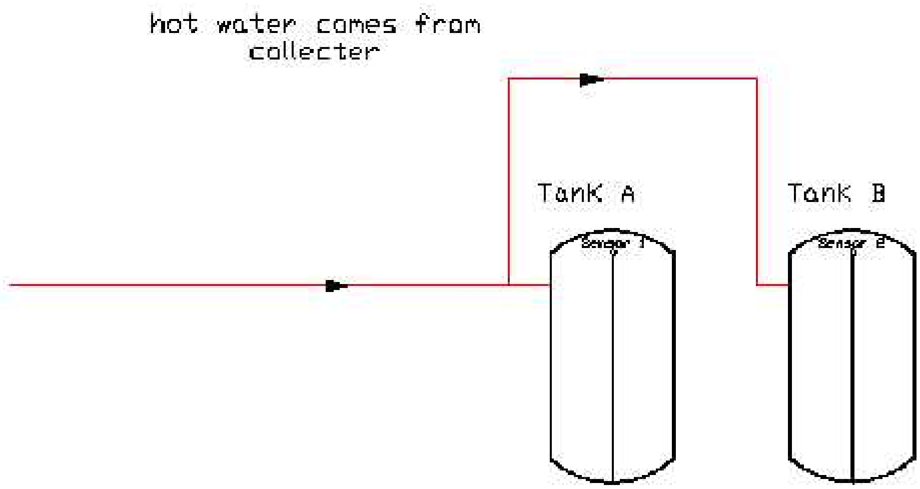


Figure (4.12): The old connection

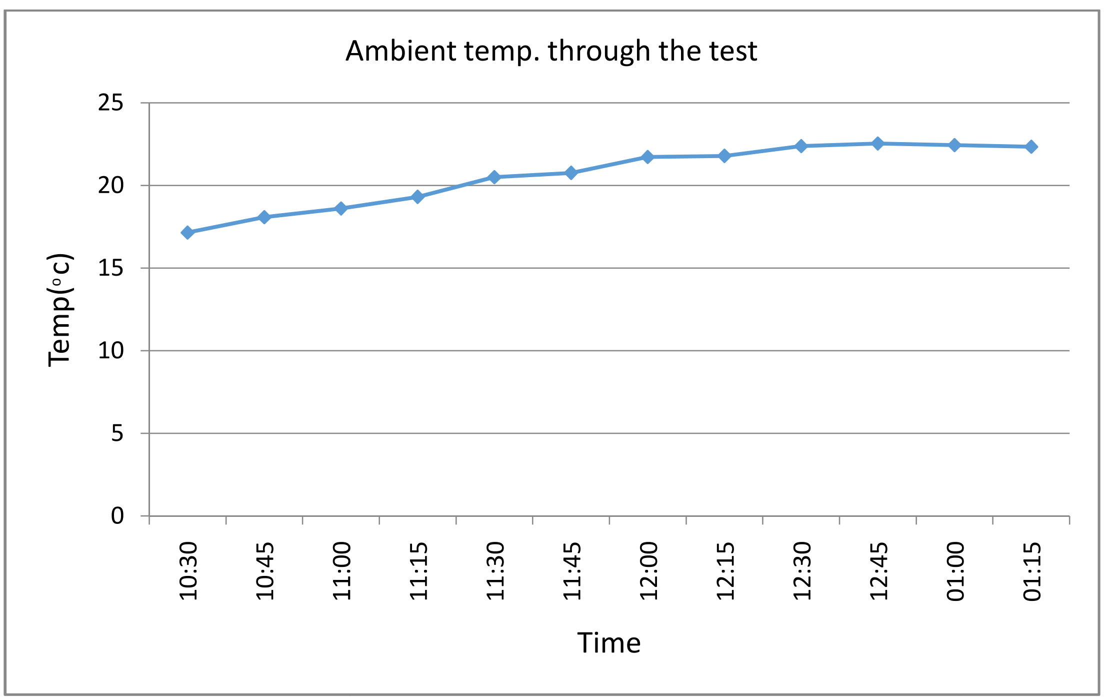


Figure (4.13): Ambient temperature through the test

After solving this problem the test repeated and these results were obtained as in figure (4.14) and figure (4.15), (see table B5& table B6).

Notice that the temperature increase inside both tanks parallel to each other and reaches the final temperature value which is about 36.5 ° C as an average value in the same time which means that the problem was solved by a new connection.(see figure (4.16) and figure (4.17)).

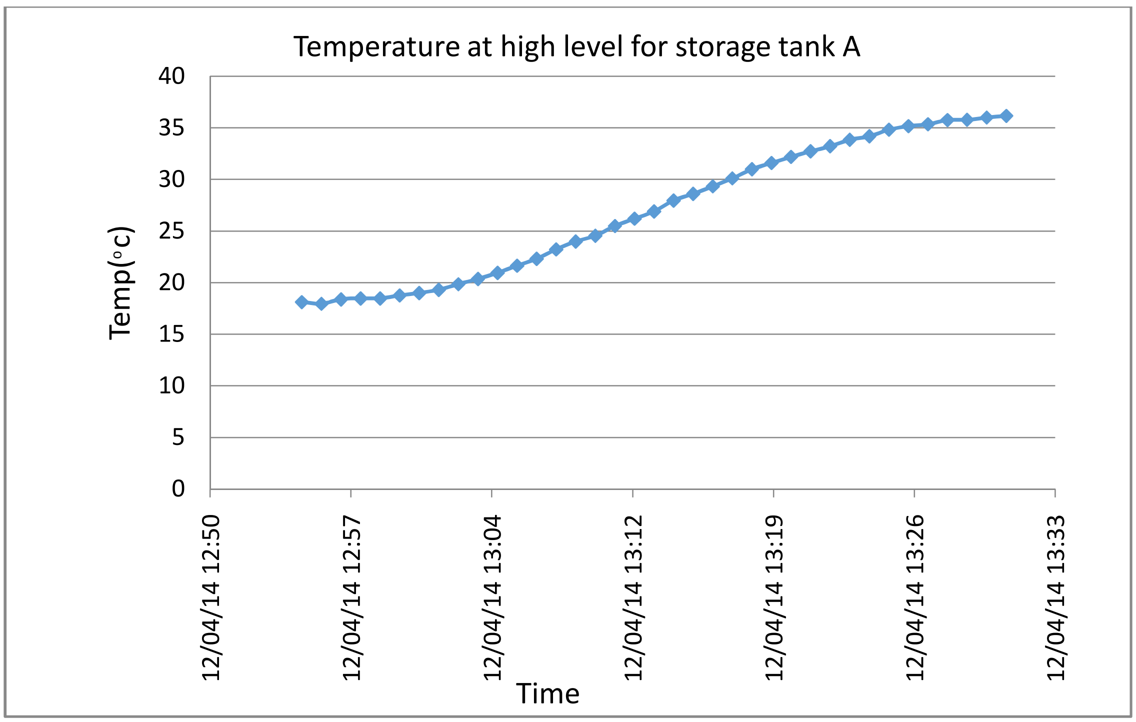


Figure (4.14): Temperature at high level for storage tank A (□c) (heating two storage tanks together)

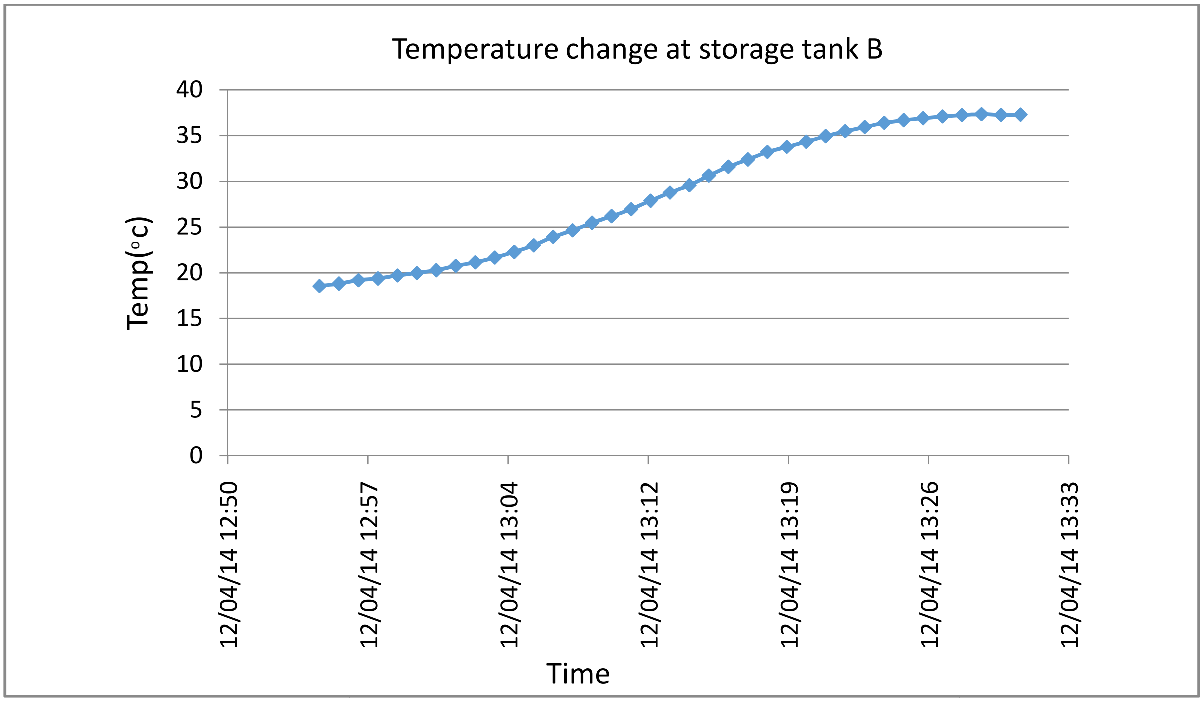


Figure (4.15): Temperature change at storage tank B(heating two storage tanks together)

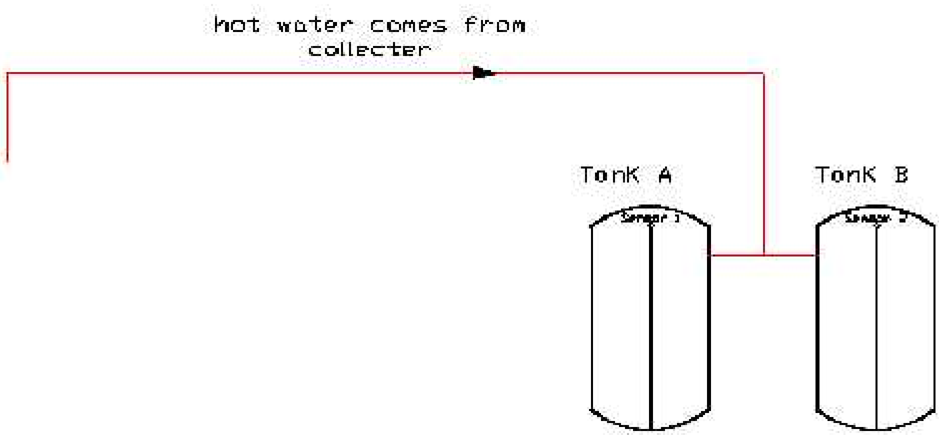
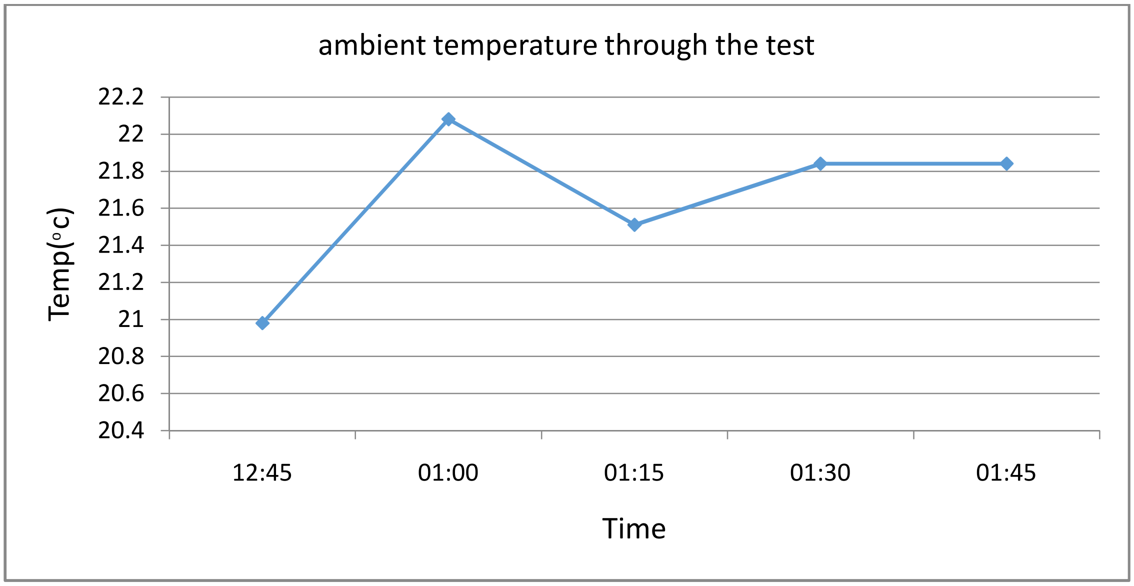


Figure (4.16): New connection



Figure(4.17): ambient temperature through the test

4.5 Change in temperature for two storage tanks (load test):

After water heating inside two storage tanks in the previous test the system was loaded to simulate the real uses of this system and to monitor the decreasing in the value of water temperature inside the two tanks together; the result was unexpected because the water which goes to users taken from the two storage tanks at the same time, but the test showed a different result.

