Palestine Polytechnic University

College of Engineering and Technology

Mechanical Engineering Department

Graduation Project

Testing the performance of SDHW Systems and their annual outputs and a comparison between Palestinian standards and European Standards for testing solar collectors

Project Team

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Acknowledgement

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It's our pleasure to thank whoever participated in backing up this project to be a real and successful one.

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Abstract

Solar domestic hot water systems are gaining acceptance worldwide including in Palestine. The system constitutes simple design and can be easily manufactured. In Palestine, there exist several workshops that manufacture SDHW systems however; the locally manufactured systems have not been subjected to testing their performance. It is very essential to identify the performance characteristics of these systems that will help us study their long-term technical and economical feasibility. The project will consist of two stages; in the first stage three identical SDHW systems produced by three different workshops will be tested to identify their relevant performance characteristics and later these characteristics will be used in a mathematical computer model (SDHW System) that is based on the LabView program to compare the systems outputs. In the second stage two selective systems produced locally will be also tested. Recommendations will be drawn and reports will be prepared and sent to the participating workshops.

At one stage the standards for testing the performance of solar collectors presented by the Palestinian Standards Institute will be examined and the results will be compared to those obtained using the ISO method.

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NOMENCATURE

A_C	Aperture area of the collectors, m^2
C_P	Specific heat of water at constant pressure, kJ/kg k
C_S	Storage tank heat capacity, kJ/k
D	Day of year, dimensionless
dl	Length of the day light, second
F''	Collector flow factor, dimensionless
F''_{eff}	Effective value for collector flow factor, dimensionless
f	Annual solar fraction, dimensionless
f_d	Daily solar fraction, dimensionless
f_m	Monthly-average solar fraction, dimensionless
G	Equivalent normal solar irradiance on a horizontal plane, w/m^2
G_T	Equivalent normal solar irradiance on a collector plane, w/m^2
H	Monthly-average daily radiations on a horizontal plane, w/m^2
H_T	Monthly-average daily radiations on a collector plane, w/m^2
J_S	Stratification coefficient for the solar storage tank, dimensionless
M_L	Total draw-off mass of water from the system during the day, kg
M_S	Mass of water inside the storage tank
$\dot{m}_c$	Mass flow rate of the heat transfer fluid through the collectors, kg/s
N	Number of days in a month
NTU	Number of transfer unit, dimensionless
Q_c	Total energy contained in the system, MJ
Q_{in}	Energy input into the system, MJ
Q_L	Demand energy load at 60°C, MJ

Q_{loss} Storage tank energy loss, MJ

Q_{out} Useful energy extracted from the system. MJ

Q_R Energy remaining in the tank after the draw-off, MJ

T^* Derived value of reduced temperature for steady conditions, $^\circ C\ m^2/w$

T_a Ambient air temperature, $^\circ C$

T_{ac} Ambient Air temperature measured around the collector, $^\circ C$

T_{an} Overnight ambient air temperature, $^\circ C$

T_{as} Ambient air temperature measured around the store

T_c Mains cold water temperature supplied to the system, $^\circ C$

T_D Hot water demand temperature recommended by BS 5918 ref. (60 $^\circ C$)

T_e Water exist temperature, $^\circ C$

T_i Water inlet temperature, $^\circ C$

T_m Mean plate operation temperature, $^\circ C$

T_S Water temperature in the storage tank, $^\circ C$

$\bar{T}_S$ Average water temperature inside the storage tank, $^\circ C$

T_{sf} Final water temperature inside the store after 48 hours, $^\circ C$

T_{si} Initial water temperature inside the store, $^\circ C$

U Collector heat loss coefficient, $W/m^2\ k$

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

Greek letters

δt	Length of day, seconds
Δt	Time increment for irradiance measurement, seconds
η	Derived value of collector efficiency for steady indoor conditions, dimensionless
η_o	Zero-loss collector efficiency, dimensionless
ξ	Collector Effectiveness, dimensionless
$\xi_{H.E}$	Effectiveness of a heat exchanger located in the collector-store loop, dimensionless

Chapter One

INTRODUCTION

1.1- General Idea About Project and Its Importance

A solar Domestic Hot Water (SDHW) system is one of the methods that used to test the thermal performance of solar system. this project based on selection of a solar systems that is locally a available. Which consist from collector, and storage tank. With a special properties. And this test is performed by two methods according the British and Palestinian instructions.

We compare between the results according to the British instruction and the result according to the Palestinian instruction. By doing three tests storage tank test, collector test and the performance test. But the tested collectors should be from the same type.

This method of test depends on sensors that measure many variables in solar collector and storage tank in (SDHW) system, these variables are: temperature of fluid inlet to the solar collector, temperature of fluid going out from the solar collector, storage tank temperature, ambient temperature, irradiance and flow rate of fluid that enter the solar collector. All sensors and measuring instruments will be connected to pre-programmed portable data recording systems that can be then connected to the computer for further processing.

By using the lab view program and the data of short term we calculate the yearly performance of the system. The program can perform these mains functions: calculate the heat loss coefficient of the storage tank, heat loss coefficient of the solar collector , energy enter to the solar collector. finally we will draw many charts for describing the solar domestic hot water efficiency.

Depending on the previous results, we compare between the results of the British instruction and the results of the Palestinian instruction to find which is better for using it. Then we give a certificate to the productive company for this system with a support from the research unit of energy.

1.2- Literature Review

The solar energy is a type of renewable energy which is used in many applications, because it is natural energy and available permanently, in the late 1970s different types of Solar Domestic Hot Water systems were developed throughout the world and has become the most common application of solar energy in world.

This project based on energy conversion criteria, natural renewable energy will be used to get thermal energy by solar collector systems.

Since the early 70th the interest for solar thermal energy and thus solar thermal collectors has been growing steadily world-wide. During this time, the knowledge and the measurement of the thermal performance of the individual solar collector designs, has played an important role in the development of better and more efficient components. Also already from the beginning, the testing of the thermal performance has been made according to test methods that requires something what's called "steady state conditions" for the collector, like e.g. in ASHRAE 93-77 (Society of Heating Refrigeration Air Conditioning Engineers) or the international standards ISO 9806-1 (glazed collectors) and ISO 9806-3 (unglazed collectors).

Testing under "steady-state conditions" today, means in practice, that a very simplified collector model describes the performance of the solar collector and that a number of experimental parameters are thus required to be stable or within certain limits during the test period.

The output results of the test is the thermal efficiency function of the collector and in practice it's thermal efficiency for operating temperatures measured in a solar Simulator or outdoors at noon and under clear sky conditions. In most climates, such operating conditions correspond to a very limited part of the service time of the collectors and therefore often give us too limited information to assess or predict their annual performance. This is especially valid for certain types of collectors. At the same time, the annual performance under given operating conditions is the final answer normally searched for.

Type's methods for test component of conventional systems (separate collectors, storage). Like as: The Solar Collector and System collecting Group (CSTG) of the European commission and the international energy agency (IEA) are each developing a test method for Solar Domestic Hot Water (SDHW) systems. The tow test methods enable long-term performance prediction to be based on short-term tests.

In ASHRAE 95 the SDHW system fall into one of three classifications, according to the relationship between solar collector and storage tank, these are:

1. **Integral Collector-Store System**

This system has its store within the collector which is directly exposed to the solar irradiance. In the integral collector storage solar system shown in Figure (1-1) at right, the hot water storage system is the collector. Coldwater flows progressively through the collector where it is heated by the sun. Hot water is drawn from the top, which is the hottest, and replacement water flows into the bottom. This system is simple because pumps and controllers are not required. On demand, cold water from the house flows into the collector and hot water from the collector flows to a standard hot water auxiliary tank within the house

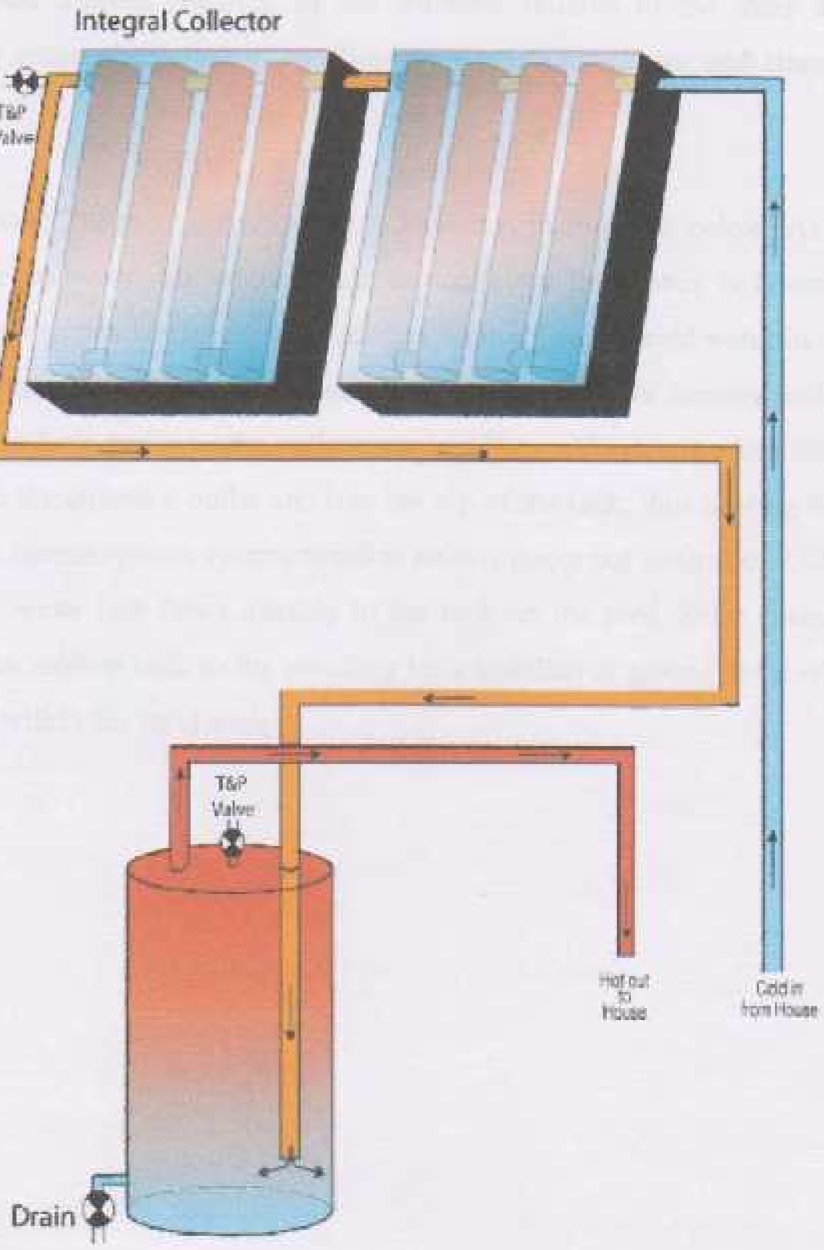


Figure (1.1): Integral Collector-Store System

2. Thermosyphon System

The thermosyphon system is a system which utilizes only the change in density of heat transfer medium in the collector relative to the store and heat exchanger to cause circulation of the fluid between the collector and store or heat exchanger.

A typical Thermosyphon system is indicated in Figure 6 below. As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it heats, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. Gravity then pulls heavier, cold water down from the tank and into the collector inlet. The cold water pushes the heated water through the collector outlet and into the top of the tank, thus heating the water in the tank. A thermosyphon system requires neither pump nor controller. Cold water from the city water line flows directly to the tank on the roof. Solar heated water flows from the rooftop tank to the auxiliary tank installed at ground level whenever water is used within the residence.

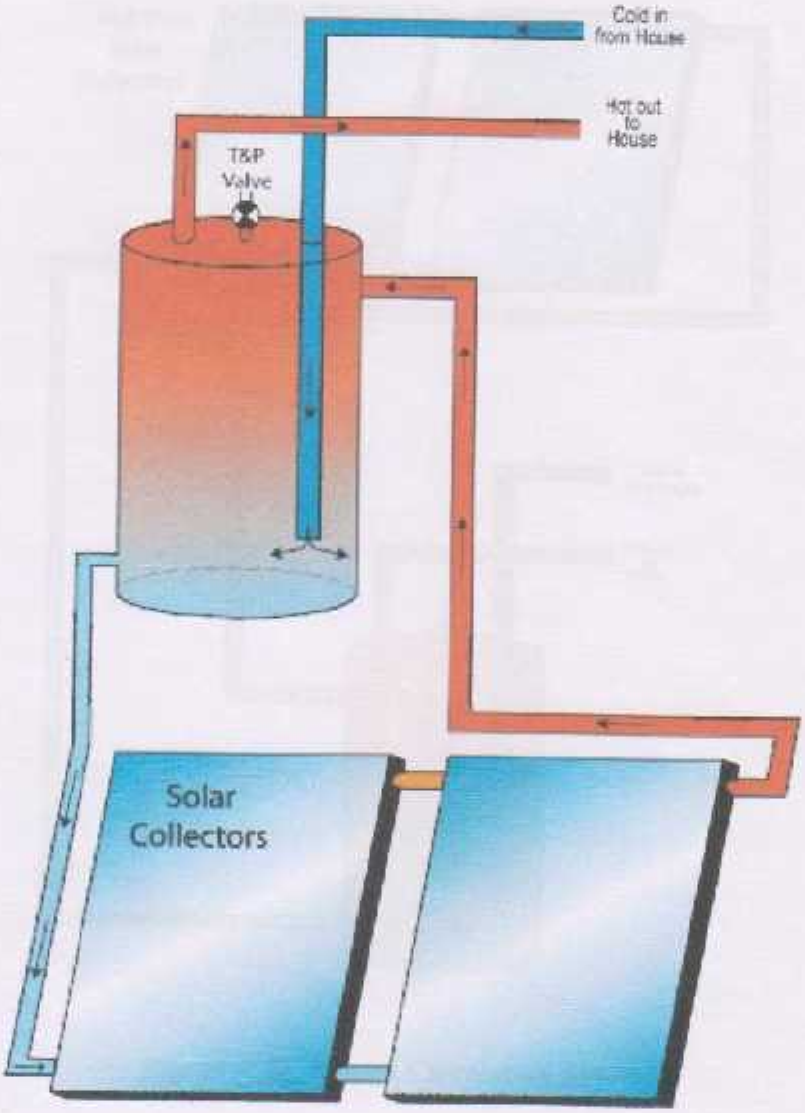


Figure (1.2): Thermosyphon System

3. Forced circulation system

This system utilizes mechanical means requiring external power to circulate the heat transfer medium through the collector.

