Study on Thermal Performance Assessment of Solar Hot Water Systems (SHWS) in Malaysia

by

Fariza Fansara Binti Fauzi

11740

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

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AP Ir Dr SHAHARIN ANWAR B SULAIMAN
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted for this project, and that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Fariza Fansara Binti Fauzi)

ABSTRACT

Solar Hot Water Systems (SHWS) are gaining popularity in Malaysia due to increasing electricity price as well as the environmental awareness of using fossil fuels. The penetration of these systems and the technologies into Malaysian markets is a welcoming development. However, there is a need for a proper rating system for solar hot water in relation to quantify the overall energy savings. In order to develop the rating systems, a study on thermal performance assessment of SHWS in Malaysia is required. Until now, there has been no method of assessing the thermal performance for these systems thus consumers have no way of assessing the economy of their SHWS. In view of this, Malaysia should be prepared for such development by supporting consumers in assessing the SHWS. Furthermore, at the national level, the contribution of this technology to the reduction of greenhouse gas emissions cannot be quantified. The main objective for this project is to study the thermal performance assessment of SHWS in Malaysia by using combined direct measurement and computer modeling or simulation method. In order to evaluate the thermal performance of the system, a computer model known as TRNSYS Simulation Program is employed whereby most of the main components which are relevant to the systems are interconnected in the model. In order to study the thermal performance of SHWS, various researches were done in order to establish reliable input parameters to be entered into the performance rating software. The rating software is develop mainly for this purpose and is discussed in detail in this report. The results for this project revealed the rating of the SHWS produced by the manufacturer based on the thermal performance achieved from the software. The principal conclusion was that although the proposed thermal performance rating calculation method has not been certified and endorsed by Malaysian government, yet the development of the thermal performance rating assessment is the first and crucial step that leads to minimize the energy performance of the SHWS. The proposed thermal performance rating will also help to quantify the energy savings and greenhouse gas emissions reduction of the systems.

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First and foremost, thanks to Allah S.W.T for letting I live my life, now at least for 22 years. With His blessing, I am able to complete my Final Year Project with full strength and great health. It is my pleasures to thank all individuals that have directly and indirectly made this project a success.

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LIST OF ABBREVIATIONS

EWH	Electric Water Heater
FYP	Final Year Project
GColl	Solar Irradiance at Solar Collector
MdColl	Solar Radiation at Solar Collector
QAux	Auxiliary Heat Transfer Rate at Storage Tank
SHWS	Solar Hot Water Systems
SWH	Solar Water Heating
TiColl	Inlet Temperature at Solar Collector
ToColl	Outlet Temperature at Solar Collector
TTop	Top Temperature at Storage Tank
UTP	Universiti Teknologi PETRONAS

CHAPTER 1

INTRODUCTION

The ultimate supplier of energy for the whole life on earth is the sun (James, 2005). Solar energy is environmental friendly and therefore it is an attractive alternative to fossil fuels. Using the solar energy to heat up water is not a new idea. Back in those years, people are using black painted water tanks as a simple solar water heater in a number of countries for many years. Solar Water Heating (SWH) technology has been greatly improved from time to time and nowadays there are more than 30 million of solar collectors installed all over the world (Ali et al, 2009).

The introduction of solar systems in Malaysia is an indication that it has potential market and this is an encouraging development. However, a methodology for assessing the thermal performance of these systems is required to ensure that they delivered the claimed energy savings and contribute significantly to reducing emissions of the greenhouse gases to the environment (Halawa, 2011).

1.1 Background Information

Solar Hot Water Systems (SHWS) have started gaining its popularity in many ASEAN countries due to increase in population as well as environmental concerns from the use of fossil fuels (Halawa, 2011). Malaysia is not an exception given that the country has abundant of solar energy all the year round and thus making it suitable for development of solar energy systems. Malaysian households have been regarded as the potential market for SHWS (Ali et al, 2009).

Currently most of the Malaysian households are still relying on the electric water heaters for their water needs mainly because of the high initial cost of SWHS compared to electric water heaters (Ali et al, 2009). People are not quite aware of the consequences that may occur using electric water heaters since the primary source for this energy is the fossil fuel. Furthermore, the highly subsidized fuel and electricity prices in Malaysia have made electric water heaters attractive in term of the overall costs (Bernama, 2012). Nevertheless it is expected that SHWS will be demand soon when Malaysia becomes net fuel importer in the coming decade.