The test showed that the temperature decreased just at the storage tank A as in figure (4.18) (see table B7)which means that the second storage tank B is out of this operation (load operation) figure (4.19) (see table B8), it is too difficult to find the main source of problems as this problem due to the system operation is under gravity (There is no pump force the system), here the change of connection did not solve this problem. See figure (4.20).

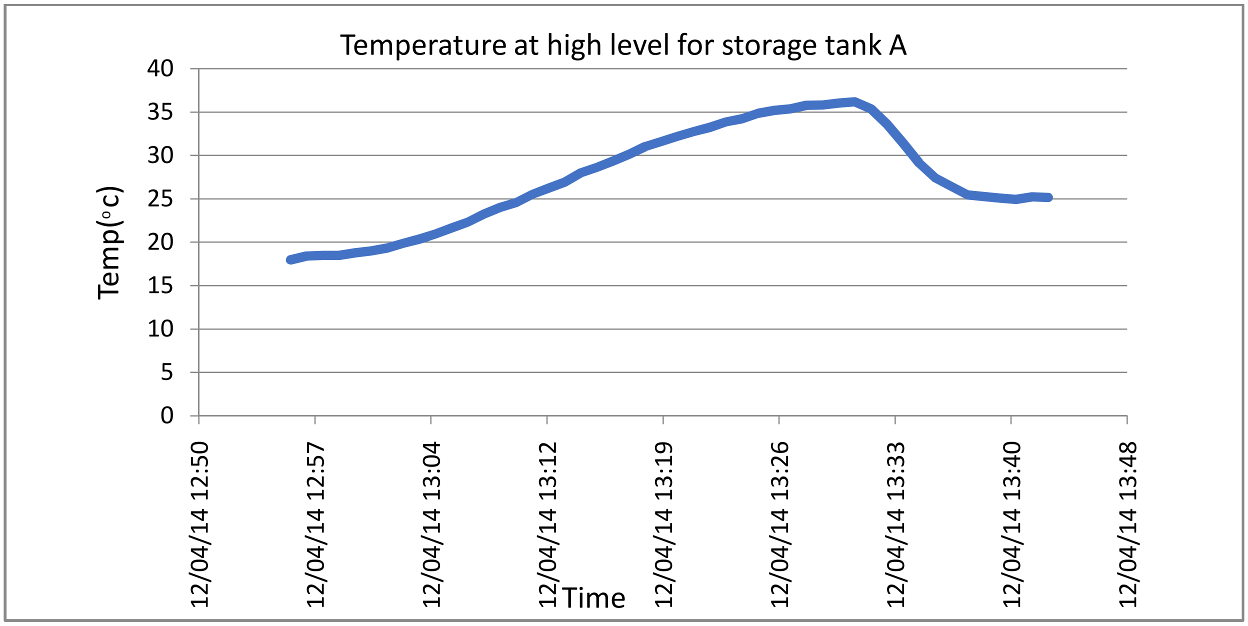


Figure (4.18): Temperature at high level for storage tank A during heating and load test

Table and fig below for tank B:

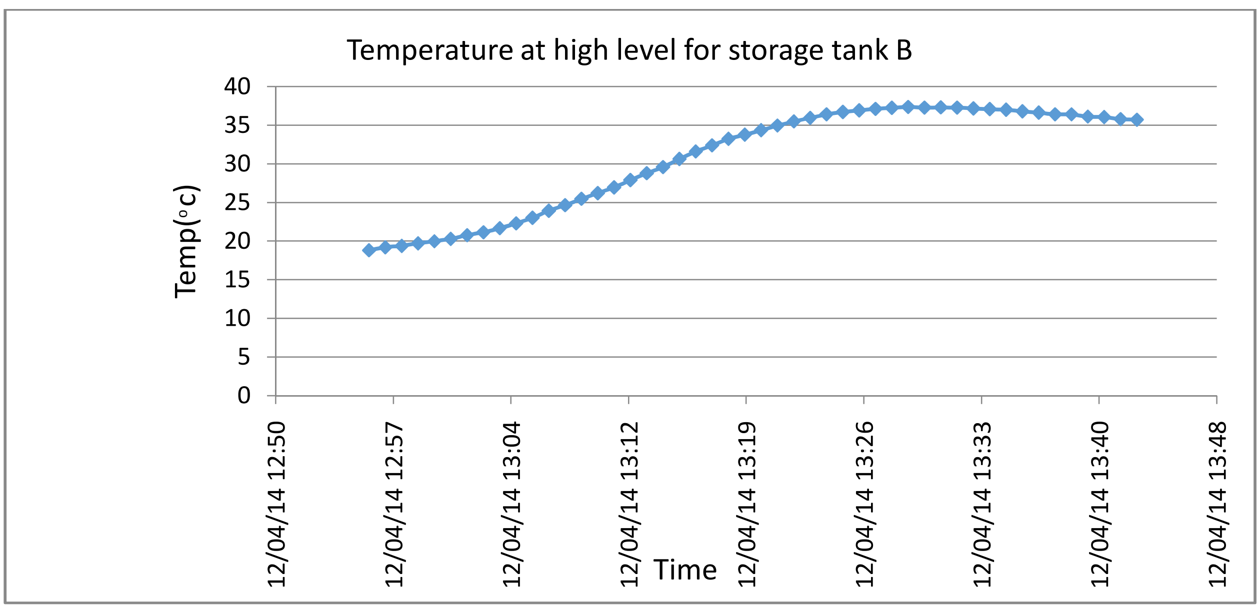


Figure (4.19): Temperature at high level for storage tank B during heating and load test

The test showed that the temperature decreased just at the storage tank A which means that the second storage tank B is out of this operation (load operation), it is too difficult to find the main source of the problems as this problem due to the system operation is under gravity (There is no pump force the system), here the change of connection did not solve this problem. See figure (4.20).

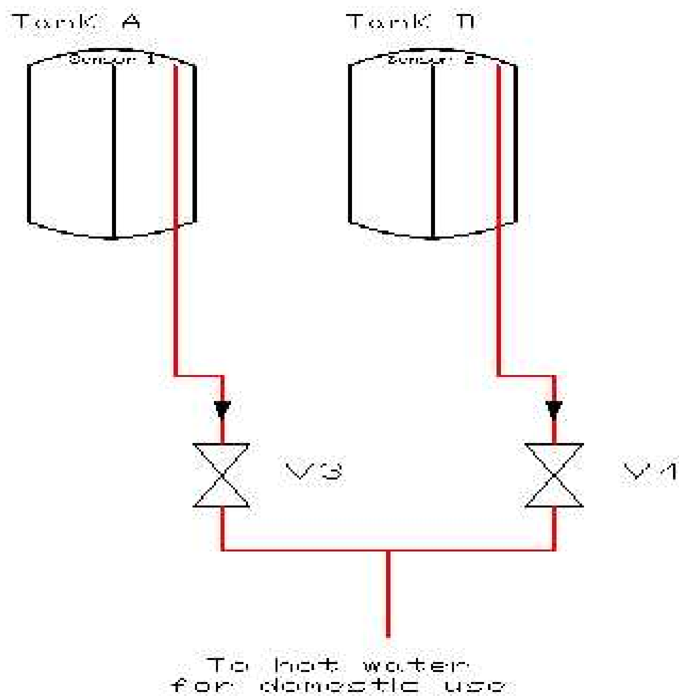
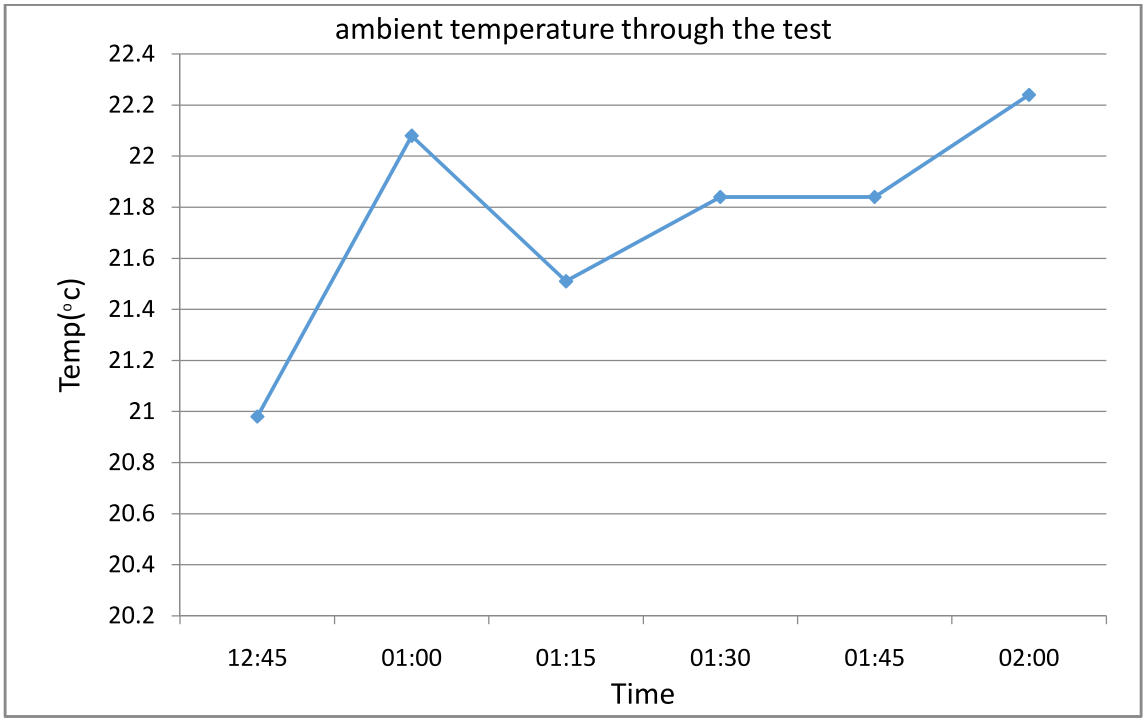


Figure (4.20): The new connection of hot water from tanks to domestic use



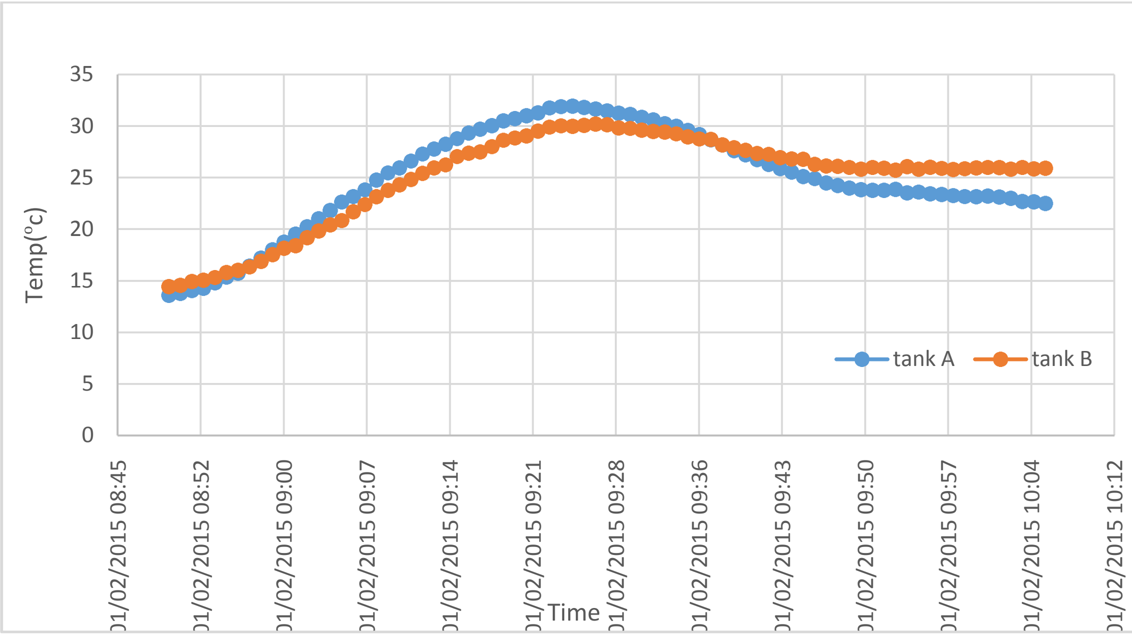
Figure(4.21):ambient temperature through the test

This problem solved after many tests, and after confirming the system did not have any air bubbles which prevent the flow from tank B.