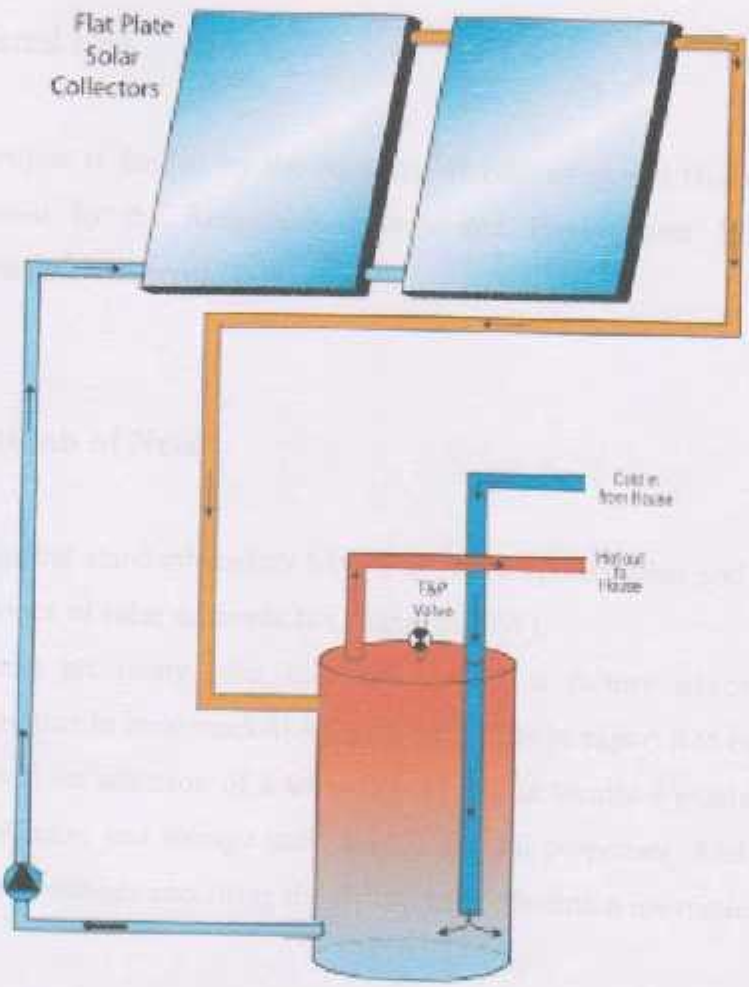


Figure (1.3): Forced Circulation System

The first two systems classified above are often referred to as passive system, since no external energy source is required, where as the third system is referred to as an active system, since some form of external energy is required.

1.3 - Estimated cost

This project is funded by the Ministry of Education and Higher Education and implemented by the Renewable Energy and Environment Research Unit (REERU). Parts and items cost 500$.

1.4 - Recognition of Need

Each global standard society have a standard specification and method for testing performance of solar domestic hot water (SDHW).

In Palestine there are many solar collector systems a factory which build and distribute this product in local markets widely and wishes to export it to outside.

This project based on selection of a solar system that is locally a available. Which consist from collector, and storage tank. With a special properties. And this test is performed by two methods according the British and Palestinian instructions.

Chapter Two

Methods of Performance Testing of SDHW Systems

2.1 - Introduction

As a result of the development of different types of SDHW system there exists a need to understand, predict and compare the performance of three systems from the local market , the behavior of SDHW system is rather complex. Although it consists of only a few components, there is a complicated interaction between them in response to the variation in irradiation and user demand.

These variation are specific to the geographical location and the life style of the user , so that it could not be expected that experience in other countries would be a reliable guide to system behavior in, for example, Britain . Moreover, if the behavior were sensitive to the variations in user demand, even between similar households, this might make it difficult to predict the performance for a given installation in more than general terms.

A number of simplified methods for predicting the SDHW systems performance became available in the second half of the 1970s. At the University of Wisconsin, klein, Beckman and duffie (1976) reported the f-chart method which based on many runs of the detailed simulation programms TRNSYS (klein et al. 1975). Beckman, klein and duffie (1977) presented the f- chart method in more detail in book form. Klein and backman (1979) described the further development of it into the Φ, f-chart method, by incorporating empirical correlation for the energy available to the collector, which has been obtained by klien (1978). The Φ, f-chart method was modified later by braun et al. (1982) that extended the method to include open loop systems in the prediction correlations. At the University Of Wale Collage Of Cardiff, brinkowrth (1978) derived a procedure for predicting the performance of an idealized system. In this procedure the store was assumed to be indefinitely large. Kenna (1981) used more realistic hour-by-houre model to identify a number of dimensionless parameters of the SDHW system. These parameters are used directly to calculate the solar fraction; the method was called the "SEU design method ".

In the European commission, the participants of the collector and system group (CSTG) developed a procedure for predicting the performance of the SDHW systems. The procedure was derived to cope with the weather conditions in northern Europe based on performing a number of short – term tests on the SDHW system. The data obtained from the tests are used in an Input/output, I/O, and correlation to identify several parameters. These parameters could then be used in the same correlation to predict the long-term performance using day-by-day calculations.

The international energy agency (IEA) has also developed a method for performance testing and long-term performance predictions of the SDHW systems.

The short term tests are based on ASHREA 95-1981 test procedure. As in the CSTG procedure, the data of the short term testing are supposed to be used in a number of correlations to identify several parameters which in turn may be used to predict the annual performance of the SDHW system.

2.2 - The CSTG Method

The short term testing in this project depend on CSTG method, equations of this method will be showed in chapter (3).

2.2.1 - CSTG and Participants of The CEC-Collector Short-Term Performance Testing

- **Background:**

A number of requirements have been defined by the participants of the CEC-collector and system testing group (CSTG) which lead to a method for testing SDHW systems. These requirements were:

1. The method should be applicable to all types of SDHW systems. This includes pumped circulation, thermosyphon systems, ICS (Integral collector-store Systems) , and systems employing two phase heat transfer (boiling/ condensation) collectors.

2. The method should be suitable for predicting the long- term performance in any European climate.

3. The test procedure should be suitable for outdoor and indoor use because of the unreliable European weather, and because a number of the European countries have an indoor testing facility. (But this project suitable for outdoor testing due to the good weather in Palestine).

4. The test procedure should be short and cheap.

Two approaches have been identified as being capable of meeting the above requirements. In the first approach the results of testing SDHW systems for a number of days can be used directly to predict the long-term performance in any operating conditions. In the second approach the system component parameters can be identified separately by performing a separate collector performance test, and separate dynamic test of the store.

2.3 - New Modeling Method In This Project

This project presents a new approach to solar collector testing, based on the present ASHRAE.

In this project we make a derivation of new equations modeling (long term performance prediction of SDHW systems) , which depends on short term performance testing according to the CSTG method these modeling contain the specific coefficients which are needed to be known in order to calculate and predict the performance of SDHW system.

To study a short term testing is done to get many parameters according to the outdoor testing circumstances, the solar collector and the storage tank in order to use these parameters in long term testing to calculate the performance of SDHW system. These parameters are measured by sensors, and then transferred by data logger system to portable computer. Where there is special programs which are created to process the parameter that where measured from the short term testing and calculate the performance of SDHW system.

2.4 - Measuring and Controlling Instrumentation In Project

A- Temperature Measurements

Four temperature measurements are required during testing.
These are:

1. Fluid inlet temperature to the system
2. Fluid temperature difference between the outlet and the inlet to the system
3. Storage tank temperature.
4. Ambient temperature.

The measurements were performed using platinum resistance thermometer (PRT) probes fitted in the correct places. The probe used to measure the store temperature was installed in place of anode protection bar through the storage tank end flange.

The ambient air temperature was measured using a PRT temperature transducer, fixed in a shelter and placed at the back of the storage tank, shaded from any solar radiation. The temperature difference between the fluid outlet and inlet from the system is measured directly by a thermometer.

B- Irradiance Measurements

A Pyranometer, used to measure the irradiance over the test plane. When measure irradiance; the Pyranometer should be put in different position over the test plane, and take many reading then take average of these readings to determine the mean irradiance.

C- Flow Rate Measurements

Measure the flow rate of water at inlet of the collector, which can be measured by Turbine Flow meter.

D- Temperature Regulation

The control of the fluid inlet temperature has been achieved by the Pumping System, with a digital motor speed control, to keep the inlet temperature constant in collector, and keeping constant input pressure.

E- Data Logger

All sensors and measuring instruments were connected to the data logger system, which consisted of a data reception device that takes the signal generated by the sensors and convert it to a suitable signal and transmit it to a computer, to use it in the program which calculates the coefficients to predict the performance of SDHW system.

Chapter Three

THERMAL ANALYSIS OF OUTDOOR ESTING

3.1- SDHW System Component Testing

3.1.1 - Storage tank heat loss testing

- **Testing Method:**

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

By assuming a fully mixed store losing heat to constant ambient temperature T_a, the store energy balance equation can be written as:

$$M_s \; C_p \;\; T_s^{\cdot} = UA_s \;\; (T_a - T_s) \quad \ldots\ldots (3.1)$$

Where:

M_s Mass of water inside the storage tank, kg

C_p Specific heat of water at constant pressure, kJ/kg C

$T_s^{\cdot}$ Average temperature of storage tank. °C

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

T_a Ambient air temperature, o C

T_s Water temperature in the storage tank, o C

Integrating equation (3.1) over the test duration (t hours) result in

$$T_{sf} = T_{si} + (1 - \exp(-\lambda t))(T_a - T_{si}) \qquad \text{............(3.2)}$$

Where

Tsf is the storage tank final temperature. o C

Tsi is the storage tank initial temperature. o C

And the value λ is:

$$\lambda = UA_S / M_S C_P \qquad \text{............(3.3)}$$

Equation (3.2) could be reduced to

$$1 - \exp(-\lambda t) = \frac{(T_{sf} - Tsi)}{(Tsf - Ta)} \qquad \text{............(3.4)}$$

Now we find the product of the surface area and heat loss coefficient of the storage tank as follow:

$$\text{Then } UA_S = \frac{-1}{t} M_S\ C_P\ \ln\left[1 - \frac{(T_{sf} - T_{si})}{(T_a - T_i)}\right]$$

t: time in second.

From SDHW System Program to taking place this result in table (3.1) and the diagram in figure (3.1).

• **Data of test:**

Table (3.1): data of storage tank test

T_{si} °C	T_{sf} °C	T_a °C	Duration (t)hours	UA_s W/K	M_s kg	C_p kJ/kg C
75.20	58.60	26.34	48	1.3462	127	4.18

t = 48 hours * 60 minute * 60 second =172800 second

T_a= average of ambient temperature for along time of test.

Note: the value of T_{si} and T_{sf}it is an average for the temperature values in the store tank

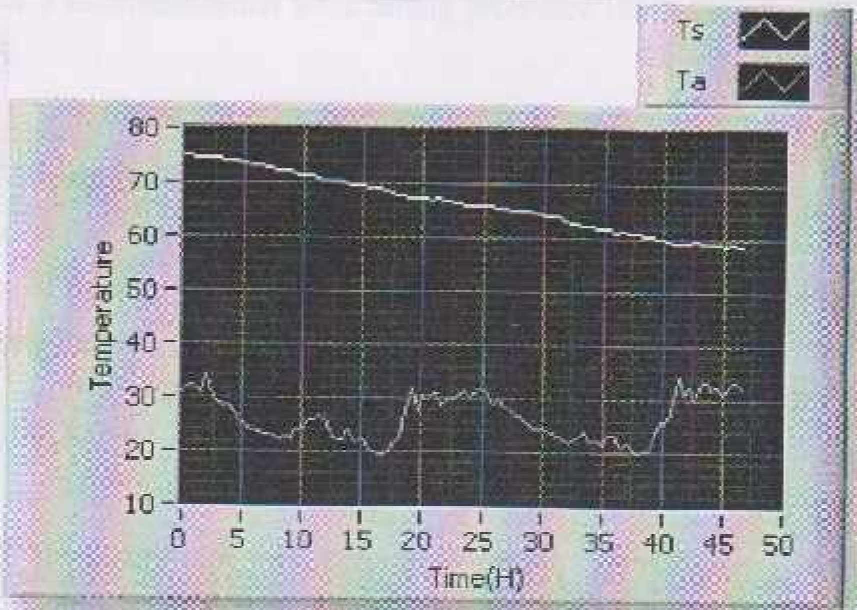


Figure (3.1): Store Temperature Diagram

Wight Line: value of temperatures in the store tank.

Read Line: value of ambient temperature.