The costs of using fossil fuels to the environment are hidden. Burning fossil fuels releases carbon into the atmosphere where it leads to the global climate changes that will disrupt life as can be seen on every corner of the Earth nowadays. When fossil fuel such as coal is burnt, chemicals are released into the atmosphere that causes acid rain, polluting rivers, lakes and soil. Acid rain will kills wildlife, trees, and vegetation as well as degrades the buildings and anything else that exposed to it. This is all eventually due to the used of fossil-fuels (Ramlow et al, 2006).

The comparison in Table 1.1 shows that using renewable energy brings greater advantages as compared to non-renewable energy. In relation to this, SHWS can be one of the best options in implementing the use of renewable energy.

Table 1.1: Comparison between renewable energy and non-renewable energy (Keshav, 2010)

RENEWABLE ENERGY	NON-RENEWABLE ENERGY
(i) Renewable sources are energy sources that will not run out. It will always be there since the primary source is the natural energy.	**(i)** The primary source is fossil fuels. It is considered as non-renewable since it took for about million of years to recover back the fuels.
(ii) These include Solar Energy, Wind Energy, Geothermal Energy, Wave Energy and Hydro Energy.	**(ii)** Fossil fuels include coal, oil and natural gas. These resources come from animals and plants that have already died millions of years ago.
(iii) Renewable energy emits lower greenhouse gases.	**(iii)** Fossil fuel cause lots of pollution.

The schematic of a SWHS is shown in Figure 1.1 (Ramlow et al. 2006). During clear days, the solar collector array receives the solar radiation and this heats the water that comes from the storage tank. During cloudy days or at night, the water is heated by a back-up heater using gas or electricity. For an efficient system, the water tank needs to be properly insulated so that energy contribution from the back-up system is minimized.

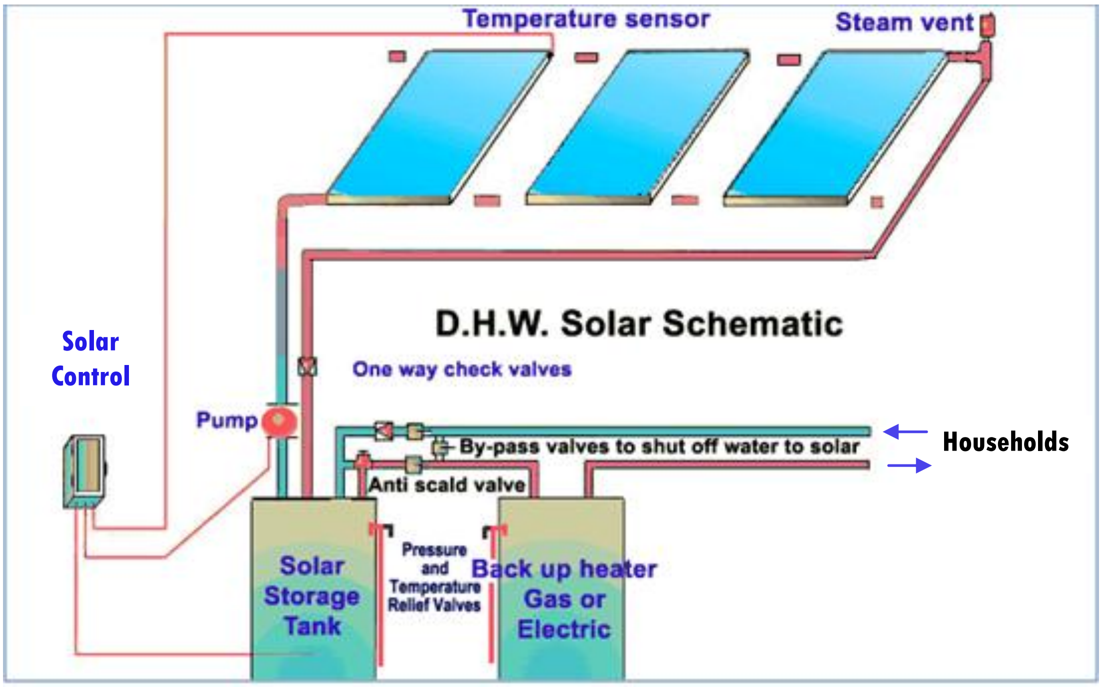


Figure 1.1: Schematic for domestic solar hot water systems (Ramlow et al, 2006)