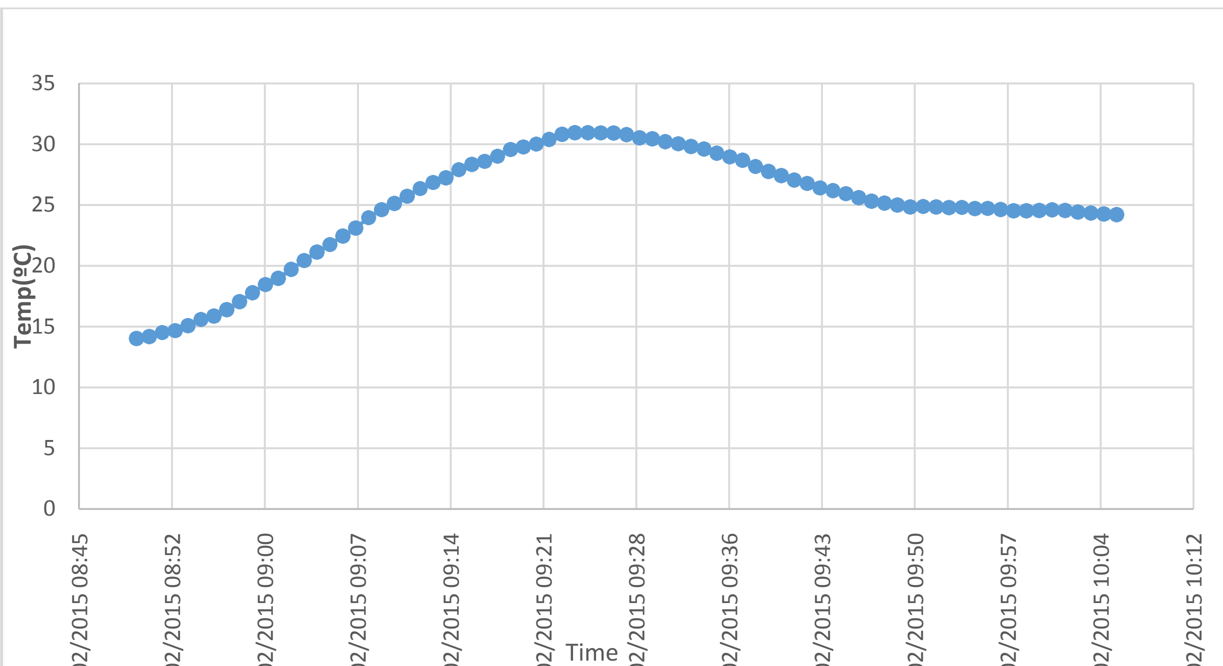
Fig (4.22) shows that the temperature inside tank A and tank B increased together, and the two temperatures was without large difference.

To raise the temperature up to about 33 ºC from initial temperature 14 ºC a 35 minutes was needed. Then the system was loaded to be sure that the temperature inside two tanks will decrease. This means that the new connection was useless.

(see fig (4.23)) and table B9.



Figure(4.22): Change in temp. for two storage tanks during heating and loading



Figure(4.23):average change in temp. for two storage tanks during heating and loading

4.6 The temperature change at the tank in flow test for one tank, and the temperature of water at Consumption valve:

The water was heated up to 47° C inside one storage tank, then the system was submitted for irregular use by opening the consumption for water many times each time with specific flow rate for few minutes. (See figure(4.22)).

Two sensors were used for this test one inside the storage tank (at high level) and the other fitted in a position to measure the temperature of consumed water. See figure (4.24) and(4.25).

Figure (4.24) indicates the decreasing of the water temperature inside the tank, the test was applied using one storage tank, the curve shows that the rate of decreasing is low with small flow rate, but with higher flow rate the temperature of the water inside the tank decreased the temperature much more.

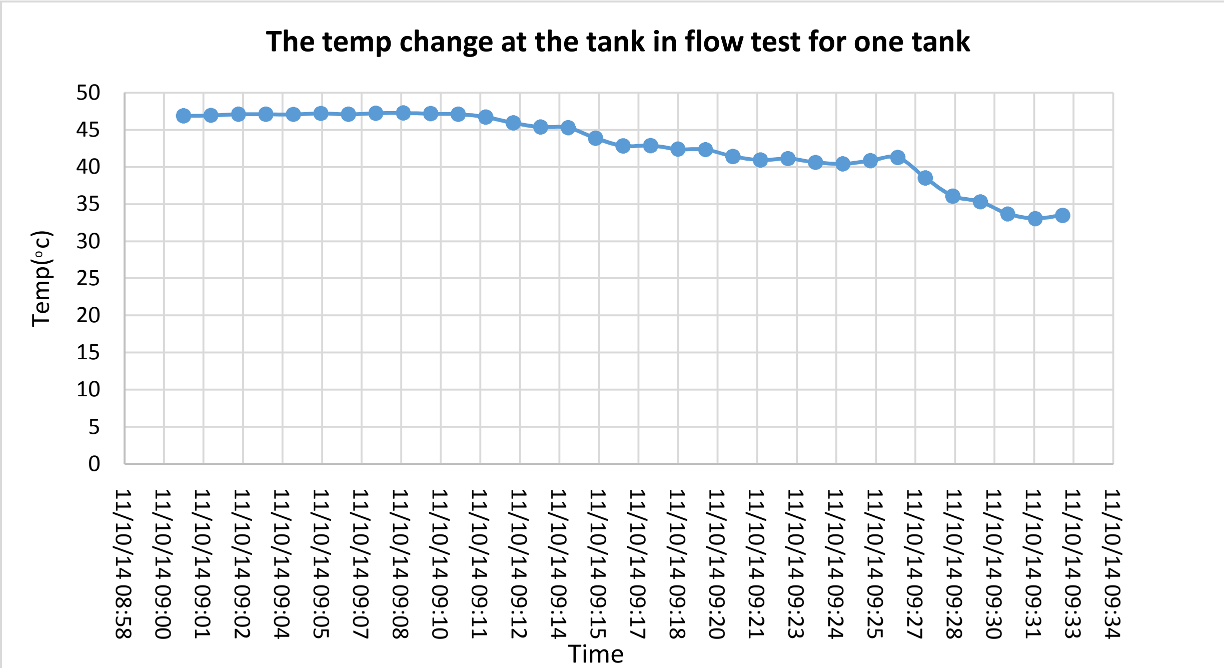


Figure (4.24): The temperature change at the tank in flow test for one tank

Figure (4.25) show the change in temperature at a position near the outlet valve that send the hot water to users, for the first period the temperature nearly constant (about 30 c) due to the cold water occupied the pipes, but after the flow of water started the temperature increased suddenly as the hot water from the highest level at the tank reached. The curve after this period show that the temperatures, which the sensors at two position measured, are nearly equals.

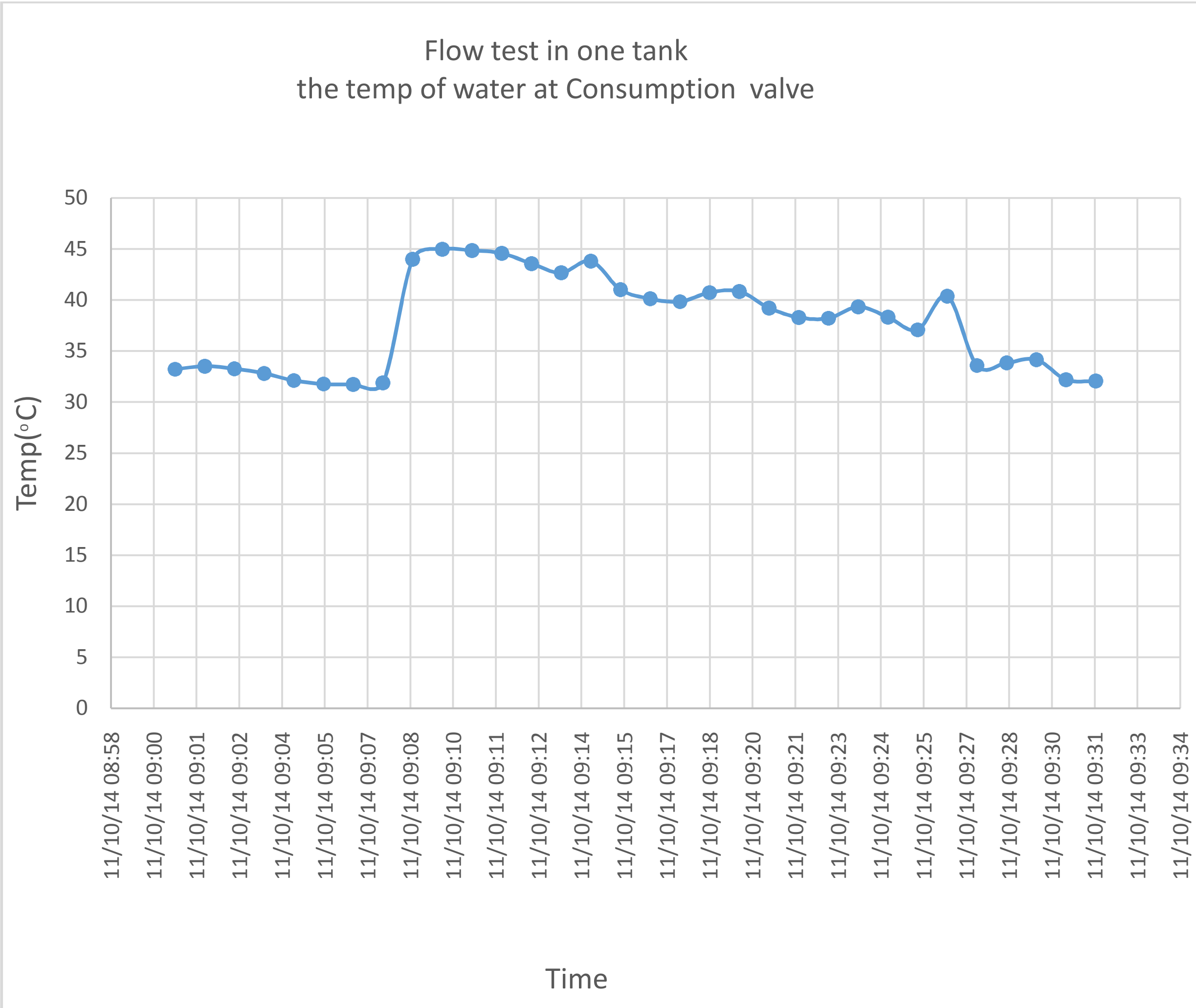


Figure (4.25): Flow test in one tank, the temperature of water at consumption valve