3.1.2 Collector thermal performance testing

- **Testing method:**

The transient response of the thermosyphon collector and the change of the heat transfer fluid flow rate with the change in the incident irradiance, represent the difficulties associated with the development of a standard test procedure for testing thermal performance of a system. However, the method used to test collector operating with constant flow rate is the steady-state method. The method was first proposed by Hill and kausuda (1974), and it is published by ASHRAE standard (1974) and latter ANSI/ASHRAE 93-2003. The method has been adopted for use by the international energy (IEA) and the European commission (1980) working groups. Later the British standard institution has published the method in BS 6757: (1986) there was a recommendation for a testing procedure using the solar simulator was included.

The steady state testing method depends on measuring the instantaneous parameters of collector that should correspond the stationary conditions over a period of 15 to 20 minutes. A straight line presentation could then be plotted using the relationship:

$$\eta = \eta_o - U T^* \qquad \text{............ (3.6)}$$

Where:

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

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

$$T^* = (T_m - T_a)/G_T \qquad \text{............ (3.7)}$$

The mean plate operating temperature Tm is given by:

$$T_m = (Ti+Te)/2 \qquad \text{............ (3.8)}$$

Where:

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

T_i: Water inlet to collector temperature,°C

T_e: Water exist from collector temperature,°C

The slope U in the equation (3.6) represents the collector heat loss coefficient. The intercept with the Y axis η_o is the collector heat loss efficiency or the optical efficiency.

- **Energy of Collectors:**

The energy output of the collectors is calculated as:

$$\mathbf{Q_{out}} = m_c C_P (T_e - T_i) \qquad \text{........... (3.9)}$$

Where:

T_e : Water exist temperature, °C

T_i : Water inlet temperature, °C

$$\mathbf{Q_{in}} = G_T A_C \qquad \text{............ (3.10)}$$

Q_{in} : Energy input into the system, MJ

G_T : Equivalent normal solar irradiance on a collector plane, w/m2.

A_C : Aperture area of the collectors, m2

• **Energy collected by the two (in series) collectors:**

When tow collectors or more (the same type) are connected in series, by using the Duffie and backman correlations the new resulting parameters can be given as:

$$\eta_{O\,new} = \eta_o \left(1 - \frac{k}{2}\right) \quad \text{............ (3.11)}$$

$$U_{new} = U\left(1 - \frac{k}{2}\right) \quad \text{............ (3.12)}$$

Where k is given by:

$$k = \frac{UA_s}{m_c\ C_p} \quad \text{............ (3.13)}$$

The area of collectors (Ac) playing the method in new equations for multiple collectors in series.

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

Figure (3.2) the collector thermal performance testing, where it can be seen that all the steady-state points were fitted to the line. The stationary data points can be seen in table (3.2). And the Figure (3.3) from SDHW System Program.

Table (3.2) collector performance testing

$m_c = 0.0107\ kg/s$

Tm	ΔT	Ta	T*	η
°C	°C	°C	m2/w	%
33.65	23.7	23.5	0.0114	58.97
33.6	23.8	23	0.0118	58.66
33.55	23.9	23.5	0.0111	58.34
31.9	20.8	23	0.0099	51.23
31.8	21	23	0.0098	51.95
31.8	21	22.5	0.0104	52.14
30.99	19.58	22.7	0.0095	49.46
30.99	19.58	22	0.0102	49.36
30.84	19.88	21.8	0.0104	50.45
29.5	17.6	22.4	0.0083	45.68
29.65	17.3	22.2	0.0088	45.12
29.6	17.4	21.7	0.0097	47.44
26.8	12	21.3	0.0069	33.14
26.7	12.2	21	0.0074	34.93
26.6	12.4	21.3	0.0072	37.41
24.2	7.4	22	0.0030	22.51
24.1	7.6	22.3	0.0028	26.03
24	7.8	22.7	0.0021	27.95
22.75	5.3	22.6	0.0003	21.91
22.6	5.2	22.4	0.0004	23.25
22.05	4.5	22	0.0001	20.23
21.75	3.7	21.6	0.0003	16.52
21.55	4.1	21.2	0.0008	20.23
21.4	3.2	20.7	0.0017	17.65

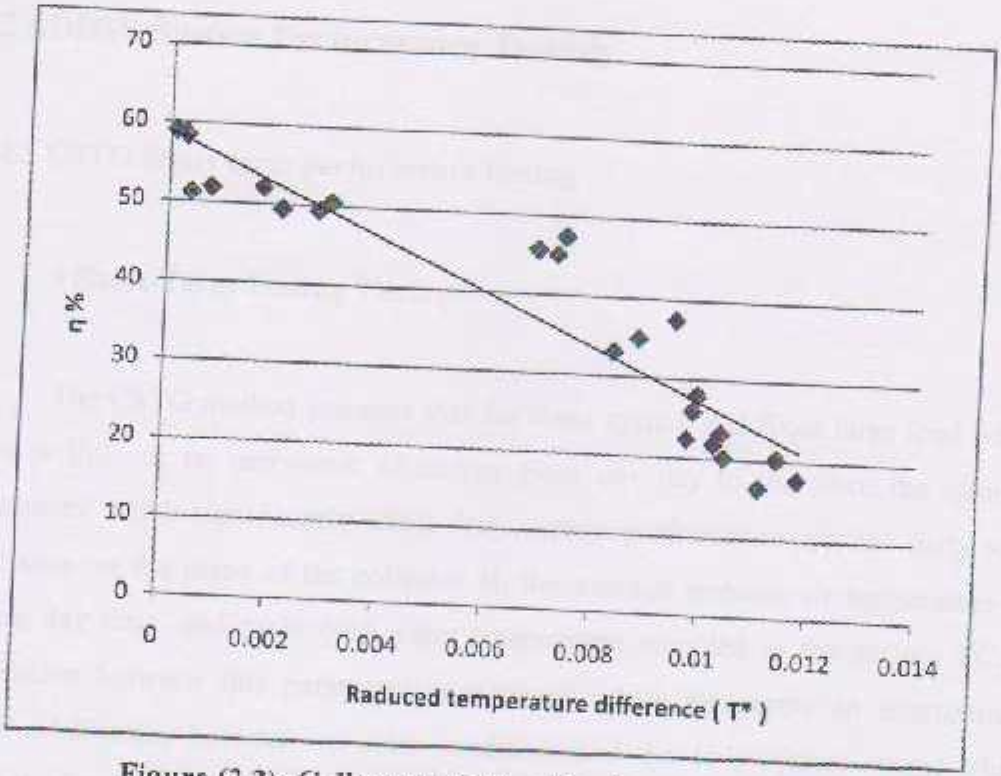


Figure (3.2): Collector Thermal Performance Testing

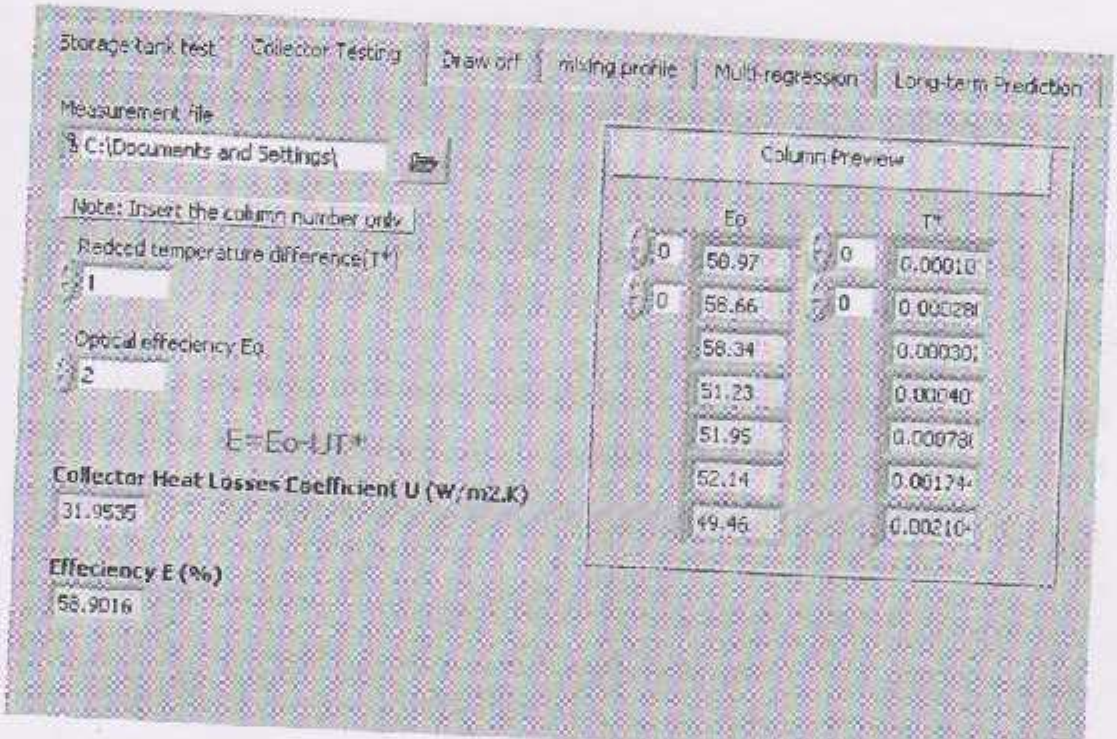


Figure (3.3) Collector testing part in SDHW system program

3.2 SDHW System Performance Testing

3.2.1 CSTG Short-term performance testing

- **Short-Term Testing Theory:**

The CSTG method assumes that for fixed system and fixed large load where there is little or no carry-over of energy from one day to the next, the climatic parameters which significantly affect daily system performance are: the daily solar irradiance on the plane of the collector H, the average ambient air temperature Ta during day time, and main cold water temperature supplied to the system TC. A correlation between this parameter is assumed which represents an approximate linear relationship between the solar irradiance and the daily system output which takes the form

$$Q_{out} = a_1 H + a_2(T_a - T_c) + a_3 \qquad \text{........... (3.14)}$$

The daily output Qout can be plotted versus the daily input in an "Input/output" diagram (I/O diagram).

The correlation expressed in equation (3.14) forms the basis of the test method where, from results of several tests employing different values of H, Ta and Tc, the values a1,a2 and a3 can be determined using a least-square fit method or any other regression method.

- **Outdoor Testing Procedures**

The test procedure carried out consists of one day tests which are independent of each other. For each test the system should first preconditioned bringing the store temperature to the mains cold water temperature. During that time the collector should be covered to ensure no heat gained by radiation. The circulation of water through the store will be stopped after ensuring that the temperature in the store is stopped after ensuring that the temperature in the store is uniformly distributed. The system is then charged by taking off the collectors' cover. Charging could be attained over a period starting from 11:00 LST until 03:00 LST.

Immediately after the charge phase a single draw-off of three times the store volume should be done ensuring that there was no carry over of energy to the next day. The test day should be repeated over several days (15days) to ensure different irradiance levels, ambient air temperature, and mains water temperature. The irradiance will be measured over the plane of the collectors during carrying out any set of tests. During the charge phase, hourly measurements will be performed for the ambient air temperature, and the store temperature. During draw-off from the system the temperature difference between the outlet and the inlet to the store, the store temperature inside the store will be recorded every 60 seconds.

- **Short_ Term Test Data and Analysis**

The CSTG method did not mention the optimum number of tests to be carried out. In our project three tests have been performed because of the time that prohibited more tests to be carried out. Every test used different irradiance from others, low irradiance, medium irradiance, and high irradiance. The following Tables (3.3), (3.4) and (3.5) contain the data of short term test, and every value (of Qout, H, and (Ta-Tc)) it is an average of 7 values, we taken the average for Accuracy.

Table (3.3) value of short term test (Low H)

Q_{out}	H	$T_a - T_c$
6.001	1.899	-2.571
5.914	3.71	-2.838
5.902	5.129	-3.026
5.896	6.627	-3.217
5.885	7.84	-3.449
5.868	8.755	-3.498
5.76	9.674	-3.657
5.296	9.179	-3.771
4.276	8.325	-3.721
3.078	8.106	-3.8
2.205	6.813	-3.899
1.682	5.311	-3.949
1.348	4.335	-4.065
1.059	3.201	-3.983
0.835	2.623	-4.087
0.63	1.988	-4.296
0.45	1.531	-4.269
0.337	1.017	-4.223
0.251	0.691	-4.201
0.191	0.392	-4.115
0.148	0.177	-3.434
0.108	0.723	-2.715
0.079	0.453	-2.106
0.051	0.201	-1.631
0.031	0.135	-1.321
0.017	0.14	-1.202
0.007	0.145	-1.161
0.005	0.149	-1.109
0.005	0.154	-0.943
0.01	0.163	-0.925

Table (3.4) value of short term test (Medium H)

Q_{out}	H	$T_a - T_c$
9.145	3.799	-2.309
9.122	7.416	-2.333
9.091	10.255	-2.399
9.066	13.257	-2.426
9.037	15.682	-2.607
8.963	17.512	-2.900
8.842	19.351	-3.003
8.552	18.360	-3.052
7.787	16.651	-3.174
6.306	16.208	-3.310
4.550	13.628	-3.462
3.217	10.620	-3.419
2.460	8.673	-3.421
1.845	6.400	-3.290
1.418	5.245	-3.380
1.049	3.974	-3.327
0.724	3.064	-2.960
0.522	2.035	-2.953
0.369	1.380	-2.866
0.260	0.784	-2.686
0.182	0.352	-2.289
0.124	1.448	-2.153
0.087	0.901	-2.080
0.057	0.402	-2.195
0.040	0.269	-2.182
0.025	0.280	-2.160
0.018	0.291	-2.231
0.015	0.302	-2.131
0.013	0.313	-1.855
0.008	0.323	-1.918

Table (3.5) value of short term test (High H)

Q_{cut}	H	$T_a - T_c$
4.816	5.698	-4.290
9.424	11.130	-5.980
14.064	15.386	-6.292
18.624	19.880	-6.500
23.168	23.520	-6.591
27.040	26.264	-6.760
29.888	29.022	-6.916
28.352	27.538	-6.981
25.712	24.976	-6.955
25.040	24.318	-6.942
19.152	20.440	-6.812
14.560	15.932	-6.604
11.888	13.006	-6.097
8.128	9.604	-5.876
6.656	7.868	-5.707
5.040	5.964	-5.551
3.616	4.592	-5.226
2.400	3.052	-4.732
1.472	2.072	-4.524
0.832	1.176	-4.446
0.384	0.532	-4.394
1.712	2.170	-4.524
0.960	1.358	-4.446
0.432	0.602	-4.394
0.288	0.406	-4.719
0.304	0.420	-4.524
0.304	0.434	-4.615
0.320	0.448	-4.420
0.336	0.462	-4.316
0.352	0.490	-4.368

To find coefficient a_1, **a2, and** a_3 in equation (3.14) we must substitute the values of last table (3.6) form used SDHW System Program.