1.2 Problem Statement

The penetration of SHWS and the technologies into Malaysian markets is a welcoming development thus makes most of SHWS manufacturers or suppliers kept introducing their systems in the market. However, there is a need for a proper rating system for solar hot water in relation to quantify the overall energy savings. In order to develop the rating system, a study on thermal performance assessment of SHWS in Malaysia is required. Until now, there has been no method of assessing the thermal performance of these systems thus makes consumers have no way of assessing the economical feasibility of the systems. As such the claimed thermal performance of the systems by manufacturers cannot be verified.

In view of this, Malaysia should be prepared for such development by supporting consumers in assessing the SHWS. At the national level, the contribution of this technology to the reduction of greenhouse gas emissions cannot be quantified. This rating system of solar hot water is already done in several countries such as Australia. However, the rating system cannot be implemented in Malaysia due to the weather condition as well as the characteristics of the system components which different from one country into another thus make the project more relevant to be executed.

1.3 Objectives and Scope of Study

The main objective for this project is to study the thermal performance assessment of SHWS in Malaysia by using combined direct measurement and computer modeling or simulation method. In order to evaluate the thermal performance of the system, a computer model known as TRNSYS Simulation Program is employed whereby most of the main components are interconnected in the model. In this project a method of rating the thermal performance of SHWS is developed using a wide range of operating information in Malaysia.

The scope of this study includes:

i) identification of various types of SHWS available in Malaysia.

ii) collection of data on hot water consumptions of Malaysian households.

iii) identification of the main parameter that affect the performance of SHWS

iv) development of TRNSYS Simulation Program to achieve thermal performance for SHWS

v) establishment of a thermal performance rating calculation method for SHWS in order to estimate the energy savings and greenhouse gas emission reduction by using these systems

1.4 The Relevancy of the Project

While SHWS have energy savings and greenhouse gas emissions reduction potential, they also can become redundant or even burden to the environment if they are not properly designed. Since there is no official method of assessing the thermal performance of SHWS in Malaysia yet, this project would be providing such an opportunity. The proposed rating systems will help to establish the guidelines for such a proper design.

The project is very significant to be executed in order to assess the thermal performance of the SHWS sold by Malaysian manufacturers and suppliers which will lead to the system's rating. Even though the rating system is already exist in other countries, it is not practical to be implemented in Malaysia due to the weather condition as well as the components characteristics which is different from one country into another. Consumers will also have their right to assess the economical feasibility of the systems and this will lead to the identification of the reduction of greenhouse gas emissions as well as the energy savings by using such a proper systems. There are some researches done related to the assessment of SHWS thermal performance as well as the rating systems used which is discussed in detail in Chapter 2.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Until recently many researchers have shown interest in the field of thermal performance of Solar Hot Water Systems (SHWS). They have carried out numerous studies, laboratory experiments and field observations to illuminate the goodness of this field. Their findings and suggestions are reviewed here.

2.1 Energy Rating of Domestic Water Heaters in Australia

Morrison & Tran (1992) have studied the energy rating of domestic water heaters in Australia. The project has addressed the problem of rating conventional and renewable energy domestic water heaters and represents a unified scheme for rating all forms of water heaters. The scheme provides a means of rating electric, gas, solar and heat pump water heaters. The procedure is based on data available under existing Australian standards and uses a computer simulation model to determine annual task cycle energy efficiency. It is argued that a ranking scheme based on metered energy consumed gives the best indication of both energy and carbon dioxide ranking of domestic water heaters.

Based on research done by George (2010), energy efficiency rating of domestic appliances is usually evaluated for a standardization set of operating conditions. This approach has been adopted for gas water heaters and is currently being considered for electric water heaters. However standardized rating procedures cannot be applied to solar water heaters or heat pump water heaters as these devices experience an extremely wide range of operating conditions and it is not possible to develop a meaningful ranking order from single point tests.

One of the major impediments to the acceptance of solar and heat pump water heaters is the difficulty a consumer has in comparing the performance star rating scheme for a gas water heater with a claim of a level of annual energy saving for a solar water heater. If a different rating system is developed for electric water heaters, it will complicate the task of promoting high quality, low pollution solar and heat pump water heaters (Morrison & Tran, 1992).