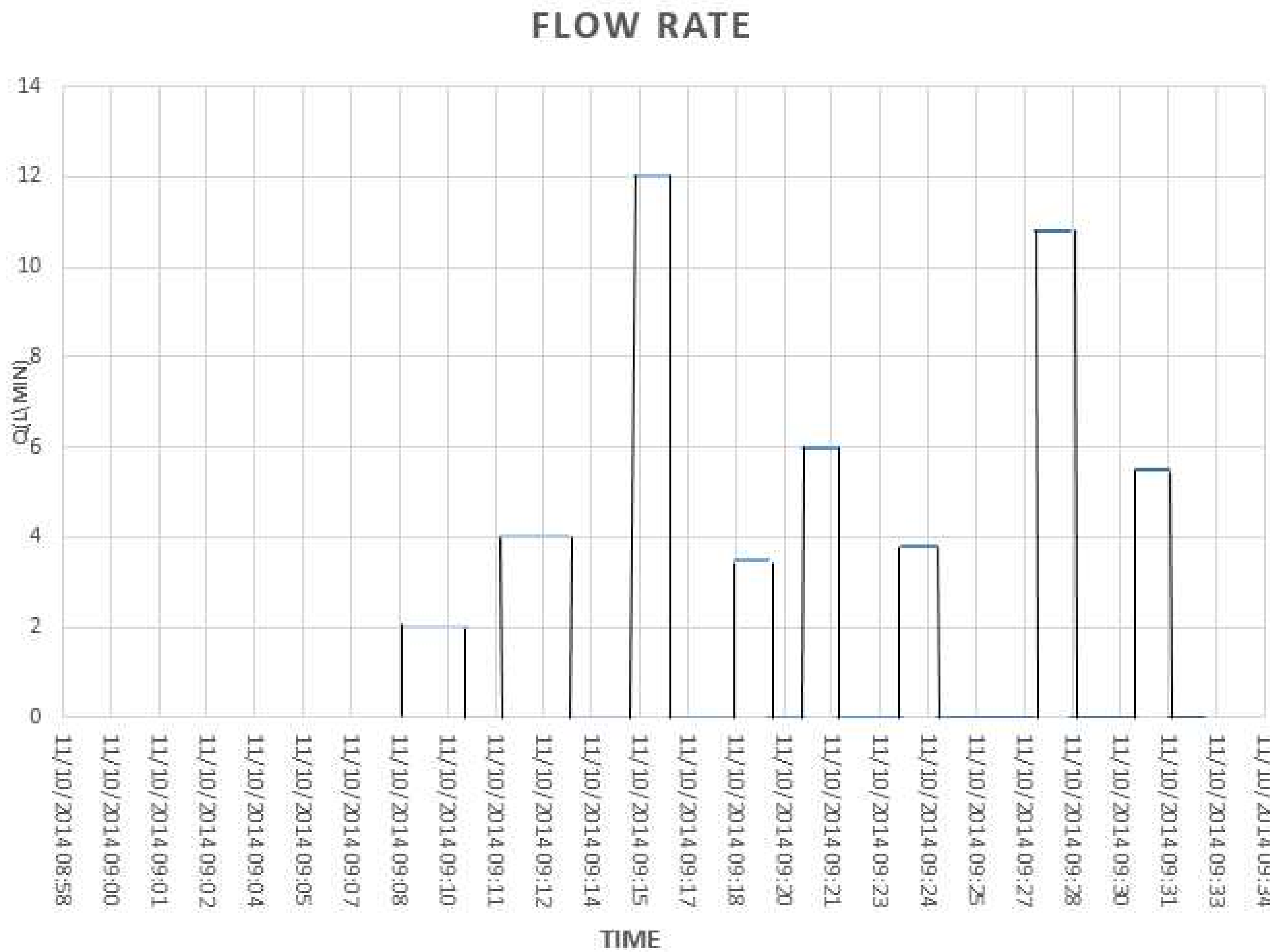


Figure (4.26): The flow rate through the test

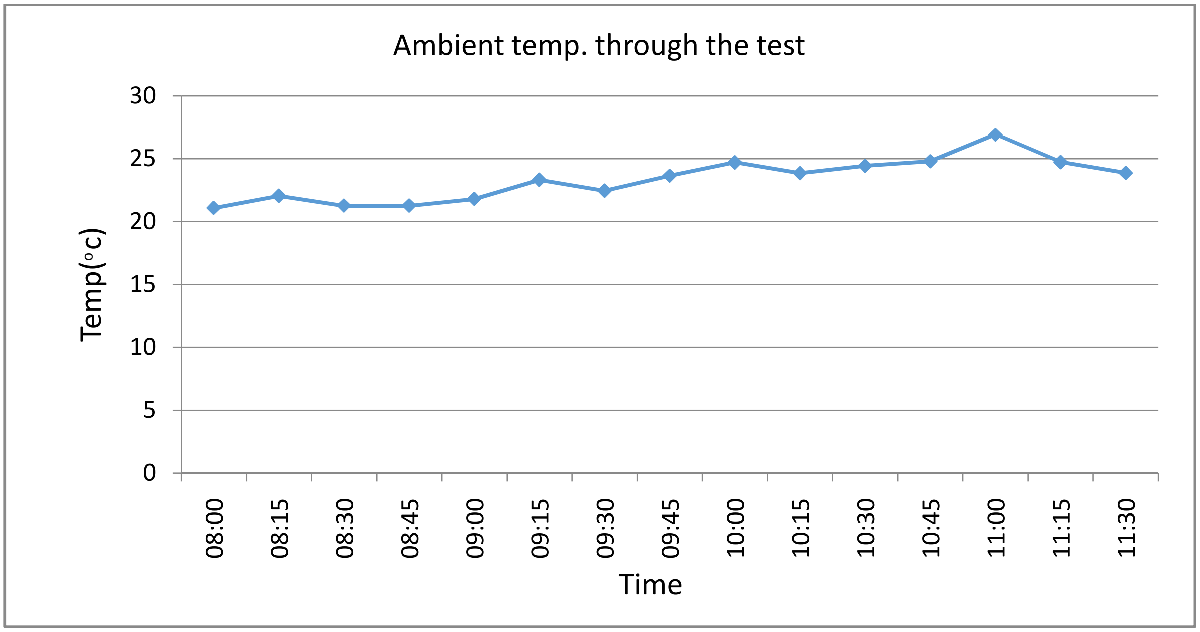
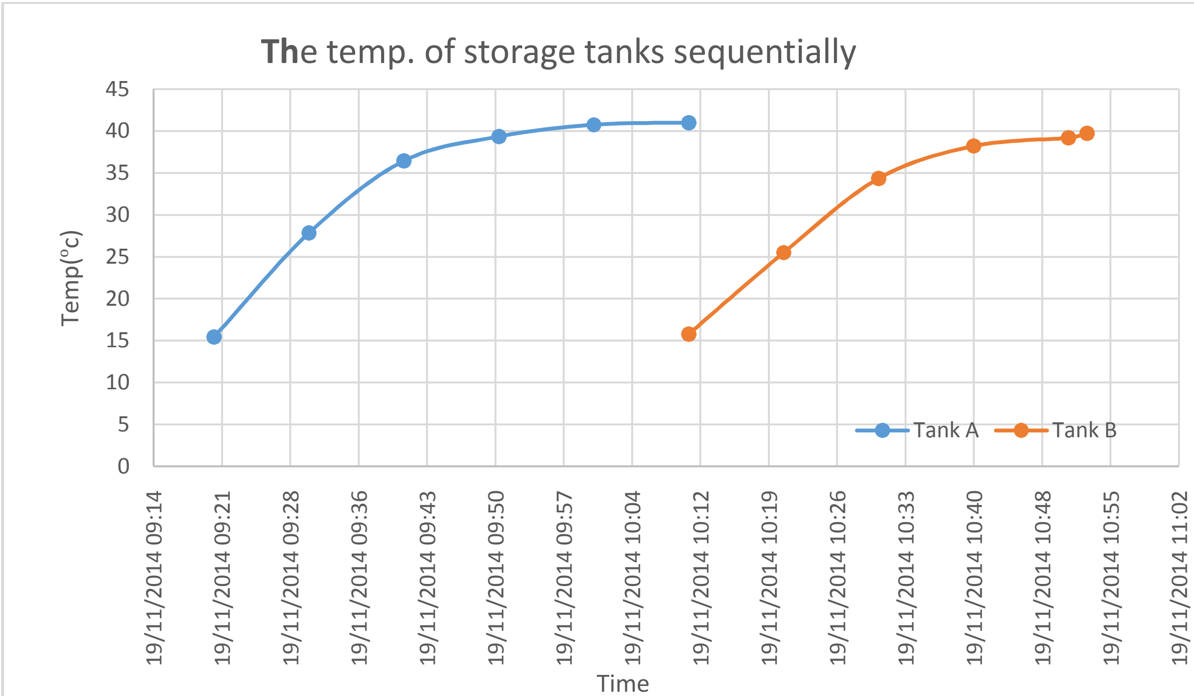


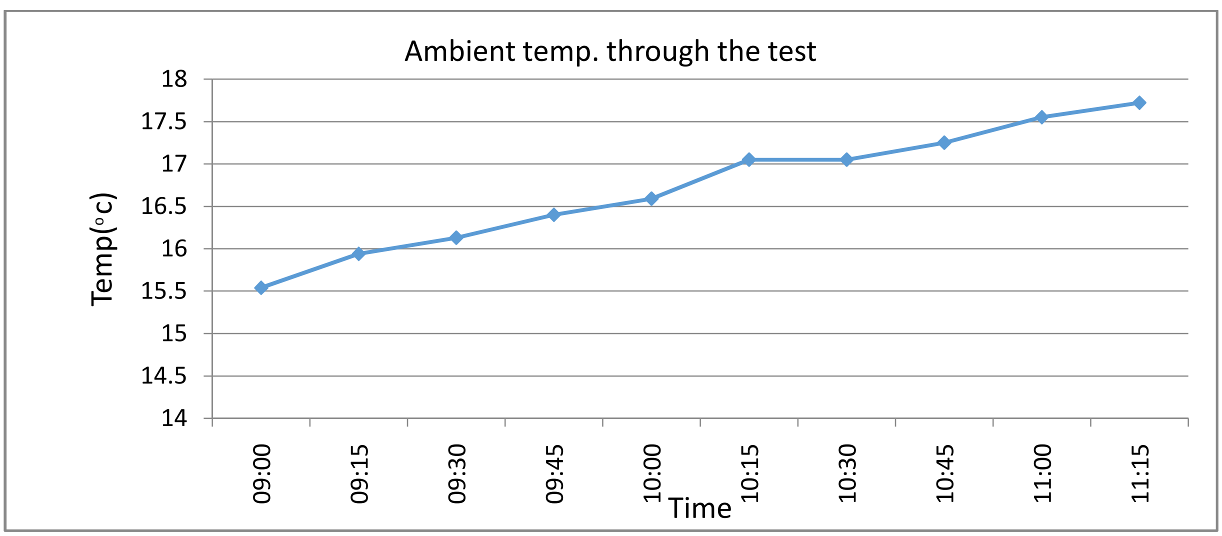
Figure (4.27): Ambient temp. through the test

4.7 Raise the temperature of storage tanks sequentially:

The primary goal for this test is to simulate what control system will do. You can notice that the two storage tanks started from the same initial temperature which is 15° **C**. the storage tank A (blue line in figure (28)) take 40 minutes to reach a temperature of 40 ° **C** while the second storage tank B was separated by closing the two manual valves, after the storage tank A reached 40 ° **C** it was separated and the storage tank B was connected with collector, and it take the same time to reach the same temperature. (See figure (4.28) and tableB10)).



Figure(4.28): The temp of storage tanks sequentially



Figure(4.29): Ambient temperature through the test

Figure (4.30) show that heating two storage tanks sequentially take less time to heat two storage tanks parallel with each other, after heating the first storage tank (blow curve) and reached more than 40 □c the valve between it and the collector will be closed and the valve between it and the domestic will be opened to allow the user to use a hot water, at this moment the second storage tank will be closed to using and opened for heating.

The yellow series represent the heating process for two tanks connecting to collector and the difference between one and two storage tanks is clear, after two storage tanks reached the maximum temperature at identified period (see tableB11)) the hot water was allowed to flow to user, of course the temperature will decrees, but at low rate due to large capacitance and continuous of heating by the collector.

As the first tank (blow curve) was closed for heating and opened for using, the user will start to use the hot water that comes from it, but the decrease in the water temperature inside the tank will be large due to small capacity and the separation from heating process.