Table (3.6) the value of a1, a2 and a3 parameters

Cases	a1 m^2	a2 $MJ/K.day$	a3 MJ/day
Low H	0.3252	0.6452	0.9574
Med	2.603	0.6004	6.4255
High H	1.4653	1.1645	5.9466

This table will be used in the long term performance test

- **Draw off profile**

The performance of any SDHW system is dependant on the internal operation of its component .One of the most information parts of the SDHW system is the storage tank. During extraction of energy the type of the store is dependant on the flow rate. The Stratification will decrease with increase in the flow rate through the store due to increase in mixing between mains cold water interring the store and the hot water inside the store.

- **Draw off profile Test Analysis**

The SDHW system showed its horizontal storage tank tends to fully mixed during the charge phase and during extraction of energy the store appease in energy input, Figure (3.4), (3.5) and (3.6) represent the draw-off profile as a function in the irradiance H. The discharged heat Q_{out} is proportional to the area under the curve. Figure (3.7) is a plot for different draw-off profilers.

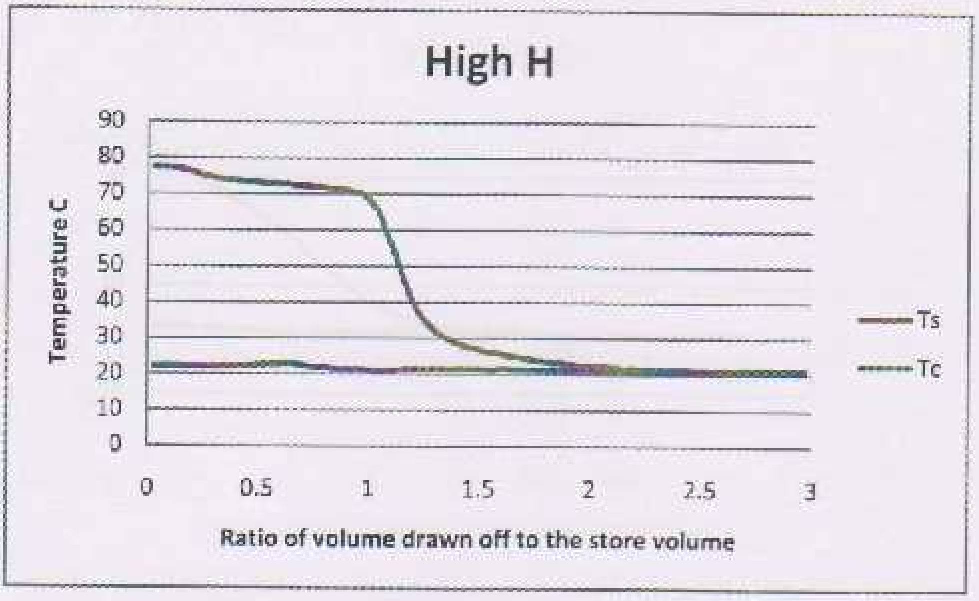


Figure (3.4): Draw-off Profile for High H

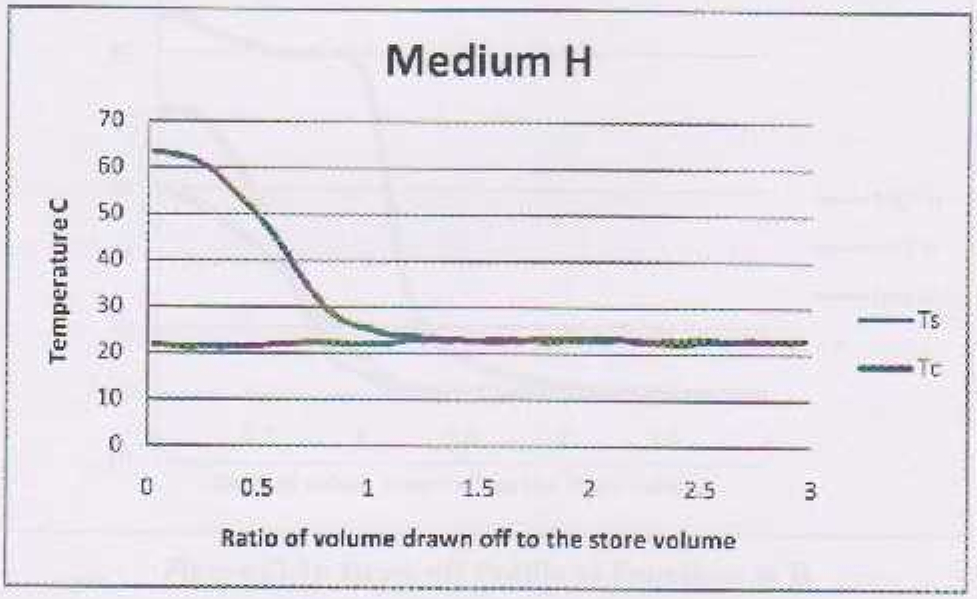


Figure (3.5): Draw-off Profile for Medium H

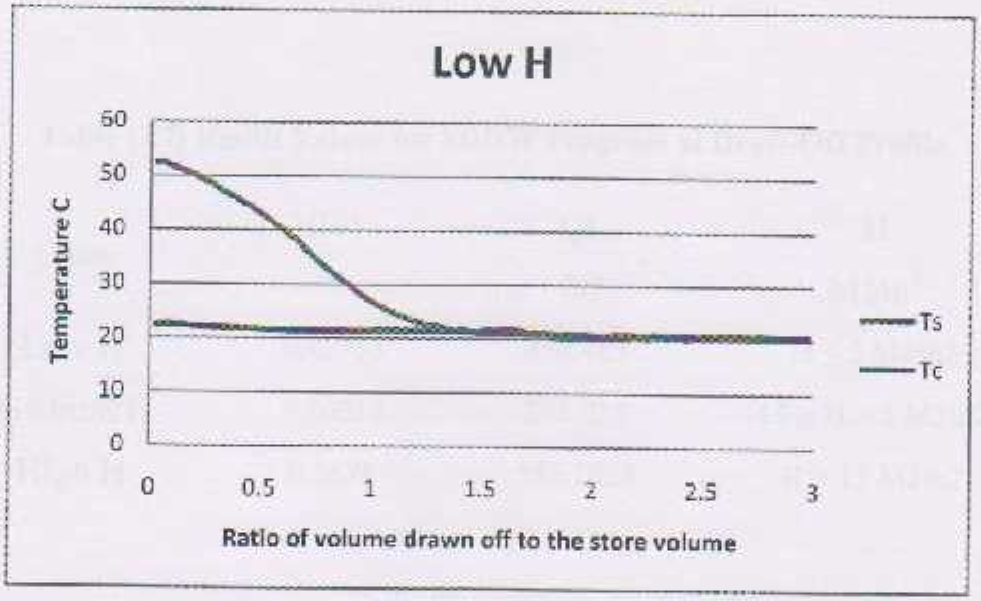


Figure (3.6): Draw-off Profile for Low H

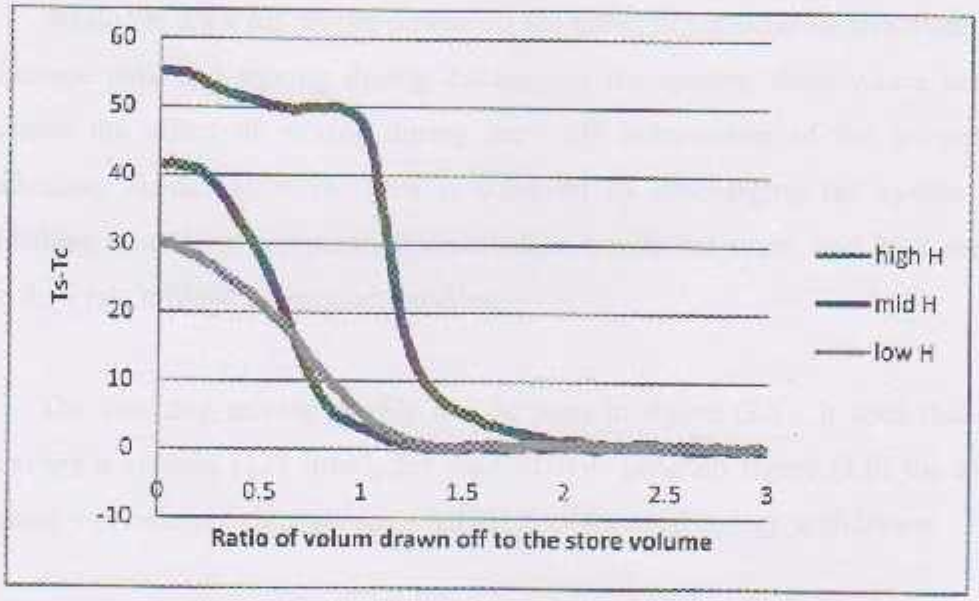


Figure (3.7): Draw-off Profile as Functions in H

On this test we are used the SDHW system program to plot the different draw off profile on multi periods to determine the total energy of the storage tank and the value of the f (v) for reference consumption volume. This values found in table (3.7).

Table (3.7) Result Values for SDHW Program at Draw-Off Profile

Cases	f(v)	Qt *MJ*	H MJ/m^2
Low H	0.45755	459.483	$H \leq 5$ MJ/m2
Medium H	0.50038	273.035	$15 \geq H > 5$ MJ/m2
High H	0.5678	155.1923	$H > 15$ MJ/m2

- **Mixing profile**

While the draw off profile represents the effect of temperature stratification in the storage tank and mixing during discharging the system, there was a need to determine the effect of mixing during draw off independent of the temperature stratification inside the store. This is achieved by discharging the system after establishing a uniform temperature distribution inside the store, and by using the same flow rate utilized in draw off profiles.

The resulting mixing profile can be seen in figure (3.8). It seen that after consuming a volume (127 litter), for used SDHW program figure (3.9) the energy extracted will be approximately ($g_v = 0.30617$) of the total energy withdrawn.