2.1.1 Energy Efficiency Rating for Conventional Heaters

The existing star rating scheme for gas water heaters was developed as an internal gas industry means of differentiating between standard and high efficiency gas storage water heaters (Energy Rating Inc, 1991). The scheme provides a simple means of separating high efficiency heaters, usually with return flue or condensing flue, from conventional chimney flue systems. The gas-rating scheme does not take account of the effects of load cycle operation nor does it account for variations of environmental conditions such as cold water supply temperature and ambient temperature.

A procedure for determining the energy consumption of electric water heaters has been presented in Australian Standard AS1056.4 based on Energy Rating Inc (1991). For off-peak water heaters which is the most common electric water heater in eastern Australian states, AS1056.4 uses a simple 10% adjustment to account for the varying temperature conditions in off-peak storage tanks, and makes no allowance for the effect of load induced mixing on the quantity of useable hot water, effect of flow diffusers to promote stratification or the effect of improved insulation on the promotion of stratification.

2.1.2 Energy Efficiency Rating for Solar Water Heaters

The annual energy saving of a solar water heater can be evaluated by experimental procedures defined in Australian Standards AS2813 and AS2984 (Energy Rating Inc, 1991). System performance evaluation procedures such as AS2813, using a solar simulator, or AS2984 using outdoor measurements, have the advantage that the systems are tested as a black box and hence the testing authority does not need to take the system apart, or need to know the internal operation in order to determine the performance.

The disadvantage of these procedures is that they are expensive to carry out or require a long monitoring period (George, 2010). Methods for quantifying the efficiency of solar water heaters include:

i) Solar simulation tests - Australian Standard AS2813
ii) Short term outdoor tests - Australian Standard AS2984

iii) Long term outdoor tests
iv) Outdoor comparative performance testing relative to a reference system
v) Analysis of long term performance based on component testing of the solar collector and storage tank.

Although the first two methods are well developed, both are expensive to perform. Long term outdoor testing requires monitoring over at least twelve months and outdoor comparative testing has significant uncertainty due to aging of the reference system (George, 2010).

The solar simulator based standard, AS2813 was adopted to allow assessment of performance under controlled conditions. This standard also includes a procedure for computing annual energy savings for outdoor operation. Similar standards have been adopted in the USA and by the International Standards Association based on. However these standards only rate systems for a defined solar day. To provide the extra information needed to determine annual outdoor performance the Australian simulator standard requires a much longer test period and hence is more expensive to perform than the ASHRAE or ISO standards (Energy Rating Inc, 1991).

An outdoor test procedure, AS2984 has also been adopted by Standards Australia. The test period is governed by climatic conditions at the test site and a test period of 9 to 12 weeks is generally required. The annual energy savings are determined using a model to correlate the short term tests. The existing Australian Standards can be applied to any design of solar water heater, however these methods are expensive to apply due to the high cost of simulator testing and the long test period required for outdoor testing based on the new water heater standards (SA Water, 2004).

The performance of many types of solar water heaters have also been evaluated using correlation models, however, correlation methods are not as accurate as detailed TRNSYS simulation calculations (Klein et al, 2005). Correlation modeling was developed to save computation time with a corresponding loss of accuracy however with the ready availability of fast desk top computers correlation models are being displaced by the more fundamental and hence more accurate detailed simulation models.

2.1.3 Water Heater Load Cycle Performance Simulations

The annual performance of conventional water heaters operating under load cycle conditions can be readily evaluated from knowledge of the standing heat loss or maintenance rate of a gas storage water heater, and draw-down delivery capacity of the tank (Morrison & Tran, 1992). Once these factors are known by using the existing standard test procedures a short time step simulation program can be used to follow the temperature variations in the tank in response to loads, tank heat loss and energy source operation. The long term performance of solar water heaters can be readily evaluated if the efficiency of the solar collector and heat loss characteristics of the tank and solar plumbing are known.

A detailed mathematical analysis over a typical climatic year for the location of interest will require inputs of component characteristics and hourly solar radiation and ambient temperature data. Appropriate climatic data is available for 22 locations in Australia including all capital cities. Numerous simulation programs have been developed for determining the performance of solar water heaters. The most widely used computer model is the TRNSYS package (Klein et. al, 2005). Researchers in Australia have contributed to the development of this code and have also developed many extensions to suit Australian solar equipment and Australian component testing procedures. TRNSYS has also been used extensively by Australian companies for developing new solar products and evaluating system designs.