Gray curve was obtained as assimilation using mathematical equation by ignoring the term $(\dot{m}cp)f$ and substituted it by zero, the equation 2.5 will be:

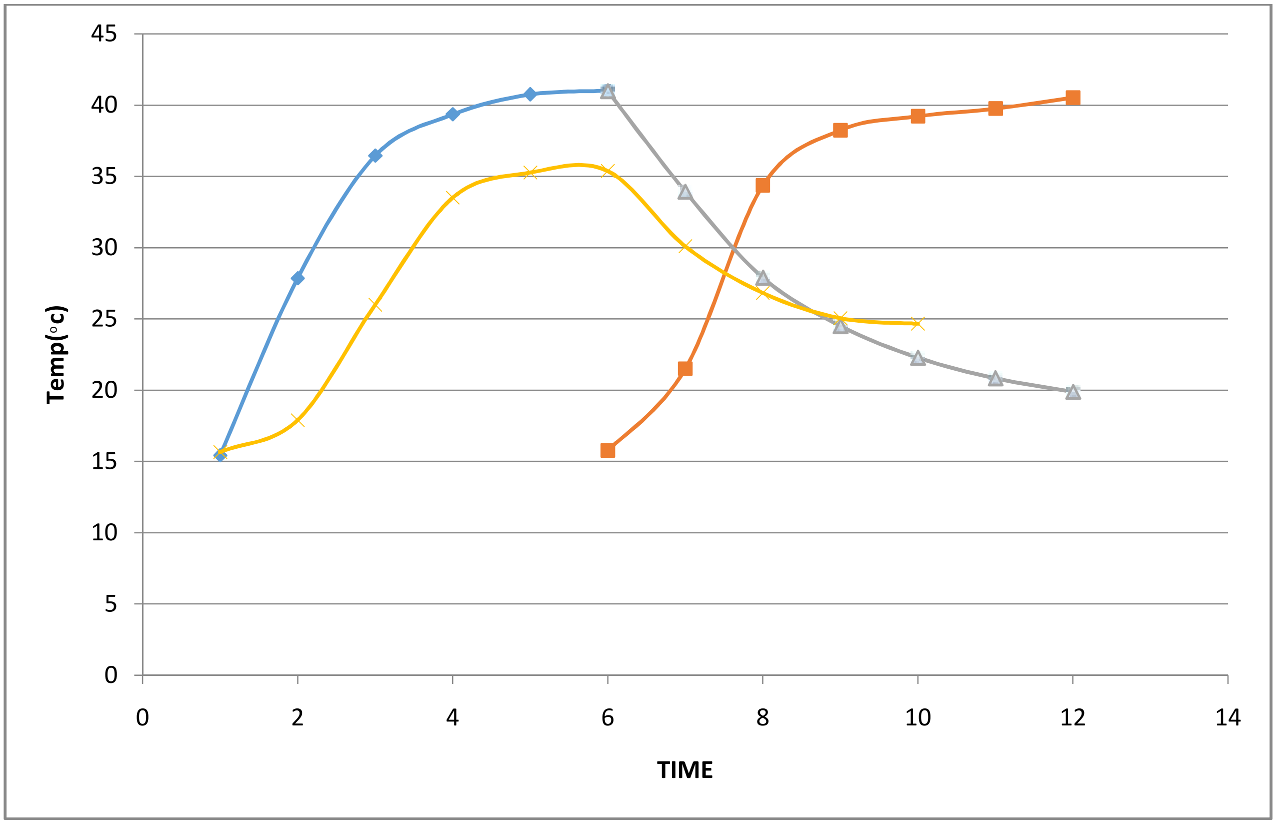
$(mc)t\ (dT/dt) = Qcold - Qtank$ [6] ……… (4.1)

$Qtank = mv\ cp\ Tt$ ……… (4.2)

$Qcold = mv\ cp\ Tc$ ……… (4.3)

$(\Delta Tt/\Delta t) = mv\ cp\ (Tc - Tt)/(mc)t$ [6] ……… (4.4)

When the gray curve intercept the yellow one, switching at this point could open the second tank for using and open the first for heating again due to the second tank have larger energy than the 100 liter capacitance, this analysis shows that this system is more efficient than the commercial one.



Figure(4.30): Comparison between switching strategy and commercial one

4.8 Simulation of system work using manual valve :

The best strategy should reached by switching the valves at suitable time to increase heat capturing. A two manual valves was putted at the return pipe from the collector to the two tanks in order to prevent the hot water from entering the second tank while just a one tank required to minimize the heating capacity. This enables us to isolate the tank we do not need complete isolation.

Fig (4.31). The valve between domestic use and the valve between the tank B and collector, in additional The valve between the collector and tank B, all must be closed. Notice that at first period (from11:38 am to 12:15 pm).

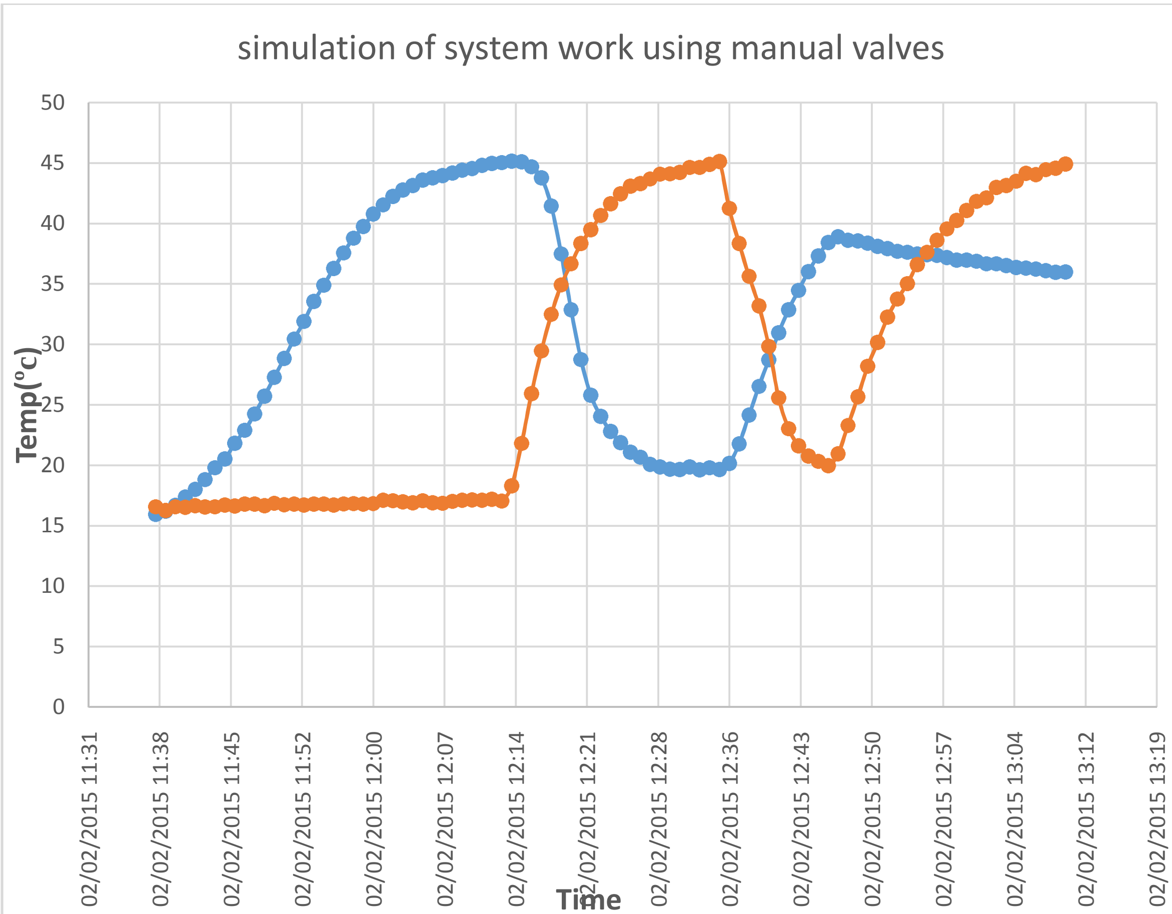
The temperature of tank A increased up to 45 °c (mean time 35 min.) while the temperature of tank B remained constant. At (12:15 am) the process invert, tank A was separated from the collector, and opened to domestic use (continuously flow 2 L\min), while tank B separated from domestic use and opened to the collector to heat it is water.

The temperature at tank A fall from 45 °c to 36 °c during5 minutes at flow (2 L\min) while tank B climbed from initial temperature to 36 °c at same time which means that we got high temperature at short time. The switching time cold late until the temperature at tank A fall to 25 °c at this moment the water temperature at tank B is about 40 °c, which is suitable to use, and so.

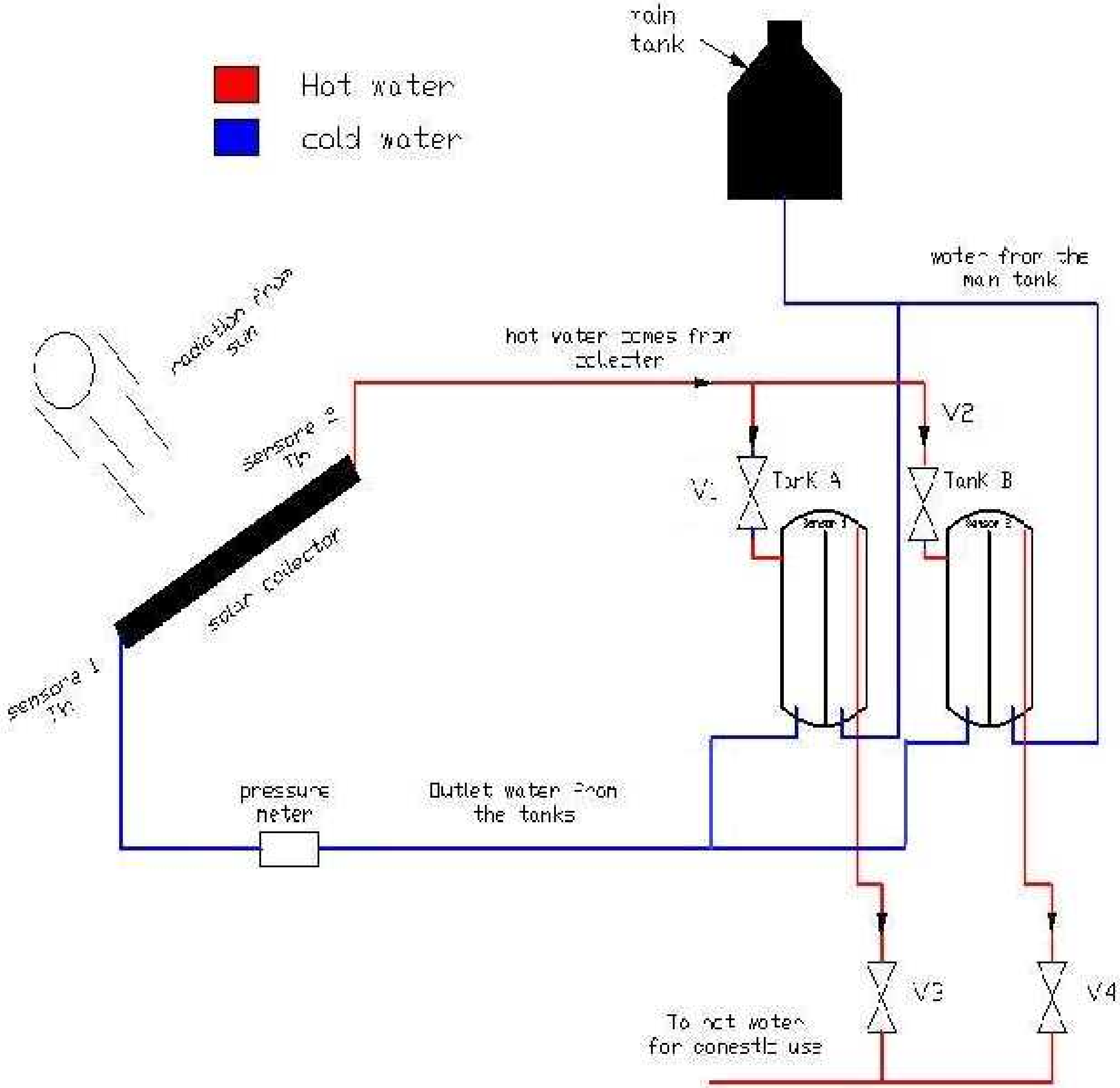
After adding two valves to the system, the total number of valves became 6 valves, which raise the total cost of the system, we prefer to test the system, while just a one tank was heating (tank B).

At time (12:47 pm) the valve between the collector and tank A was closed and the valve between tank A and domestic use was close while the valve between tank A and the collector (the cold water from the tank to the collector was open). Notice that the change in temperature inside tank A was very small during about

20 minutes, this means that we can ignore this change, and we can eliminate the two valves that was fitted between the two tanks and the collector (at cold water pipe). (see table B12).



Figure(4.31):simulation of system work using manual valves



Figure(4.32): layout of the system after replaced the valve 1&2

4.9 Project Conclusion

Because of the period that needed to heat the 50 liter storage tank is less than the 200 liter, especially in the morning period the previous project shows that the new model system is more efficient than the commercial one.