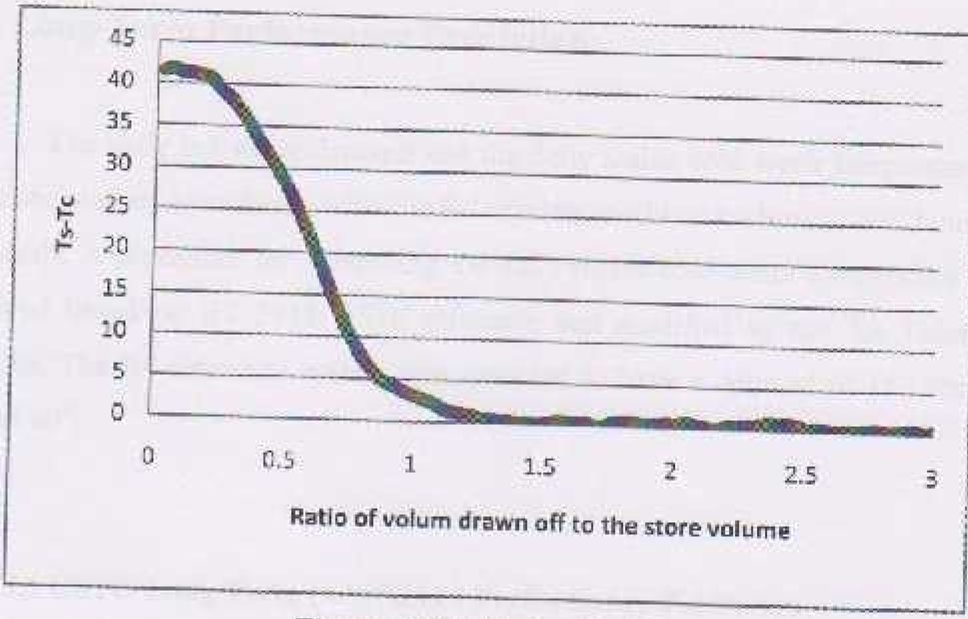


Figure (3.8): Mixing Profile

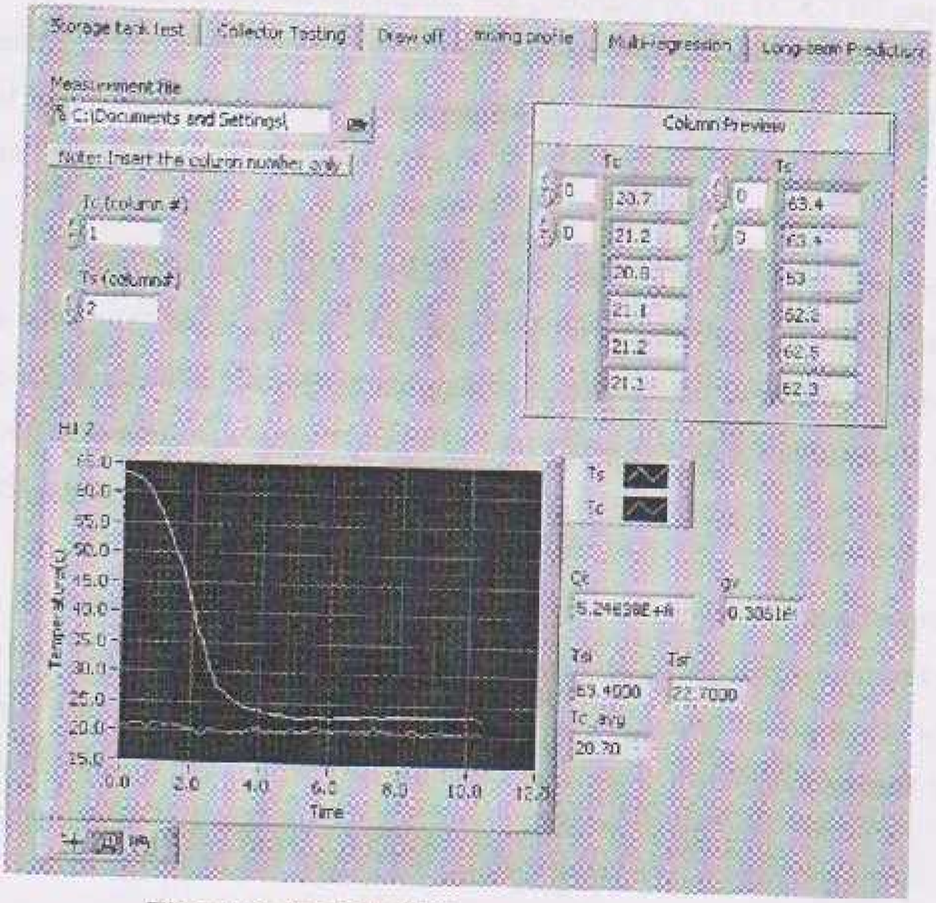


Figure (3.8): SDHW Program Mixing Profile

3.3 Long-Term Performance Prediction

The daily hot water demand and the daily mains cold water temperature will be calculated in accordance with the Palestinian conditions, climatic and household demands. A procedure for computing the daily mains cold water temperature might be used based on BS 5918: 1980 reference and modified to suit the Palestinian climate. The BS reference system was assumed to have a demand of 150 liters per day at 60°.

3.3.1 CSTG Long Term (ANNUAL) Performance Prediction

The method of annual calculation was published by the EC-CSTG group uses the results of the short-term test to produce useful information on the monthly and annual solar energy output from the system for any climatic condition and load demand.

A day-by-day calculation procedure was adopted, in which the performance of the system is calculated for each day using the climatic data for each day, and taking into account any energy in the system is carried over from the previous day. The long-term performance is calculated by assuming the performance of the system for each day in the period under consideration.

The method assumes that if the water in the storage tank is at a temperature higher than the cold water temperature at the beginning of the day, due to carry-over of energy from the previous day, this energy is equally spread over the tank volume at start of the next day (i.e. the storage tank is always in a fully mixed state with a uniform temperature at the start of each day).

The total energy captured by the first operating day is given by the I\0 diagram. The draw-off temperature profile enables the division of this amount of energy into useful energy extracted during draw-off and energy carried over.

The energy remaining in the storage tank will partly be lost overnight due to heat losses , and will force the system to start the next morning at a temperature higher than the cold supply temperature. At this stage, and for each of following days, the assumption mentioned before is made so that the energy is uniformly distributed over the store, leading to a uniform temperature at the beginning of the next day.

At the end of the second day and all the following days the system output can be calculated using the morning store temperature. A division is made in used and remaining energy using the draw-off profile. This energy output represent only a part of the total energy output, as the system refilled with water at temperature T_c and not the morning store temperature. The division of the second part of the extracted and remaining energies is made based on the mixing-profile.

3.3.2 Input Data Used in Long-Term prediction procedure the long-term performance calculation used the following input data

- **Short-Term Test Data**

1. I\0 diagram

The results of the indoor short-term test presented in the I\0 diagrams as a performance parameters a_1-a_3 used in the I\0 correlation:

$$Q_{out}(3v) = Q_{out} = a_1 H + a_2 (T_a - T_c) + a_3 \qquad \text{............ (3.15)}$$

Q_{out} (3v) represent all energy available in the storage tank volume which can be extracted by a large draw-off (three times the store volume).

2. Draw-off profile

The draw-off temperature profile expressed as a function of volume, f(v), and normalized so that the area under the draw-off profile will be fined. A Simpson method will be used to determine the value f(v) for the reference consumption volume.

As the value is an irradiance dependent one, f (v) will be calculated as a function of H. (see section 3.2.1)

3. Mixing profile

The mixing draw-off profile expressed as a function of volume and normalized so that the area under the profile will be fined. The function g (v) could be calculated using e.g. Simpson method when discharging the average daily consumed hot water amount (see section 3.2.1).

4. Component performance parameters

The store heat loss coefficient calculated from store thermal testing will be used. The value will be calculated as in section 3.1.1.

- **Climatic Data:**

1. The hourly global and diffuse irradiance for the period July 1, 2007 to July 1, 2007 will be used. The data were collected by the Weather Station Laboratory of the Renewable Energy and Environment Research Unit.
2. The average daily and overnight ambient air temperature for the same period.

• **Demand data:**

1. A fixed daily demand load
2. Daily demand temperature of 50° C.
3. The daily mains cold water temperature.

3.3.3 Prediction procedure

The conditions for day 1 can be expressed as:

Irradiance = H_T (1).

Daily ambient temperature = T_a (1).

Over night ambient temperature = T_{an} (1).

Mains cold water temperature =T_C (1).

Draw-off mass = M_L kg.

The system begins the day at the system at 6 hours after temperature T_C (1). And a draw –off of M_L is performed at six hours after solar noon.

Step1: energy available:

The total energy contained in the system at 6 hours after solar noon, Q_c is calculated using the I/0 correlation,

Where:

$T_a = T_a(1)$, $Tc = Tc(1)$, and $H = H_T(1)$:

$$Qc(1) = a1\ HT(1) + a2\ (Ta(1) - Tc(1)) + a3 \quad \text{..........} (3.16)$$

Step2: energy drawn off

The energy contained in a draw-off of M_L, as opposed to the total energy contained in the system, is calculated using the function f (v)

$$Q_{out}(1) = Q_C(1) * f(v) \quad \text{..........} (3.17)$$

Step 3: energy left in the storage tank

The energy remaining Q_R can be calculated as

$$Q_R(1) = Qc(1) - Q_{out}(1) \qquad \text{............ (3.18)}$$

Step 4: energy lost over night

The method did not include how to calculate overnight energy loss. The form used in the calculation is:

$$Q_{loss}(1) = UA_s(\ddot{T}_s(1) - T_{an}(1)) \ (24\text{-}d1(1)) \ 0.0036 \ \ (MJ) \qquad \text{............ (3.19)}$$

The value dl (1) is the daylight hours, expressed as

$$dl = 24\frac{w_s}{\pi} \qquad \text{............ (3.20)}$$

Where W_s is the sunset hour calculated as in Duffie and Beckman (1990)

The average storage tank temperature is calculated as:

$$\ddot{T}(1) = T_c(1) + \frac{Q_{out}}{M_L C_P} \qquad \text{............ (3.21)}$$

It is then assumed in CSTG procedure. That by the morning the store has returned to a fully mixed state and the water is at a uniform temperature T_S (2), which takes the form:

$$T_s(2) = T_c(1) + \left\{\frac{Q_R(1) - Q_{loss}(1)}{C_s}\right\} \qquad \text{............ (3.22)}$$

Where C_s is the storage tank heat capacity which can be calculated as

$$Cs = M_S \, C_P \qquad \text{............ (3.23)}$$

Step 5: demand load and solar fraction

The demand load Q_l is calculated for a fixed demand temperature T_D equal to 50C.

$$Q_L(1) = M_L C_p (T_D - T_C(1)) \quad \text{............(3.24)}$$

The daily solar fraction f_d takes the form

$$fd = \left\{ \frac{Qout(1)}{Q_L(1)} \right\} \quad \text{............ (3.25)}$$

The conditions for day 2 are:

Irradiance $= H_T\,(2)$

Daily ambient temperature $= T_a\,(2)$

Overnight ambient temperature $= T_C\,(2)$

Mains cold water temperature $= T_C\,(2)$

The same draw-off mass $= M_L = 150$ kg

The system starts the day at a temperature $T_s\,(2)$ as calculated in step for of day 1

Step 1: energy available:

(a) One part of the energy available is that which would have been collected if the system had been refilled with water at the initial temperature $T_s\,(2)$. This is calculated using equation (3.39) With

Ta = Ta (2), Tc=Tc (2), and H= HT(2)

$$QC.P1\,(2) = a1\,HT\,(2) + a2\,(Ta\,(2) - TS(2)) + a3 \quad \text{............ (3.26)}$$

(b) One part of the energy available is that which would have been collected if the system is refilled with water at T_c (2) which is lower than $T_s(2)$. This is given by the product of the storage tank mass ms and the difference between T_s (2) and T_c (2)

$$Qc.p2\,(2) = Ms\,Cp\,(Ts\,(2) - Tc\,(2)) \quad \text{............ (3.27)}$$

The subscripts p1 and p2 represent parts 1 and 2 respectively

Step 2: energy drawn-off:

(a) One part of the energy contained in the drawn-off mass M_L, as opposed to the first part of the total energy available, $Q_{c.pl(2)}$ is calculated using the function f (v)

Qout.pl (2) = Q c.1 (2) * f (v) .... (3.28)

(b) The proportion of the carried over energy which is extracted in the consumption mass ml is calculated by using the mixing profile

Qout.p2 (2) = Qc.2 (2) * g (v) .... (3.29)

(c) The total energy extracted:

Qout (2) = Qout..p1 (2) + Qout.p2 (2) .... (3.30)

Step 3: energy left in the storage tank:

(a) Energy left due to the first part of total and contain energies:

QR.pl (2) = Qc.pl (2) – Qout.pl (2) .... (3.31)

(b) The proportion of the carried over energy which is left in the store

QR.p2 (2) = Qc.p2 (2) - Qout.p2 (2) .... (3.32)

(c) Total energy left in the store at the end of the second day:

QR (2) = QR.p1 (2) + QR.p2 (2) .... (3.33)

Step 4: energy lost overnight:

As for day 1, the lost energy takes the form

$$Q_{loss}(2) = UA_s(\dddot{T}_s(2) - T_{an}(2))\,(24 - d1(2))\,0.0036 \quad \{MJ\}$$ .... (3.34)

And

$$\dddot{T}_s(2) = T_c(2) + \frac{Q_{out}(2)}{M_L C_P}$$ .... (3.35)

The store morning temperature is:

$$T_s(3) = T_c(2) + \frac{Q_R(2) - Q_{loss}}{C_S}$$

.... (3.36)

Step 5: demand load

$$Q_L(2) = M_L\ C_p(T_D - T_c(2))$$

.... (3.37)

The solar fraction for day 2 is:

$$f_d = \frac{Q_{out}(2)}{Q_L(2)}$$

.... (3.38)

The procedure can be continued by starting again at step 1 of day for each month, the solar fraction can be calculated as

$$f_m = \frac{\sum^{N}_{DAY=1} Q_{out}(DAY)}{\sum^{N}_{DAY=1} Q_{out}(DAY)}$$

.... (3.39)

The summation is made over the number of days, N, in the month.

The yearly solar contribution is calculated by assuming the values over the 12 months in the year:

$$f = \frac{\sum^{12}_{MONTH} Q_{out}(MONTH)}{\sum^{12}_{MONTH} Q_L(MONTH)}$$

.... (3.40)

- **Long- term results**

The resultants of the annual performance prediction using the CSTG method lasted in table (3.8) . The monthly solar fractions and system output are seen in tabls(3.9),(3.10),and (3.11) .

The same coiffecents a_1,a_2,and a_3 lasted in table (3.6) Where used in the prediction procedure. The annual delivered energy Q_{out} , which is the sum of the daily delivered energy , was calculated using affixed demand volum of 150 litters, and a demand temperature of 50°C .

Table (3.8) results of the annual performance prediction using CSTG method

GSTG parameters		Solar fraction f_m %	Energy output Q_{out} KWh	Energy delivered QL KWh
1	a1= 0.253 a2=0.542 a3=0.837	9.63535	293.95	3050.7
2	a1=1.201 a2=1.011 a3=5.203	42.96	1310.53	3050.7
3	a1=2.004 a2=0.536 a3=5.623	57.1482	1743	3050.7

Table (3.9) Monthly Solar Contribution using the CSTG procedure
CSTG parameters a_1=0.3252, a_2=0.6452, a_3=0.9574

GSTG parameters	Solar fraction fm %	Energy output Qout KWh	Energy delivered QL KWh
Jan	3.89401	11.6211	298.43
Feb	5.22078	13.3872	256.41
Mar	7.9453	20.8988	363.42
Apr	8.4494	19.6692	232.79
May	14.2876	31.8739	223.09
Jun	15.4944	32.279	208.34
Jul	14.7412	32.279	219.3
Aug	15.4081	36.1046	234.32
Sep	13.5018	33.43	247.6
Oct	9.5566	26.5933	278.27
Nov	6.81876	19.5049	286.05
Dec	5.3638	16.2555	303.06
Annual	9.6354	293.95	3050.7

Table (3.10) Monthly Solar Contribution using the CSTG procedure
CSTG parameters a_1=1.4653, a_2=1.1645, a_3=5.9466

GSTG parameters	solar fraction fm %	Energy output Qout KWh	Energy delivered QL KWh
Jan	20.674	61.6987	298.43
Feb	26.8786	68.9225	256.41
Mar	39.1549	102.99	363.42
Apr	41.913	97.5684	232.79
May	64.973	144.995	223.09
Jun	68.1597	141.995	208.34
Jul	64.5153	141.484	219.3
Aug	63.3904	148.538	234.32
Sep	54.1309	134.026	247.6
Oct	38.5502	107.274	278.27
Nov	29.5122	84.4188	286.05
Dec	25.2971	76.6657	303.06
Annual	42.9583	1310.53	3050.7

Table (3.11) Monthly Solar Contribution using the CSTG procedure

CSTG parameters a_1=2.003, a_2=0.6004, a_3=6.4255

GSTG parameters	solar fraction fm %	Energy output Qout KWh	Energy delivered QL KWh
Jan	28.8481	86.0932	298.43
Feb	37.3112	95.6783	256.41
Mar	53.9452	141.894	363.42
Apr	57.8748	134.726	232.79
May	87.5099	195.223	223.09
Jun	90.6406	188.829	208.34
Jul	85.5986	187.721	219.3
Aug	81.9816	192.102	234.32
Sep	69.1035	171.098	247.6
Oct	49.1047	136.644	278.27
Nov	38.5489	110.268	286.05
Dec	34.0352	103.148	303.06
Annual	57.1482	1743	3050.7

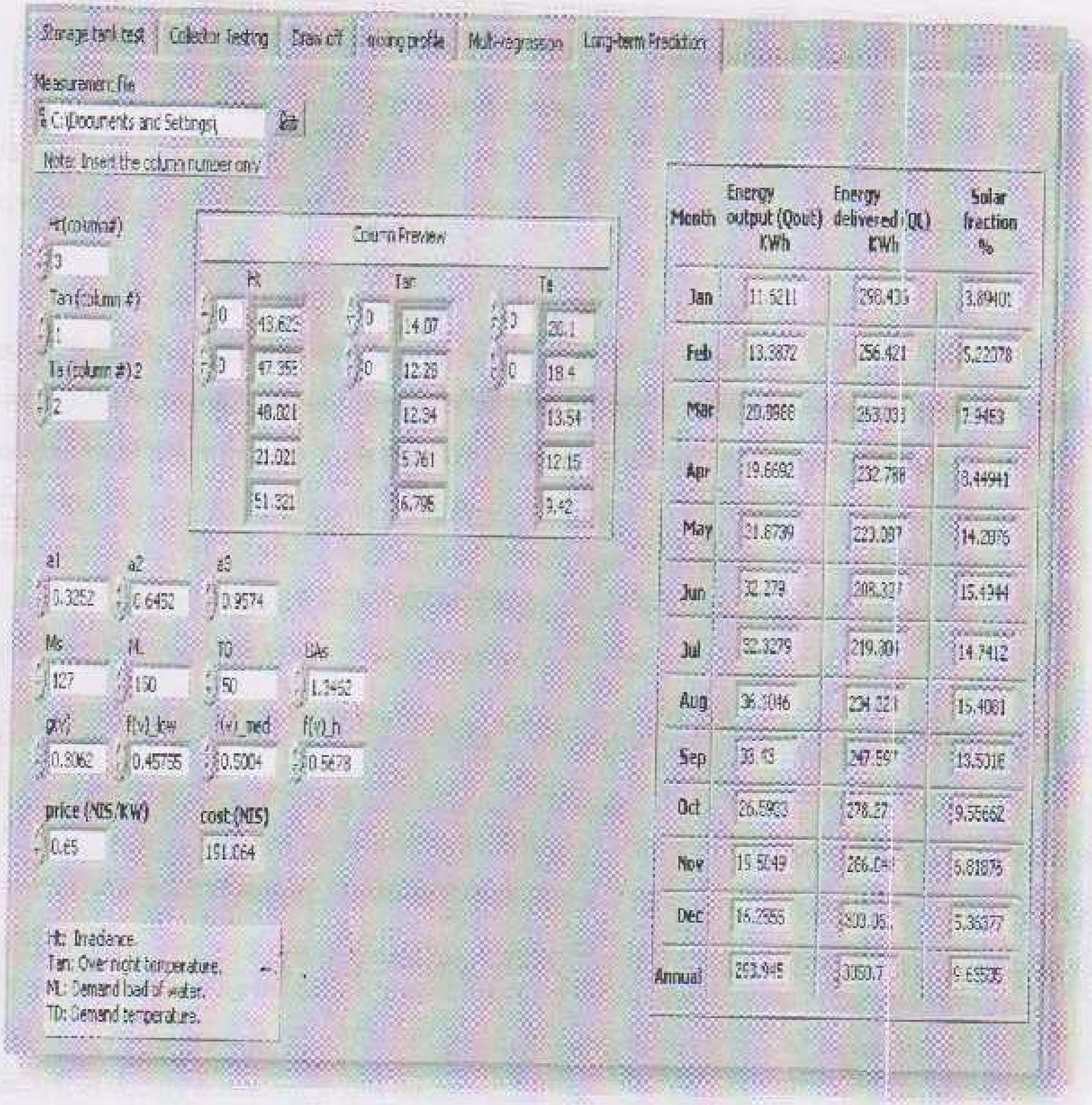


Figure (3.9): SDHW Program long terms.

- **Conclusion**

It was seen that estimated long-term system performance using the CSTG day-by-day predicton procedure is sensitive to the change in parametar a_1,a_2,and $a_3$which depend on the leved of irradiance (low, medium or high) in draw-off profile.

In the tables (3.9),(3.10),and (3.11) the energy output and the solar fraction are different from table to another due to the change in parameters a_1,a_2,and a_3,in table (3.9)the annually energy output is 293.95 kWh(sum of energy output for 12 months) and Solar fraction f_m is 9.63535 (Avareg of Solar fraction for 12 months) are grater that energy output and Solar fraction of table (3.10)and(3.11) because the parameter a_1,a_2,and a_3 where used in long-term system performance were calculated from short term test when the irradiance is high . and the same comparison between table (3.10)and table (3.11).

3.3.4 Solar Domestic Hot Water System Economics

- **Amount of money saved by this system**

It was seen from using the annual performance by the SDHW System program there amount of energy output from SDHW system are useful, and it can be calculated of this output energy according to this equation:

Cost of the energy output from SDHW system annually = Q_{out} (kWh) * Price

The cost of energy output in last three cases (see long-term results) are summered in table (3.12), and the price =0.65 NIS/kW

Table (3.12) Cost of energy extracted from SDHW

	GSTG parameters	cost of energy NIS	Energy output Qout KWh
1	a1= 0.253 a2=0.542 a3=0.837	191.06	293.95
2	a1=1.201 a2=1.011 a3=5.203	851.8	1310.53
3	a1=2.003 a2=0.6004 a3=6.9466	1133.2	1743

- **Payback period procedure**

When contemplating the use of solar energy for heating water , the way the process can be selected to determine the economic feasibility is compared to the cost of the solar system with the amount provided that the system of electricity or fuel. In spite of our solar energy without costly but the cost of such systems by receiving solar radiation and convert it into useful energy is sometimes high. The intended period of recovery time required to recover the investment cost of the project. It can be calculated payback period by the following relationship.

$$Rp = \frac{Capital\ cost}{Energy\ saving}$$

Rp : Payback period (year)
Capital cost : Cost of SDHW system in (NIS)

Energy saving : Energy output when use SDHW system (NIS/ year)

As we see this method is characterized by the simplicity and speed of decision-making. It is a good demonstration of how cash for the project. However, this method dose not takes into account the lifetime value of the project after the recovery period. But most solar heating system manufactured in Palestine production and effectiveness of a fairly large and can say here that the average life of these systems at least 20 years.

The capital cost of SDHW system in Palestine is 2000 NIS and the energy saving 1133.2 NIS/year then:

$$Rp = \frac{2500\ NIS}{1133.2\ \text{NIS/year}} = 2.21\ year$$

After this period the user of SDHW system will using the system at last 15 year.

Chapter Four

PROJECTS COMPONENTS AND ARCHETICTURAL DESIGN

4.1 - Introduction

In this project several components are used which return to SDHW system and for equipment testing.

4.2 - Solar Thermal Systems

The solar thermal system is used frequently in the world in two branches in industrial and in Solar Domestic Hot Water system. Process hot water, Hot air and Process steam.

➔ Types of Solar Domestic Hot Water Systems

There is a dazzling array of domestic hot water system designs. For the most part, however, they are broken into three groups depending on the following two characteristics.

- **Direct (Open Loop)**

The water being heated is the water you drink.

- **Indirect (Closed Loop)**

A heat exchanger is used to transfer heat from a collector fluid to water you used. Potable water never mixes with the heat exchange fluid. The heat exchange fluid varies, depending on the type of system, from plain water to propylene glycol.

- **Passive Solar Heating**

Using absorptive structures with no moving parts to gather and hold heat. Just as the name implies, passive solar heating allows the sun to do all the work. That is, there is no additional mechanical assistance.

- **Active solar heating**

Active solar heating uses concepts similar to passive solar heating. However, active solar takes the power of the sun and amplifies it. Using specially designed mechanical systems, active solar heating can generate much more heat for space heating and hot water than passive solar alone.

Different combinations of these two characteristics result in the following three major classifications of solar domestic hot water systems.

1) Direct (Open Loop) Active
2) Direct (Open Loop) Passive
3) Indirect (Closed Loop) Active

Solar collectors are at the heart of most active-solar energy systems. The collector absorbs the sun's light energy and changes it into heat energy. This thermal energy can then be used to provide heated water for residential or commercial use, to provide space heating or cooling, or for many other applications in which fossil fuels might otherwise be used.

There are two basic types of active-solar heating systems, depending on whether air or a liquid is heated in the solar collector. A liquid-based system heats water or an antifreeze solution in a "hydraulic" collector, and an air-based system heats air in an "air collector."

Both of these systems collect and absorb solar radiation, then transfer the solar heat directly to the interior space or to a storage system, from which the heat is distributed. If the system cannot provide adequate space heating, an auxiliary or back-up system provides the additional heat. Liquid-based systems are more often used when storage is included.

In an active-solar water heating system, heated water is moved through the system with the aid of pumps, which increases the system's efficiency.

4.3 - SDHW System component

SDHW system contains basic component which used to heating water and keeping it, Basic elements are: Solar collector and tank.

A solar collector is a device for extracting the energy of the sun directly into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar energy striking the earth's surface at any one time depends on weather conditions, as well as location and orientation of the surface, but overall, it averages about 1000 watts per square meter on a clear day with the surface directly perpendicular to the sun's rays

Solar energy collector is the most important component of any solar energy utilization device. Different types of collectors and systems are used in process heat industries. Due to the needs and opportunities several types can be use. Here are some of them.

Many types of solar collector are use in the world, but in this project we apply the method testing one type (flat plate type).

The famous type of solar collectors is:

A. Flat-plate
B. Compound Parabolic Concentrator (CPC)
C. Evacuated Tubular Collectors
D. Parabolic Through Collectors
E. Solar Ponds

Flat-plate

Flat-plate collectors are characterized by durability, dependability, simplicity, and high solar collector efficiency. At low temperatures, the flat-plate collectors operate at high optical and thermal efficiency compared to concentrators. However, as the collection temperature goes on increasing, the efficiency of a concentrator decreases very slowly while the flat plate collector efficiency decreases very fast.

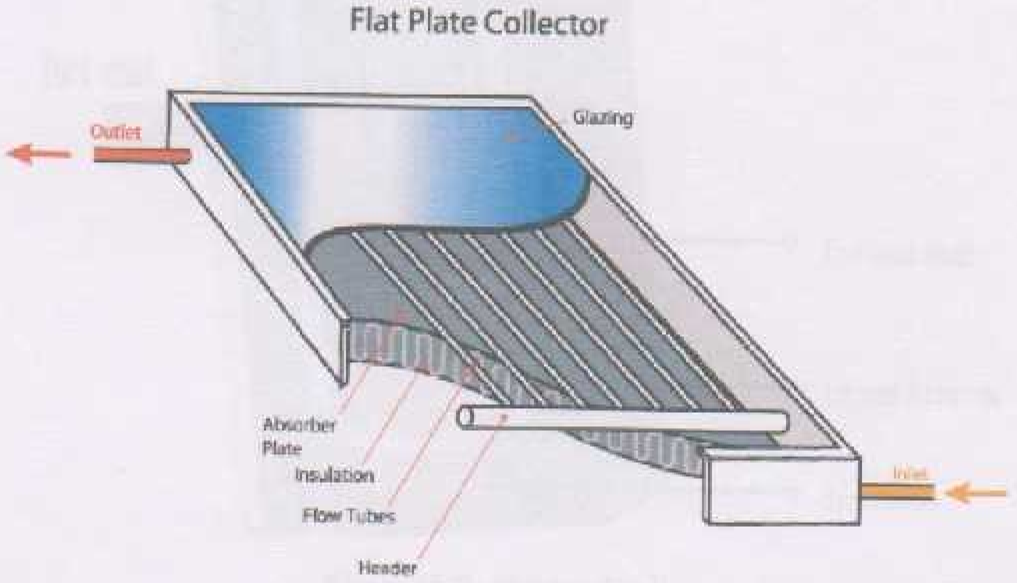


Figure (4.1): Flat - Plate Collector

Storage tank

A storage tank is required to store the heat collected duringthe day for later use. the storage tank home's existing water heater tank.