Another point that the management strategy increased added some efficiency to the system by store the hot water inside the tank and using it when the sun radiation is decrease.

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APPENDIX

Appendix

Appendix A:

Table A1: Temperature at different level in storage tank

Time	Temp, °C(Ts.l)	Temp, °C(Ts.m)	Temp, °C(Ts.h)	Temp, °C(Ts.av)
5/19/2014 10:57	36.254	42.386	45.972	41.53733333
5/19/2014 11:01	37.357	43.435	47.092	42.628
5/19/2014 11:07	38.532	44.349	48.271	43.71733333
5/19/2014 11:17	40.286	45.279	49.343	44.96933333
5/19/2014 11:27	41.678	46.321	50.508	46.169
5/19/2014 11:37	42.893	47.45	51.667	47.33666667
5/19/2014 11:47	43.982	48.704	53.001	48.56233333
5/19/2014 11:57	45.03	49.956	54.075	49.687
5/19/2014 12:07	46.13	51.313	55.638	51.027
5/19/2014 12:17	47.352	52.6	56.938	52.29666667
5/19/2014 12:27	48.637	53.962	57.745	53.448
5/19/2014 12:37	49.854	55.251	58.693	54.59933333
5/19/2014 12:47	51.137	56.303	59.407	55.61566667
5/19/2014 12:57	52.347	57.098	59.962	56.469
5/19/2014 13:07	53.479	57.786	60.35	57.205
5/19/2014 13:17	54.489	58.443	60.83	57.92066667
5/19/2014 13:27	55.444	58.943	61.315	58.56733333
5/19/2014 13:37	56.303	59.45	62.032	59.26166667
5/19/2014 13:47	57.138	59.962	62.578	59.89266667

5/19/2014 13:57	57.827	60.481	63.085	60.46433333
5/19/2014 14:07	58.485	61.05	63.645	61.06
5/19/2014 14:17	59.027	61.493	63.645	61.38833333
5/19/2014 14:27	59.492	61.897	63.411	61.6
5/19/2014 14:37	59.876	62.122	63.177	61.725
5/19/2014 14:47	60.264	61.852	62.9	61.672
5/19/2014 14:57	60.524	61.672	62.715	61.637
5/19/2014 15:07	60.786	61.36	62.486	61.544
5/19/2014 15:17	61.05	61.05	62.258	61.45266667
5/19/2014 15:27	60.962	60.742	62.032	61.24533333
5/19/2014 15:37	60.874	60.655	61.717	61.082
5/19/2014 15:47	60.786	60.568	61.493	60.949
5/19/2014 15:57	60.742	60.394	61.227	60.78766667

Table A2: Thermal capacity for the collector test

Time	T col(inlet)	T collctor (outlet)	T cold water
5/18/2014 14:14	48.404	63.271	32.613
5/18/2014 14:24	41.56	57.623	33.079
5/18/2014 14:34	37.645	54.338	34.071
5/18/2014 14:44	35.609	51.348	34.281
5/18/2014 14:54	33.704	49.006	33.835
5/18/2014 15:04	33.053	47.06	33.73
5/18/2014 15:14	32.124	45.53	32.717
5/18/2014 15:24	31.765	45.53	31.714
5/18/2014 15:34	32.278	44.135	30.621
5/18/2014 15:44	32.872	42.923	30.672
5/18/2014 15:54	33.235	41.619	30.52
5/18/2014 16:04	33.417	40.487	30.495
5/18/2014 16:14	33.339	39.545	30.596
5/18/2014 16:24	33.287	38.421	29.565
5/18/2014 16:34	32.794	37.096	28.891
5/18/2014 16:44	32.484	35.904	27.751
5/18/2014 16:54	32.201	34.624	27.421

5/18/2014 17:04	31.689	34.519	27.604
5/18/2014 17:14	31.179	34.15	27.161
5/18/2014 17:24	31.179	34.25	26.532
5/18/2014 17:34	29.991	34.308	25.404
5/18/2014 17:44	28.99	33.861	24.363
5/18/2014 17:54	28.048	32.846	22.274
5/18/2014 18:04	26.94	31.765	20.531
5/18/2014 18:14	26.402	33.391	21.103
5/18/2014 18:24	25.477	33.053	20.15
5/18/2014 18:34	24.895	33.94	20.627
5/18/2014 18:44	24.195	33.548	19.508
5/18/2014 18:54	23.16	31.535	17.225
5/18/2014 19:04	22.321	30.243	16.034
5/18/2014 19:14	21.39	29.84	15.342
5/18/2014 19:24	20.555	29.74	14.936
5/18/2014 19:34	19.746	29.565	14.673
5/18/2014 19:44	18.985	29.365	14.433
5/18/2014 19:54	18.343	29.04	14.242
5/18/2014 20:04	17.772	28.766	14.122

Table A3: Change in inlet and outlet temperature of the collector

Time	Temp, °C(Tc(out))	Temp, °C(Tc(in))
5/18/2014 5:39	17.629	12.316
5/18/2014 5:54	17.153	12.001
5/18/2014 6:09	17.415	12.074
5/18/2014 6:24	17.724	12.268
5/18/2014 6:39	18.057	12.775
5/18/2014 6:54	19.722	13.497
5/18/2014 7:09	20.15	14.673
5/18/2014 7:24	21.009	16.058
5/18/2014 7:39	22.536	17.106
5/18/2014 7:54	24.074	18.461
5/18/2014 8:09	29.439	20.46

Table A4: System overall efficiency

Time	Tc in, °C	Tc out, °C	T c avg, °C	Tt, °C	Tc/Tt	ηsystem%
5/19/2014 10:57	27.677	48.57	38.1235	41.53733	0.917813	8.218710871
5/19/2014 11:01	28.325	49.298	38.8115	42.628	0.91047	8.953035563
5/19/2014 11:07	28.965	49.956	39.4605	43.71733	0.902628	9.737175179
5/19/2014 11:17	29.916	50.578	40.247	44.96933	0.894988	10.50123046
5/19/2014 11:27	31.561	52.131	41.846	46.169	0.906366	9.363425675
5/19/2014 11:37	32.872	53.368	43.12	47.33667	0.910922	8.907823399
5/19/2014 11:47	34.757	54.602	44.6795	48.56233	0.920044	7.99556583
5/19/2014 11:57	35.609	55.56	45.5845	49.687	0.917433	8.25668686
5/19/2014 12:07	37.838	56.898	47.368	51.027	0.928293	7.170713544
5/19/2014 12:17	39.121	58.361	48.741	52.29667	0.93201	6.799031174
5/19/2014 12:27	40.028	59.154	49.591	53.448	0.927836	7.216359826
5/19/2014 12:37	41.356	59.876	50.616	54.59933	0.927044	7.295571369
5/19/2014 12:47	42.149	60.874	51.5115	55.61567	0.926205	7.37951537
5/19/2014 12:57	43.103	61.717	52.41	56.469	0.92812	7.188014663
5/19/2014 13:07	44.196	62.213	53.2045	57.205	0.930067	6.993269819
5/19/2014 13:17	44.843	62.486	53.6645	57.92067	0.926517	7.348269477
5/19/2014 13:27	45.877	63.177	54.527	58.56733	0.931014	6.898612418
5/19/2014 13:37	47.092	63.928	55.51	59.26167	0.936693	6.330680321
5/19/2014 13:47	47.482	64.79	56.136	59.89267	0.937277	6.272331621
5/19/2014 13:57	48.172	64.887	56.5295	60.46433	0.934923	6.507693235
5/19/2014 14:07	49.242	65.919	57.5805	61.06	0.943015	5.698493285
5/19/2014 14:17	49.343	66.32	57.8315	61.38833	0.94206	5.793989081
5/19/2014 14:27	49.615	64.984	57.2995	61.6	0.930187	6.981331169
5/19/2014 14:37	49.547	65.228	57.3875	61.725	0.929729	7.027136493
5/19/2014 14:47	48.905	64.79	56.8475	61.672	0.921772	7.822836944
5/19/2014 14:57	47.613	63.038	55.3255	61.637	0.897602	10.23979103
5/19/2014 15:07	46.577	63.131	54.854	61.544	0.891297	10.87027168
5/19/2014 15:17	44.073	61.271	52.672	61.45267	0.857115	14.28850389

5/19/2014 15:27	42.327	59.962	51.1445	61.24533	0.835076	16.49241302
5/19/2014 15:37	46.545	62.807	54.676	61.082	0.895125	10.48754134
5/19/2014 15:47	47.482	63.504	55.493	60.949	0.910483	8.951746542
5/19/2014 15:57	47.157	62.532	54.8445	60.78767	0.902231	9.776928439

Appendix B:

Table B1 : Change in temperature for two storage tanks connected with the solar panel

time	Temp. in tank b	Temp. in tank A	avg.. temp.
3/1/2015 11:02	15.008	15.533	15.2705
3/1/2015 11:03	15.796	16.32	16.058
3/1/2015 11:04	16.582	17.701	17.1415
3/1/2015 11:05	17.344	18.747	18.0455
3/1/2015 11:06	18.129	20.341	19.235
3/1/2015 11:07	18.985	21.652	20.3185
3/1/2015 11:08	19.96	22.944	21.452
3/1/2015 11:09	21.199	24.315	22.757
3/1/2015 11:10	22.13	25.72	23.925
3/1/2015 11:11	23.184	27.235	25.2095

3/1/2015 11:12	24.074	28.32	26.197
3/1/2015 11:13	24.968	29.49	27.229
3/1/2015 11:14	26.012	30.343	28.1775
3/1/2015 11:15	26.818	31.179	28.9985
3/1/2015 11:16	27.653	32.355	30.004
3/1/2015 11:17	28.345	32.924	30.6345
3/1/2015 11:18	29.065	33.73	31.3975
3/1/2015 11:19	29.49	34.308	31.899
3/1/2015 11:20	30.268	34.704	32.486
3/1/2015 11:21	30.824	35.262	33.043
3/1/2015 11:22	31.331	35.904	33.6175
3/1/2015 11:23	32.098	36.146	34.122
3/1/2015 11:24	32.484	36.444	34.464
3/1/2015 11:25	32.846	36.96	34.903
3/1/2015 11:26	33.313	37.343	35.328
3/1/2015 11:27	33.94	37.783	35.8615
3/1/2015 11:28	34.229	38.226	36.2275
3/1/2015 11:29	34.73	38.56	36.645
3/1/2015 11:30	35.262	38.896	37.079
3/1/2015 11:31	35.582	39.149	37.3655
3/1/2015	36.119	39.262	37.6905

11:32			
3/1/2015 11:33	36.471	39.8	38.1355
3/1/2015 11:34	36.688	39.943	38.3155
3/1/2015 11:35	37.096	40.114	38.605
3/1/2015 11:36	37.563	40.372	38.9675
3/1/2015 11:37	37.811	40.66	39.2355
3/1/2015 11:38	38.143	40.66	39.4015
3/1/2015 11:39	38.504	40.978	39.741
3/1/2015 11:40	38.56	41.065	39.8125

Table B2: Heating 100 liters by using switching strategy

time	tank a	tank b
3/1/2015 12:08	15.151	14.314
3/1/2015 12:09	16.201	14.361
3/1/2015 12:10	17.249	14.314
3/1/2015 12:11	18.818	14.242
3/1/2015 12:12	20.126	14.194
3/1/2015 12:13	21.915	14.337
3/1/2015 12:14	23.424	14.314
3/1/2015	25.162	14.481

12:15		
3/1/2015 12:16	27.186	14.361
3/1/2015 12:17	29.015	14.361
3/1/2015 12:18	30.52	14.481
3/1/2015 12:19	32.433	14.337
3/1/2015 12:20	34.071	14.361
3/1/2015 12:21	35.368	14.457
3/1/2015 12:22	36.633	14.481
3/1/2015 12:23	37.893	14.433
3/1/2015 12:24	38.7	14.457
3/1/2015 12:25	39.516	14.457
3/1/2015 12:26	40.4	14.433
3/1/2015 12:27	41.239	14.361
3/1/2015 12:28	41.473	14.505
3/1/2015 12:29		14.553
3/1/2015 12:30		15.772
3/1/2015 12:31		17.653
3/1/2015 12:32		19.841
3/1/2015 12:33		21.867
3/1/2015 12:34		23.93
3/1/2015 12:35		25.89