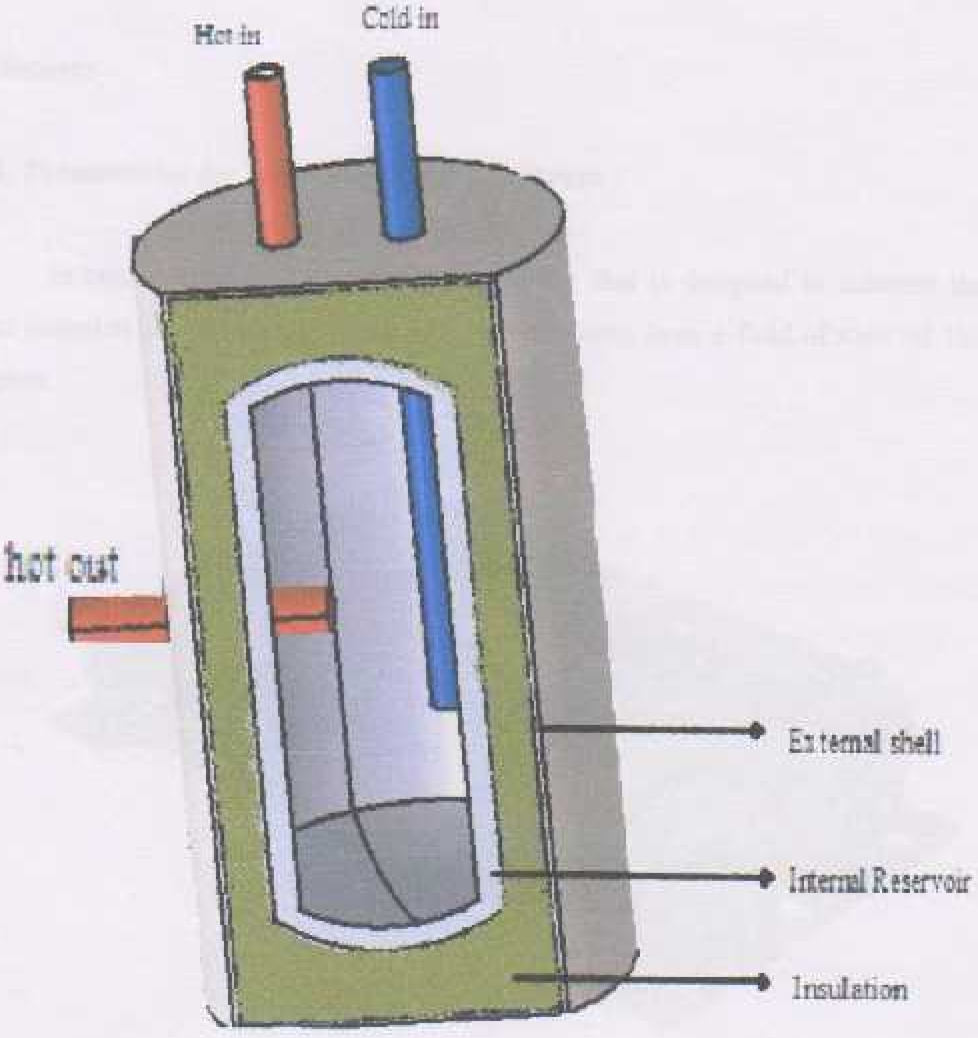


Figure (4.2): Storage Tank

4.4 - Testing Equipment

The equipment use in testing include the sensors to measure the parameters in short term testing and data acquisition card to transfer data from sensors to computer and computer to processing the data to calculate the performance of solar domestic heat water.

A: Sensors

1. Pyranometer for Measuring Solar Irradiance

In other words: a Pyranometer is a sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view of 180 degrees.

Figure (4.3): Pyranometer

2. Turbine Flow Meter

As a substance moves through a pipe, it acts on the vanes on a turbine to get it to spin. The rate of spin is measured to find out the speed of the flow.

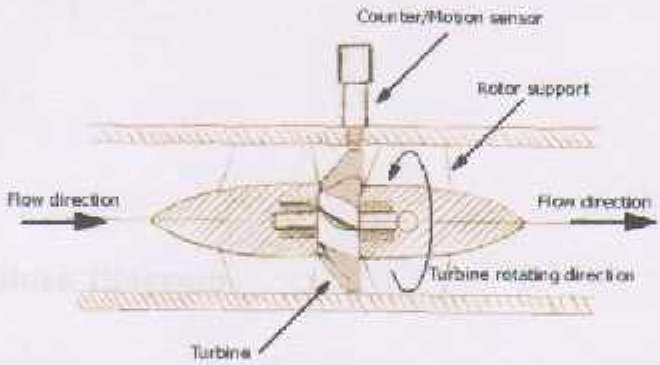


Figure (4.4): Turbine Flow meter

3. Platinum Resistance Thermometers

The resistance of a conductor varies according to its temperature and this principle is employed in resistance thermometry. By specifying a conductor material which displays a stable and approximately linear temperature coefficient of resistance over the required range, a reliable thermometer can be made.

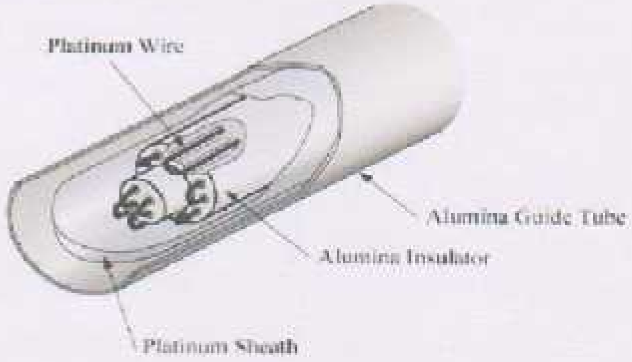


Figure (4.5): Platinum Resistance Thermometers

B: Data Logger

The data logger used to transfer the data from the sensors (which measure parameters from SDHW systems) to the laptop to use it in the program of this project.

4.5 - General Block Diagram

The block diagram of the system show the main step of performance testing procedure, in general form. Begin with outdoor testing (short- term- testing), then processing the data using general module to get the parameters which describing characteristic of tested system. These characteristic needed for calculate and predict performance using general SDHW.

Finally the yearly performance prediction calculates.

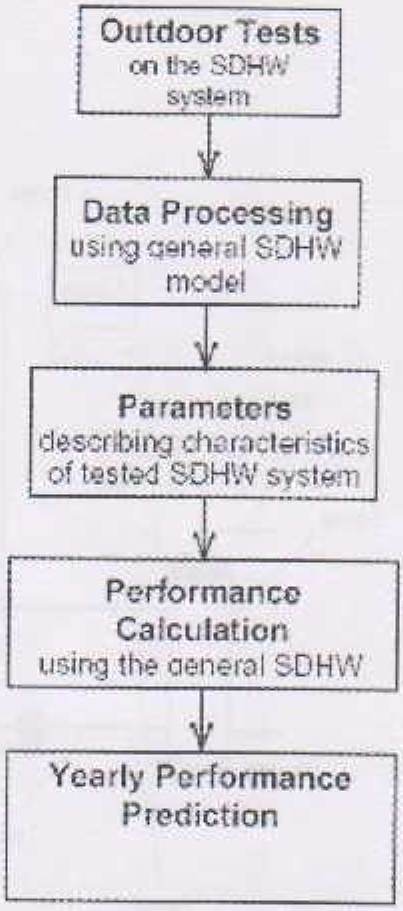


Figure (4.7): Schematic Outline of the Performance Testing Procedure on SDHW Systems

4.6 - How System Work

This figure show in general how the SDHW system testing and sensors needed to measure the variables, this variable used in long term testing.

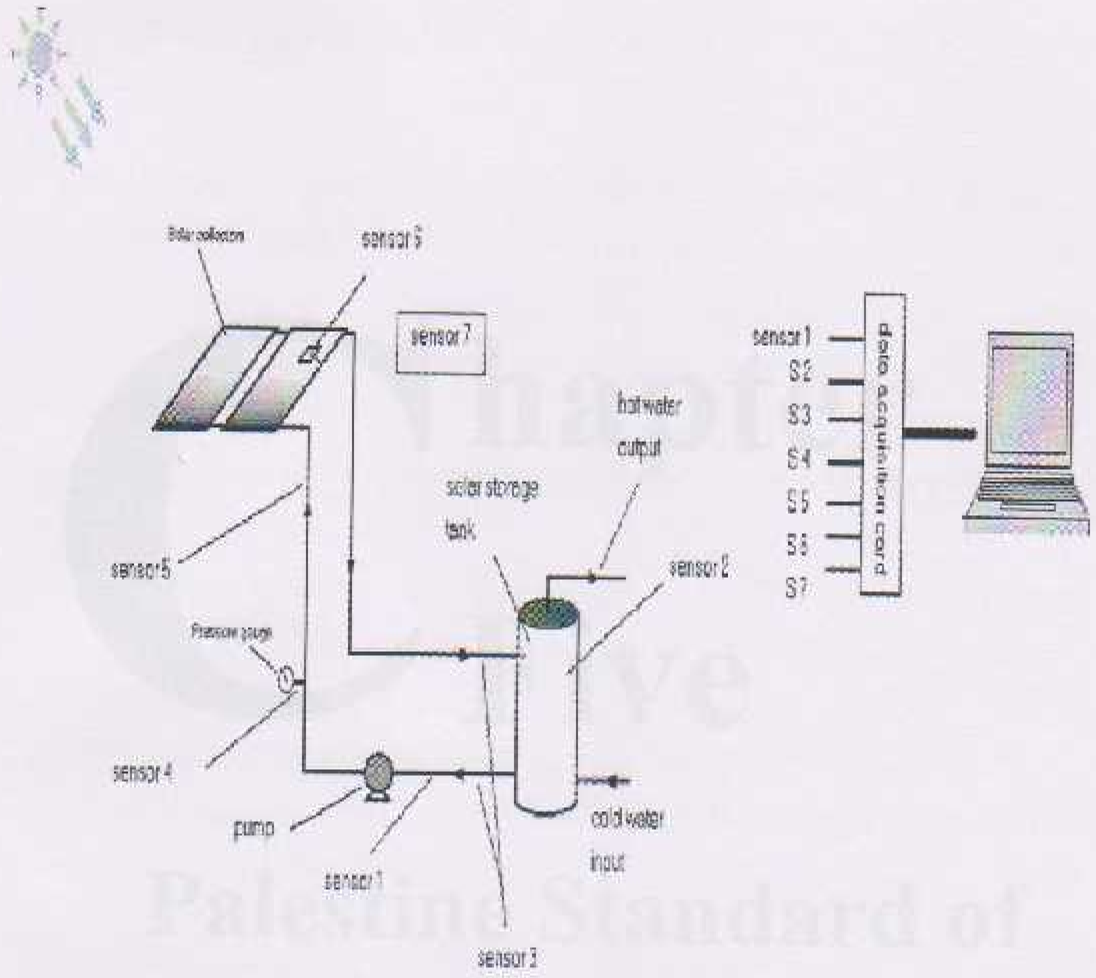


Figure (4.8): Components of Project in General.

Chapter Five

Palestine Standard of (SDHW) System: Thermal Tests for Flat Plate Collectors

5.1 - Test circumstances

* Before doing test, the collector is exposed for three days without a liquid, During these days the amount of measured radiation should be less than 1700 $kJ/m^2 . day$

* We test four commercial collectors simultaneously. If collection consists of unites we examine the unites as isolated unites with heat loss from the inferior and lateral wall.

* The system should be in alpaca that hasn't any important amount of reflected energy during the test.

* We examine the thermal efficiency between 11:00 LST until13:00 LST, we put the collection in an angle on which the sun rise be temperature, should be more than 30°C during the test.

* The peripheral temperature should be more than 30 deg during the test.

* We must make sure that the specific heat of the temperature is constant at the completely period tests is equal 0.5%.

5.2 Measurement Instruments

1- Pyranometer: - to measure the radiation.

2- sensors: - to measure the temperature.

3- Flow meter: - to measure the flow rate of the liquid.

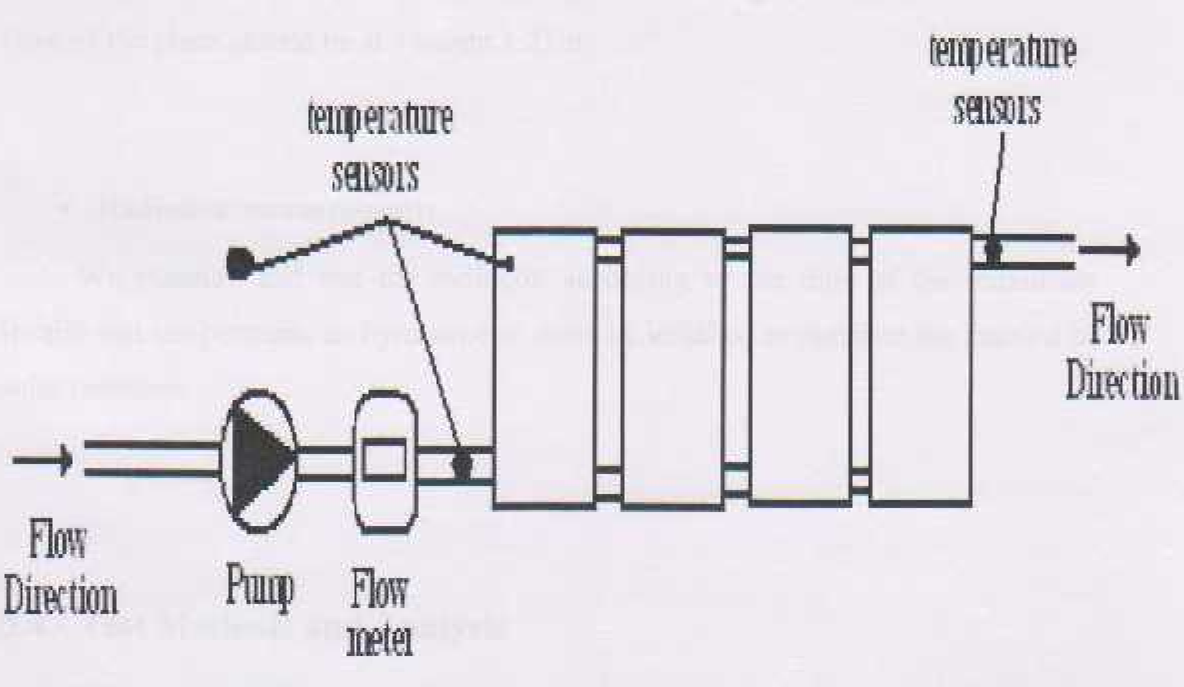
5.3 The Collectors and Test Circumstances

The test of collector may be one of these collectors.

1-Closed loop: - a loop with a collector that has a constant level.

2-Open loop:-a loop with a constant flow rate for the liquid.

In this project I will choose open loop system because it is the available product in our city as seen in the following **figure (5-1)**



The solar collector should be put fixed at the site of the test with required angle as shown in the table (5-1)

$$\frac{q_u}{A_a} = I_t(\tau\alpha)_e - U_L(t_p - t_a) = \frac{m^{\cdot}}{A_a}\ C_p\ (t_{f,e} - t_{f,i}) \qquad \ldots\ldots\ (5.1)$$

Where:

q_u: Energy input into the system, J

A_a: Area of the collector's glass, m^2

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

U_L: Collector heat loss coefficient, $W/m^2\ k$

t_p: Plate operation temperature, ° C

t_a: Ambiant air temperature, ° C

$t_{f,e}$: Water exist temperature, ° C

$t_{f,i}$: Water inlet temperature, ° C

C_p: Specific heat of water at constant pressure, kJ/kg k

$m^{\cdot}$: Mass flow rate of the heat transfer fluid through the collectors, kg/s

To simplify the process of obtaining detailed information about the thermal characteristics of the flat collection and to avoid the need for finding the average of the temperature of collection surface its easy to use the coefficient.

$$F_{R=} \frac{The\ acquired\ power\ that\ infact\ collected\ by\ aflat\ collection.}{The\ acquired\ power\ that\ should\ be\ collected\ .\ if\ the\ temoerature\ of\ the\ surface\ of\ the\ flat\ collection\ equalthe\ temperature\ of\ the\ internal\ liquid.}$$

By interning this coefficient to the equation (1), we obtain the following equations.

$$\frac{q_u}{A_a} = F_R\, I_t(\tau\alpha)_e - U_L\left(t_{f,i} - t_a\right) = \frac{m}{A_a}\; C_p\,(t_{f,e} - t_{f,i}) \qquad \text{.......} (5.2)$$

So that the efficiency of flat collectors is equal:

$$\eta = F_R(\tau_\alpha)_e - F_R U_L \frac{(t_{f,i}-t_a)}{I_i} = \frac{m\, C_p\,(t_{f,i}-t_{f,e})}{A_g I_t} \qquad \text{.......} (5.3)$$

A_g: General Area of the collectors, m^2

- **Test Data:**

The measurement data in this test are found in Table (5.2) and this data

1- Arpanet temperature.
2- Inlet temperature.
3- Exist temperature.
4- Collector plat temperature .
5- The irradiance on a collector .
6- The constant water flow rate 220 L/h =0.0611kg/s.
7- Area of the collector's glass =5.664 m^2.

Table (5.2) the measured value of the temperature of the Palestinian standard SDHW system

$T_{fo} - T_{fi}$	$T_p - T_a$	$T_{fi} - T_a$	It
c^o	c^o	c^o	w/m^2
14.83	20.1	-2.5	889.75
19.43	20.4	-2.3	898.25
19.68	20.1	-2.9	907
20.12	22.7	-2.25	898.875
20	21.2	-2	895
19.8	22.7	-1.3	891.75
19.8	23.2	-1.5	876.5
19.8	24.2	-0.8	878.25
19.4	24.2	-1.2	872.5
19	21.5	-1.4	853
19	20.6	-1.2	848.875
18.5	21.8	-0.7	812.125
18	20.9	-0.3	801.75
18.2	20.7	-0.2	773.25
17	19.1	-0.3	733.875
16.6	15	-1.1	727.875
14.8	13.6	-0.6	646.5
13.5	15.6	-1.7	617.75
12.8	13.3	-1.4	535.5
12.8	12.2	-1.2	495.25
11.6	11.4	-0.6	492.5
11.2	7.1	-0.3	495.75
11.5	10.4	-0.6	448.625
10	7.5	-0.1	401.375
9.2	5.4	-0.3	377.75
7.5	4.8	-0.5	345.75
5	3.3	-0.5	343.625
3	1.3	-0.6	297.375
3.2	0.4	-0.8	214.25

Table (5.1) the result of calculation on Palestinian standard of SDHW system

U w/m^2c^0	qu kw	FR	$(T_{f,i}-T_a)/I_t$ °C m²/w	η %
-3.32	4962.38	1.09	-0.00256	73.66
-3.54	5026.23	1.10	-0.00320	73.89
-4.33	5138.61	1.13	-0.00250	76.22
-4.54	5107.96	1.13	-0.00223	76.10
-3.98	5056.88	1.12	-0.00146	75.61
-4.48	5056.88	1.14	-0.00171	76.93
-4.23	5056.88	1.13	-0.00091	76.77
-3.70	4954.72	1.12	-0.00138	75.72
-4.14	4852.56	1.12	-0.00164	75.85
-4.50	4852.56	1.13	-0.00141	76.22
-4.74	4724.86	1.15	-0.00086	77.57
-4.31	4597.16	1.13	-0.00037	76.45
-6.03	4648.24	1.18	-0.00026	80.15
-5.55	4341.77	1.16	-0.00041	78.88
-6.23	4239.61	1.15	-0.00151	77.66
-6.29	3779.89	1.15	-0.00093	77.96
-3.38	3447.87	1.11	-0.00275	74.42
-7.16	3269.09	1.22	-0.00261	81.40
-10.77	3269.09	1.32	-0.00242	88.01
-7.00	2962.62	1.19	-0.00122	80.21
-8.29	2860.46	1.14	-0.00061	76.93
-11.04	2937.08	1.30	-0.00134	87.29
-11.96	2553.98	1.25	-0.00025	84.84
-13.86	2349.66	1.23	-0.00079	82.94
-5.63	1915.49	1.10	-0.00145	73.87
25.40	1276.99	0.69	-0.00146	49.55
101.82	766.19	0.28	-0.00202	34.35
121.33	817.27	0.24	-0.00373	50.86

From the equation (5.3), we extract that if we drawing the thermal efficiency in one hand and the $\frac{t_{f,i}-t_a}{I_t}$ in the other hand and seen in Figure (5.2) . We obtain a straight line that has aslope equal to $(F_R U_L)$, and its connection to the(Y- axis) is equal to $(F_R(\tau_\alpha)_e)$.

In fact the heat loss coefficient (U_L) is variable according to the collection temperature and the surrounding circumstances of the weather in addition, the multiplication result $(F_R U_L)$ is variable according to the descending angle which is between the sun radiation and the collection.

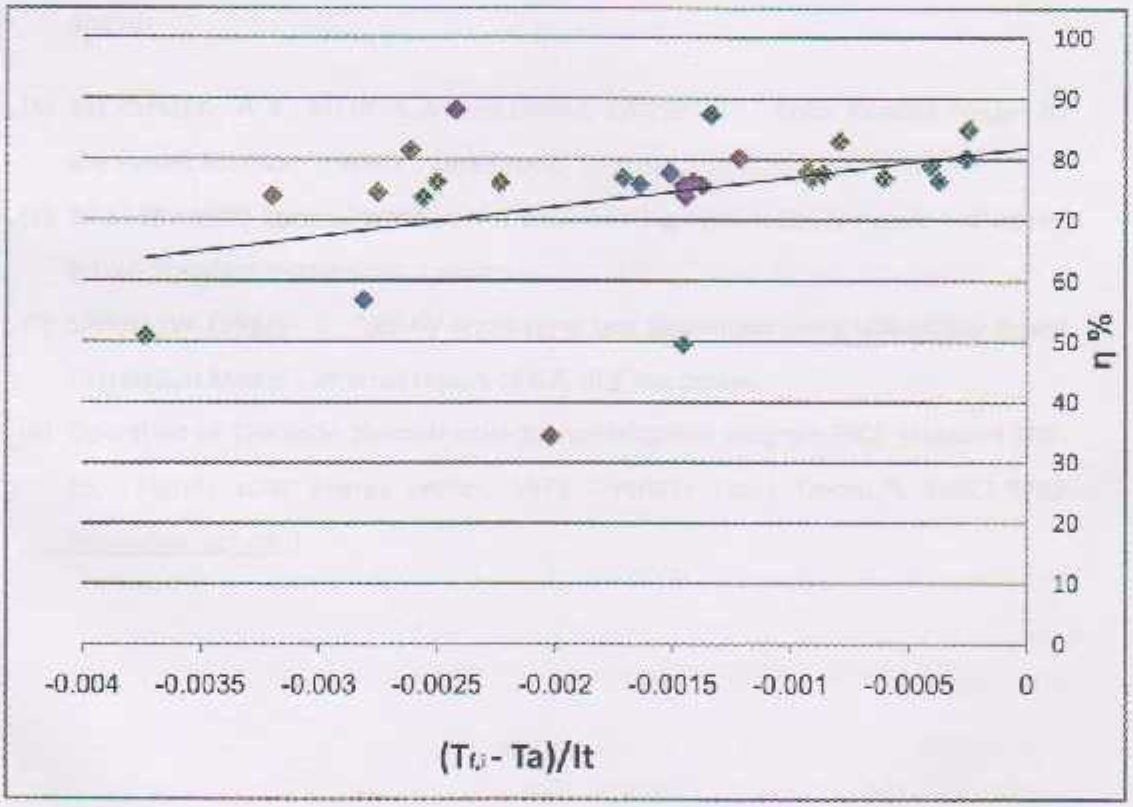


Figure (5.2) Collector Thermal Performance Testing

From the equation (5.3), we extract that if we drawing the thermal efficiency in one hand and the $\frac{t_{f,i}-t_a}{I_t}$ in the other hand and seen in Figure (5.2) . We obtain a straight line that has aslope equal to $(F_R U_L)$, and its connection to the(Y- axis) is equal to $(F_R(\tau_\alpha)_e)$.

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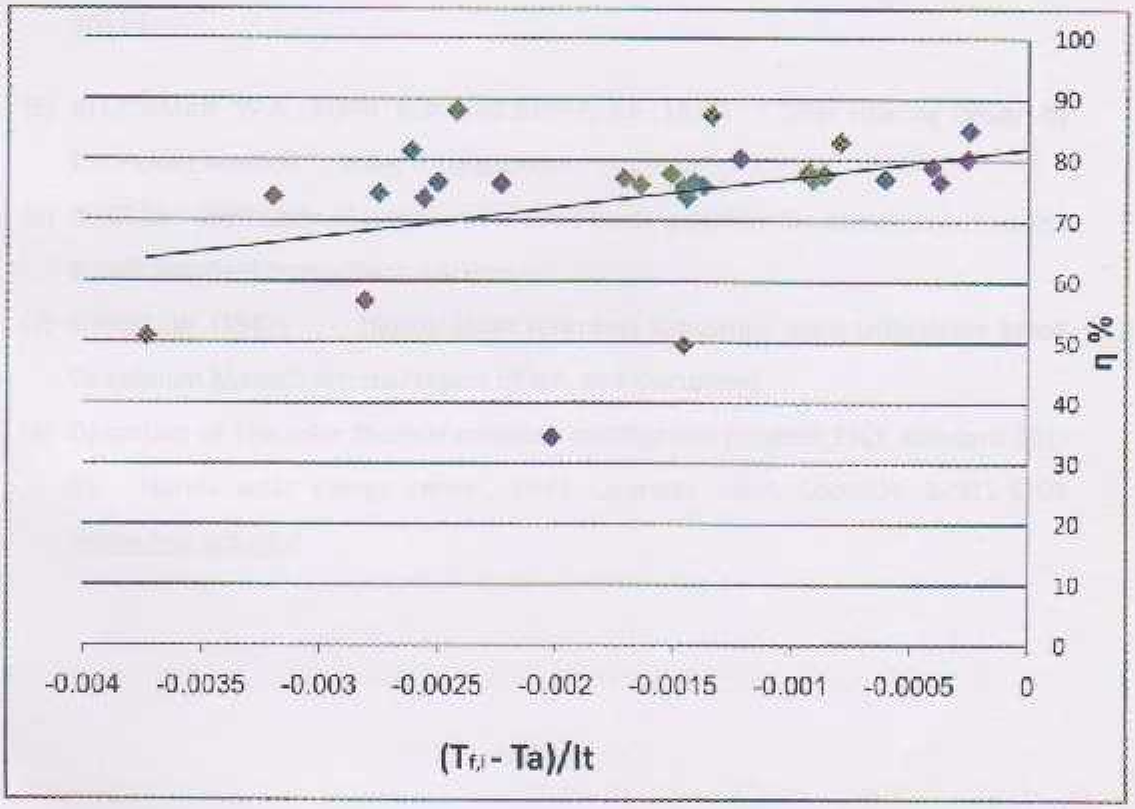

Figure (5.2) Collector Thermal Performance Testing

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