3/1/2015 12:36	27.628
3/1/2015 12:37	29.215
3/1/2015 12:38	30.672
3/1/2015 12:39	31.97
3/1/2015 12:40	33.131
3/1/2015 12:41	34.124
3/1/2015 12:42	35.075
3/1/2015 12:43	35.85
3/1/2015 12:44	36.688
3/1/2015 12:45	37.343
3/1/2015 12:46	38.004
3/1/2015 12:47	38.56
3/1/2015 12:48	39.121
3/1/2015 12:49	39.46
3/1/2015 12:50	40

Table B3: Temperature change at storage tank A for two storage tanks test (for figure 4.6) before changing the connection

Day time	Temperature at high level for storage tank A (□c)
11/20/14 09:55:05 am	16.129
11/20/14 09:55:35 am	16.106
11/20/14 09:56:05 am	16.153
11/20/14 09:56:35 ص	16.249
11/20/14 09:57:05 ص	16.368
11/20/14 09:57:35 ص	16.963
11/20/14 09:58:05 ص	17.415
11/20/14 09:58:35 ص	17.677
11/20/14 09:59:05 ص	18.081
11/20/14 09:59:35 am	18.438
11/20/14 10:00:05 ص	19.056
11/20/14 10:00:35 ص	19.865
11/20/14 10:01:05 ص	20.388
11/20/14 10:01:35 ص	21.008
11/20/14 10:02:05 ص	21.843
11/20/14 10:02:35 ص	22.681
11/20/14 10:03:05 ص	23.328
11/20/14 10:03:35 ص	24.363
11/20/14 10:04:05 ص	24.968
11/20/14 10:04:35 ص	25.793
11/20/14 10:05:05 ص	26.573
11/20/14 10:05:35 ص	27.087

11/20/14 10:06:05 ص	28.072
11/20/14 10:06:35 ص	28.617
11/20/14 10:07:05 ص	29.265
11/20/14 10:07:35 ص	30.192
11/20/14 10:08:05 ص	30.773
11/20/14 10:08:35 ص	31.535
11/20/14 10:09:05 ص	31.97
11/20/14 10:09:35 ص	32.742
11/20/14 10:10:05 ص	33.391
11/20/14 10:10:35 ص	33.914
11/20/14 10:11:05 ص	34.466
11/20/14 10:11:35 ص	34.916
11/20/14 10:12:05 ص	35.529
11/20/14 10:12:35 ص	35.877
11/20/14 10:13:05 ص	36.308
11/20/14 10:13:35 ص	36.851
11/20/14 10:14:05 ص	36.905
11/20/14 10:14:35 ص	37.343
11/20/14 10:15:05 ص	37.618
11/20/14 10:15:35 ص	37.811
11/20/14 10:16:05 ص	38.06
11/20/14 10:16:35 ص	38.309
11/20/14 10:17:05 ص	38.644
11/20/14 10:17:35 ص	38.644
11/20/14 10:18:05 ص	38.756

11/20/14 10:18:35 ص	38.952
11/20/14 10:19:05 ص	39.093
11/20/14 10:19:35 ص	39.177
11/20/14 10:20:05 ص	39.488
11/20/14 10:20:35 ص	39.403
11/20/14 10:21:05 ص	39.545
11/20/14 10:21:35 ص	39.63
11/20/14 10:22:05 ص	39.829
11/20/14 10:22:35 ص	39.829
11/20/14 10:23:05 ص	39.914
11/20/14 10:23:35 ص	40

Table B4: Temperature change at storage tank B for two storage tanks test (for figure 4.7) before changing the connection

Time	Temperature at high level for storage tank B (□c)
11/20/14 09:55:04 ص	16.82
11/20/14 09:55:34 ص	16.701
11/20/14 09:56:04 ص	16.677
11/20/14 09:56:34 ص	16.725
11/20/14 09:57:04 ص	16.558
11/20/14 09:57:34 ص	16.558
11/20/14 09:58:04 ص	16.511
11/20/14 09:58:34 ص	16.558
11/20/14 09:59:04 ص	16.606

11/20/14 09:59:34 ص	16.749
11/20/14 10:00:04 ص	16.63
11/20/14 10:00:34 ص	16.511
11/20/14 10:01:04 ص	16.654
11/20/14 10:01:34 ص	16.701
11/20/14 10:02:04 ص	16.701
11/20/14 10:02:34 ص	16.606
11/20/14 10:03:04 ص	16.725
11/20/14 10:03:34 ص	16.487
11/20/14 10:04:04 ص	16.677
11/20/14 10:04:34 ص	16.439
11/20/14 10:05:04 ص	16.487
11/20/14 10:05:34 ص	16.773
11/20/14 10:06:04 ص	16.511
11/20/14 10:06:34 ص	16.654
11/20/14 10:07:04 ص	16.725
11/20/14 10:07:34 ص	16.511
11/20/14 10:08:04 ص	16.701
11/20/14 10:08:34 ص	16.725
11/20/14 10:09:04 ص	16.892
11/20/14 10:09:34 ص	16.725
11/20/14 10:10:04 ص	16.701
11/20/14 10:10:34 ص	16.796
11/20/14 10:11:04 ص	16.796
11/20/14 10:11:34 ص	16.844
11/20/14 10:12:04 ص	16.868

11/20/14 10:12:34 ص	16.892
11/20/14 10:13:04 ص	16.773
11/20/14 10:13:34 ص	16.868
11/20/14 10:14:04 ص	17.011
11/20/14 10:14:34 ص	16.987
11/20/14 10:15:04 ص	16.987
11/20/14 10:15:34 ص	17.153
11/20/14 10:16:04 ص	17.106
11/20/14 10:16:34 ص	17.177
11/20/14 10:17:04 ص	17.13
11/20/14 10:17:34 ص	17.296
11/20/14 10:18:04 ص	17.51
11/20/14 10:18:34 ص	17.582
11/20/14 10:19:04 ص	17.843
11/20/14 10:19:34 ص	18.105
11/20/14 10:20:04 ص	18.2
11/20/14 10:20:34 ص	18.747
11/20/14 10:21:04 ص	18.937
11/20/14 10:21:34 ص	19.199
11/20/14 10:22:04 ص	19.555
11/20/14 10:22:34 ص	19.936
11/20/14 10:23:04 ص	20.198
11/20/14 10:23:34 ص	20.674
11/20/14 10:24:04 ص	20.865
11/20/14 10:24:34 ص	21.199

11/20/14 10:25:04 ص	21.604
11/20/14 10:25:34 ص	21.987
11/20/14 10:26:04 ص	22.202
11/20/14 10:26:34 ص	22.537
11/20/14 10:27:04 ص	22.896
11/20/14 10:27:34 ص	23.256
11/20/14 10:28:04 ص	23.424
11/20/14 10:28:34 ص	23.978
11/20/14 10:29:04 ص	24.363
11/20/14 10:29:34 ص	24.629
11/20/14 10:30:04 ص	24.919
11/20/14 10:30:34 ص	25.089
11/20/14 10:31:04 ص	25.574
11/20/14 10:31:34 ص	26.012
11/20/14 10:32:04 ص	26.231
11/20/14 10:32:34 ص	26.646
11/20/14 10:33:04 ص	26.891
11/20/14 10:33:34 ص	27.186
11/20/14 10:34:04 ص	27.677
11/20/14 10:34:34 ص	27.875
11/20/14 10:35:04 ص	28.196
11/20/14 10:35:34 ص	28.593
11/20/14 10:36:04 ص	28.816
11/20/14 10:36:34 ص	29.14
11/20/14 10:37:04 ص	29.414
11/20/14 10:37:34 ص	29.79

11/20/14 10:38:04 ص	30.041
11/20/14 10:38:34 ص	30.293
11/20/14 10:39:04 ص	30.646
11/20/14 10:39:34 ص	30.874
11/20/14 10:40:04 ص	31.255
11/20/14 10:40:34 ص	31.535
11/20/14 10:41:04 ص	31.689
11/20/14 10:41:34 ص	31.97
11/20/14 10:42:04 ص	32.15
11/20/14 10:42:34 ص	32.381
11/20/14 10:43:04 ص	32.717
11/20/14 10:43:34 ص	32.82
11/20/14 10:44:04 ص	33.157
11/20/14 10:44:34 ص	33.574
11/20/14 10:45:04 ص	33.757
11/20/14 10:45:34 ص	33.887
11/20/14 10:46:04 ص	34.202

Table B5: Temperature change at storage tank A, after solving this problem the test repeated and these results were obtained

Day time	Temperature at high level for storage tank A (□c)
12/04/14 12:55	18.129
12/04/14 12:56	17.962
12/04/14 12:57	18.39
12/04/14 12:58	18.485
12/04/14 12:59	18.485
12/04/14 13:00	18.771
12/04/14 13:01	19.008
12/04/14 13:02	19.318
12/04/14 13:03	19.865
12/04/14 13:04	20.365
12/04/14 13:05	20.96
12/04/14 13:06	21.652
12/04/14 13:07	22.321
12/04/14 13:08	23.232
12/04/14 13:09	24.002
12/04/14 13:10	24.557
12/04/14 13:11	25.501
12/04/14 13:12	26.207
12/04/14 13:13	26.916
12/04/14 13:14	27.974
12/04/14 13:15	28.617
12/04/14 13:16	29.34
12/04/14 13:17	30.117
12/04/14 13:18	31.001
12/04/14 13:19	31.612
12/04/14 13:20	32.201
12/04/14 13:21	32.742
12/04/14 13:22	33.235
12/04/14 13:23	33.861
12/04/14 13:24	34.202
12/04/14 13:25	34.836

12/04/14 13:26	35.182
12/04/14 13:27	35.368
12/04/14 13:28	35.77
12/04/14 13:29	35.797
12/04/14 13:30	36.012
12/04/14 13:31	36.173

Table B6: Temperature at high level for storage tank B (°c),after solving this problem the test repeated and these results were obtained

Day time	**Temperature at high level for storage tank B (°c)**
12/04/14 12:55	18.533
12/04/14 12:56	18.794
12/04/14 12:57	19.175
12/04/14 12:58	19.365
12/04/14 12:59	19.698
12/04/14 13:00	19.96
12/04/14 13:01	20.269
12/04/14 13:02	20.746
12/04/14 13:03	21.127
12/04/14 13:04	21.652
12/04/14 13:05	22.274
12/04/14 13:06	22.992
12/04/14 13:07	23.905
12/04/14 13:08	24.629
12/04/14 13:09	25.453
12/04/14 13:10	26.182
12/04/14 13:11	26.94
12/04/14 13:12	27.875
12/04/14 13:13	28.766
12/04/14 13:14	29.565
12/04/14 13:15	30.621

12/04/14 13:16	31.586
12/04/14 13:17	32.381
12/04/14 13:18	33.209
12/04/14 13:19	33.757
12/04/14 13:20	34.334
12/04/14 13:21	34.942
12/04/14 13:22	35.475
12/04/14 13:23	35.931
12/04/14 13:24	36.389
12/04/14 13:25	36.688
12/04/14 13:26	36.905
12/04/14 13:27	37.096
12/04/14 13:28	37.233
12/04/14 13:29	37.343
12/04/14 13:30	37.261
12/04/14 13:31	37.288

Table B7: Temperature at high level for storage tank A load test

Day time	Temperature at high level for storage tank A (□c)
12/04/14 12:55	18.129
12/04/14 12:56	17.962
12/04/14 12:57	18.39
12/04/14 12:58	18.485
12/04/14 12:59	18.485
12/04/14 13:00	18.771
12/04/14 13:01	19.008
12/04/14 13:02	19.318
12/04/14 13:03	19.865
12/04/14 13:04	20.365
12/04/14 13:05	20.96
12/04/14 13:06	21.652
12/04/14 13:07	22.321

12/04/14 13:08	23.232
12/04/14 13:09	24.002
12/04/14 13:10	24.557
12/04/14 13:11	25.501
12/04/14 13:12	26.207
12/04/14 13:13	26.916
12/04/14 13:14	27.974
12/04/14 13:15	28.617
12/04/14 13:16	29.34
12/04/14 13:17	30.117
12/04/14 13:18	31.001
12/04/14 13:19	31.612
12/04/14 13:20	32.201
12/04/14 13:21	32.742
12/04/14 13:22	33.235

Table B8: Temperature at high level for storage tank B the load test

Day time	Temperature at high level for storage tank B (□c)
12/04/14 12:55	18.533
12/04/14 12:56	18.794
12/04/14 12:57	19.175
12/04/14 12:58	19.365
12/04/14 12:59	19.698
12/04/14 13:00	19.96
12/04/14 13:01	20.269
12/04/14 13:02	20.746
12/04/14 13:03	21.127
12/04/14 13:04	21.652
12/04/14 13:05	22.274
12/04/14 13:06	22.992
12/04/14 13:07	23.905
12/04/14 13:08	24.629

12/04/14 13:09	25.453
12/04/14 13:10	26.182
12/04/14 13:11	26.94
12/04/14 13:12	27.875
12/04/14 13:13	28.766
12/04/14 13:14	29.565
12/04/14 13:15	30.621
12/04/14 13:16	31.586
12/04/14 13:17	32.381
12/04/14 13:18	33.209
12/04/14 13:19	33.757
12/04/14 13:20	34.334
12/04/14 13:21	34.942
12/04/14 13:22	35.475
12/04/14 13:23	35.931
12/04/14 13:24	36.389
12/04/14 13:25	36.688
12/04/14 13:26	36.905
12/04/14 13:27	37.096
12/04/14 13:28	37.233
12/04/14 13:29	37.343
12/04/14 13:30	37.261
12/04/14 13:31	37.288
12/04/14 13:32	37.261
12/04/14 13:33	37.151
12/04/14 13:34	37.069
12/04/14 13:35	36.987
12/04/14 13:36	36.769
12/04/14 13:37	36.606
12/04/14 13:38	36.389
12/04/14 13:39	36.389
12/04/14 13:40	36.092
12/04/14 13:41	36.039
12/04/14 13:42	35.77
12/04/14 13:43	35.689

TableB9:for fig (4.19).

Time	Temp at tank A (°c)	Temp at tank b (°c)	AVG. temp (°c)
2/1/2015 8:50	13.594	14.433	14.0135
2/1/2015 8:51	13.786	14.553	14.1695
2/1/2015 8:52	14.074	14.936	14.505
2/1/2015 8:53	14.266	15.055	14.6605
2/1/2015 8:54	14.816	15.318	15.067
2/1/2015 8:55	15.366	15.796	15.581
2/1/2015 8:56	15.724	16.01	15.867
2/1/2015 8:57	16.415	16.344	16.3795
2/1/2015 8:58	17.201	16.892	17.0465
2/1/2015 8:59	18.01	17.534	17.772
2/1/2015 9:00	18.747	18.152	18.4495
2/1/2015 9:01	19.508	18.414	18.961
2/1/2015 9:02	20.246	19.175	19.7105
2/1/2015 9:03	21.008	19.841	20.4245
2/1/2015 9:04	21.819	20.412	21.1155
2/1/2015 9:05	22.633	20.841	21.737
2/1/2015 9:06	23.16	21.7	22.43
2/1/2015 9:07	23.809	22.393	23.101
2/1/2015 9:08	24.75	23.16	23.955
2/1/2015 9:09	25.453	23.761	24.607
2/1/2015 9:10	25.939	24.291	25.115
2/1/2015 9:11	26.598	24.823	25.7105
2/1/2015 9:12	27.284	25.404	26.344
2/1/2015 9:13	27.751	25.939	26.845
2/1/2015 9:14	28.221	26.231	27.226
2/1/2015 9:15	28.766	27.038	27.902
2/1/2015 9:16	29.315	27.358	28.3365
2/1/2015 9:17	29.69	27.481	28.5855
2/1/2015 9:18	30.016	27.998	29.007
2/1/2015 9:19	30.495	28.617	29.556
2/1/2015 9:20	30.697	28.841	29.769
2/1/2015 9:21	30.976	29.04	30.008

2/1/2015 9:22	31.255	29.515	30.385
2/1/2015 9:23	31.74	29.89	30.815
2/1/2015 9:24	31.868	30.016	30.942
2/1/2015 9:25	31.919	29.966	30.9425
2/1/2015 9:26	31.791	30.066	30.9285
2/1/2015 9:27	31.637	30.192	30.9145
2/1/2015 9:28	31.459	30.117	30.788
2/1/2015 9:29	31.23	29.815	30.5225
2/1/2015 9:30	31.103	29.765	30.434
2/1/2015 9:31	30.824	29.59	30.207
2/1/2015 9:32	30.596	29.464	30.03
2/1/2015 9:33	30.217	29.414	29.8155
2/1/2015 9:34	29.966	29.24	29.603
2/1/2015 9:35	29.565	28.941	29.253
2/1/2015 9:36	29.165	28.742	28.9535
2/1/2015 9:37	28.667	28.692	28.6795
2/1/2015 9:38	28.147	28.171	28.159
2/1/2015 9:39	27.604	27.899	27.7515
2/1/2015 9:40	27.186	27.653	27.4195
2/1/2015 9:41	26.744	27.333	27.0385
2/1/2015 9:42	26.28	27.259	26.7695
2/1/2015 9:43	25.866	26.94	26.403
2/1/2015 9:44	25.525	26.818	26.1715
2/1/2015 9:45	25.089	26.769	25.929
2/1/2015 9:46	24.895	26.28	25.5875
2/1/2015 9:47	24.484	26.134	25.309
2/1/2015 9:48	24.219	26.085	25.152
2/1/2015 9:49	23.978	25.987	24.9825
2/1/2015 9:50	23.833	25.817	24.825
2/1/2015 9:51	23.761	25.987	24.874
2/1/2015 9:52	23.761	25.914	24.8375
2/1/2015 9:53	23.857	25.72	24.7885
2/1/2015 9:54	23.521	26.061	24.791
2/1/2015 9:55	23.593	25.817	24.705
2/1/2015 9:56	23.424	26.012	24.718
2/1/2015 9:57	23.352	25.89	24.621
2/1/2015 9:58	23.256	25.793	24.5245
2/1/2015 9:59	23.16	25.866	24.513

2/1/2015 10:00	23.136	25.939	24.5375
2/1/2015 10:01	23.208	25.987	24.5975
2/1/2015 10:02	23.112	25.963	24.5375
2/1/2015 10:03	22.992	25.817	24.4045
2/1/2015 10:04	22.681	25.987	24.334
2/1/2015 10:05	22.657	25.841	24.249
2/1/2015 10:06	22.489	25.914	24.2015

Table B10: The temp of storage tanks sequentially

Day time	Temp for ST (A)	Temp for ST (B)
11/19/14 09:20:47	15.438	
11/19/14 09:30:47	27.85	
11/19/14 09:40:47	36.444	
11/19/14 09:50:47	39.346	
11/19/14 10:00:47	40.746	
11/19/14 10:10:47	41.007	15.772
11/19/14 10:20:47		21.509
11/19/14 10:30:47		34.36
11/19/14 10:40:47		38.226
11/19/14 10:50:47		39.205
11/19/14 10:52:44		39.743
11/19/14 11:00:44		40.516

Table B11: Comparison between switching strategy and commercial one using experimental data and simulation

Day time	Temp for storage tank A (o c)	Temp for storage tank A c	Simulation for using one storage tank	Temp for using 2 storage tanks
11/19/14 09:20:47 ص	15.438			15.652
11/19/14 09:30:47 ص	27.85			17.891
11/19/14 09:40:47 ص	36.444			25.987
11/19/14 09:50:47 ص	39.346			33.495
11/19/14 10:00:47 ص	40.746			35.262
11/19/14 10:10:47 ص	41.007	15.772	40.9787	35.372
11/19/14 10:20:47 ص		21.509	33.9309	30.091
11/19/14 10:30:47 ص		34.36	27.8985	26.818
11/19/14 10:40:47 ص		38.226	24.5085	25.04
11/19/14 10:50:47 ص		39.205	22.2913	24.653
11/19/14 10:52:44 ص		39.743	20.8413	
11/19/14 11:00:44 ص		40.516	19.8929	

Table B12: For fig (4.27)

Time	tank A	tank B
2/2/2015 11:37	15.939	16.582
2/2/2015 11:38	16.201	16.272
2/2/2015 11:39	16.677	16.582
2/2/2015 11:40	17.368	16.534
2/2/2015 11:41	18.01	16.677
2/2/2015 11:42	18.818	16.558
2/2/2015 11:43	19.793	16.582
2/2/2015 11:44	20.531	16.725
2/2/2015 11:45	21.819	16.654
2/2/2015 11:46	22.896	16.796
2/2/2015 11:47	24.243	16.796
2/2/2015 11:48	25.72	16.677
2/2/2015 11:49	27.284	16.868
2/2/2015 11:50	28.841	16.749
2/2/2015 11:51	30.444	16.796
2/2/2015 11:52	31.893	16.725
2/2/2015 11:53	33.548	16.796
2/2/2015 11:54	34.889	16.796
2/2/2015 11:55	36.281	16.725

2/2/2015 11:56	37.563	16.82
2/2/2015 11:57	38.784	16.844
2/2/2015 11:58	39.743	16.796
2/2/2015 11:59	40.775	16.844
2/2/2015 12:00	41.531	17.13
2/2/2015 12:01	42.238	17.082
2/2/2015 12:02	42.773	16.987
2/2/2015 12:03	43.133	16.915
2/2/2015 12:04	43.586	17.082
2/2/2015 12:05	43.768	16.915
2/2/2015 12:06	43.951	16.868
2/2/2015 12:07	44.165	17.034
2/2/2015 12:08	44.411	17.13
2/2/2015 12:09	44.534	17.153
2/2/2015 12:10	44.812	17.13
2/2/2015 12:11	44.968	17.201
2/2/2015 12:12	45.03	17.058
2/2/2015 12:13	45.154	18.319
2/2/2015 12:14	45.092	21.819
2/2/2015 12:15	44.688	25.939
2/2/2015	43.768	29.464

12:16		
2/2/2015 12:17	41.443	32.484
2/2/2015 12:18	37.48	34.916
2/2/2015 12:19	32.872	36.661
2/2/2015 12:20	28.742	38.337
2/2/2015 12:21	25.793	39.488
2/2/2015 12:22	24.05	40.66
2/2/2015 12:23	22.8	41.619
2/2/2015 12:24	21.867	42.445
2/2/2015 12:25	21.079	43.073
2/2/2015 12:26	20.674	43.284
2/2/2015 12:27	20.079	43.677
2/2/2015 12:28	19.865	44.073
2/2/2015 12:29	19.674	44.104
2/2/2015 12:30	19.651	44.226
2/2/2015 12:31	19.865	44.627
2/2/2015 12:32	19.627	44.627
2/2/2015 12:33	19.793	44.874
2/2/2015 12:34	19.651	45.123
2/2/2015 12:35	20.15	41.239
2/2/2015 12:36	21.772	38.337

2/2/2015 12:37	24.146	35.636
2/2/2015 12:38	26.524	33.183
2/2/2015 12:39	28.717	29.84
2/2/2015 12:40	30.95	25.574
2/2/2015 12:41	32.872	23.04
2/2/2015 12:42	34.466	21.628
2/2/2015 12:43	36.012	20.77
2/2/2015 12:44	37.315	20.341
2/2/2015 12:45	38.421	19.984
2/2/2015 12:46	38.896	20.96
2/2/2015 12:47	38.616	23.304
2/2/2015 12:48	38.56	25.671
2/2/2015 12:49	38.365	28.196
2/2/2015 12:50	38.115	30.167
2/2/2015 12:51	37.921	32.253
2/2/2015 12:52	37.7	33.757
2/2/2015 12:53	37.618	35.022
2/2/2015 12:54	37.48	36.606
2/2/2015 12:55	37.425	37.618
2/2/2015 12:56	37.37	38.616
2/2/2015	37.178	39.545

12:57		
2/2/2015 12:58	36.96	40.257
2/2/2015 12:59	36.96	41.065
2/2/2015 13:00	36.878	41.825
2/2/2015 13:01	36.661	42.119
2/2/2015 13:02	36.661	42.983
2/2/2015 13:03	36.525	43.133
2/2/2015 13:04	36.362	43.495
2/2/2015 13:05	36.308	44.135
2/2/2015 13:06	36.227	44.043
2/2/2015 13:07	36.092	44.442
2/2/2015 13:08	35.958	44.565
2/2/2015 13:09	35.985	44.905

Table B13 :Heating100 liters (conventional system)

time	ambient. temp	Solar radiation(kw/m2)	wind speed km\h
3/1/2015 11:00	13.58	0.73	0.9
3/1/2015 11:15	15.5	0.748	1.7
3/1/2015 11:30	14.86	0.757	0.8
3/1/2015 11:45	14	0.78	1.2

Table B14 : Heating 100 liters by using switching strategy

Time	ambient.Temp.	Solar radiation(kw\m2)	wind speed km\h
3/1/2015 12:00	13.44	0.794	2.1
3/1/2015 12:15	14.8	0.813	2.3
3/1/2015 12:30	14.3	0.812	1.2
3/1/2015 12:45	14.73	0.823	0.7