2.1.4 Comparison of Water Heater Performance

The metered energy consumption of seven types of domestic water heaters is shown in Figure 2.2 (Morrison & Tran, 1992). All systems were assessed for the same load condition which is40 MJ/day peak winter load for zone 3 weather conditions based on Figure 2.1. The annual energy delivery efficiency ranged from approximately 250% for the three solar systems to 45% for the standard gas storage water heater. The annual energy efficiency of the high efficiency gas system was 55% and approximately 80% for the two conventional electric systems.

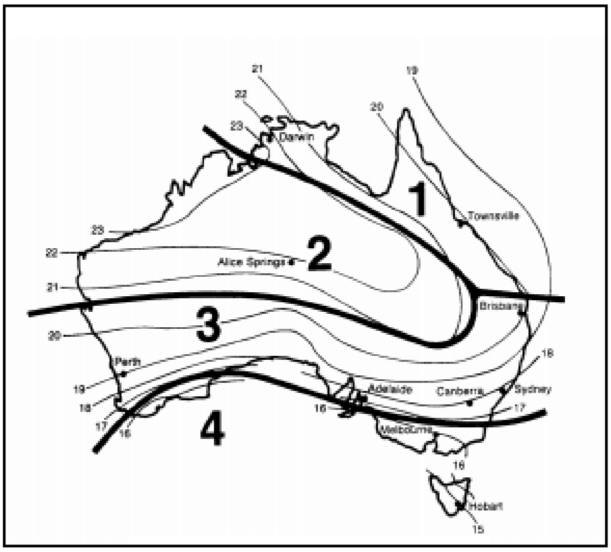


Figure 2.1: Climates zones in Australia (Morrison & Tran, 1992)

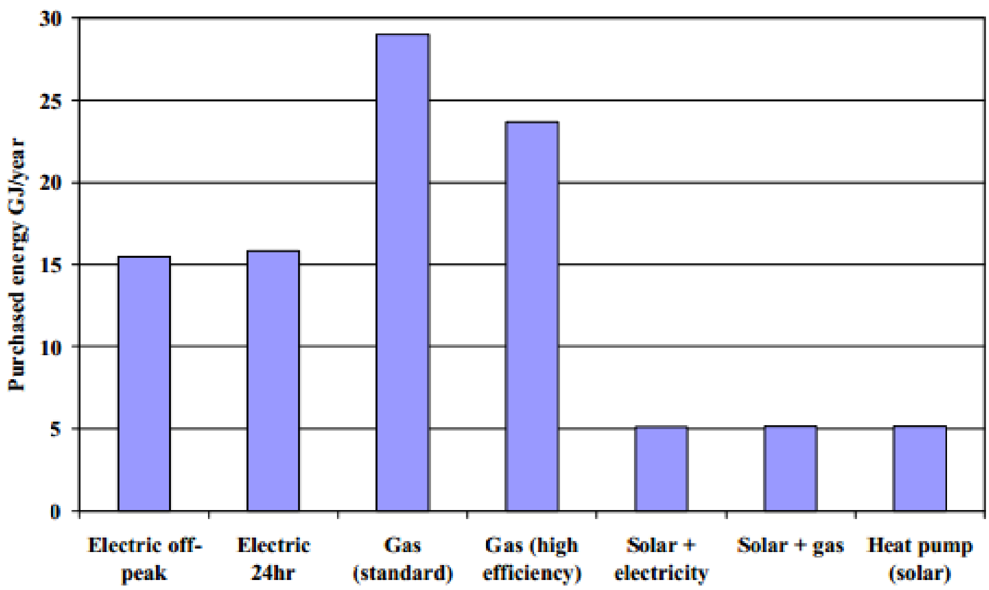


Figure 2.2: Annual task cycle energy consumption, peak load 40 MJ/day (Morrison & Tran, 1992)

The comparative performance information in Figure 2.2 clearly differentiates between different products and if presented as a 10 point star rating system with two stars reserved for future developments, ranking would apply:

$$stars = \frac{10 - annual\ energy, GJ}{3} \tag{2.1}$$

The ranking systems would be as follows:

i) 7 to 8 - Solar water heaters (electric boosting) and solar boosted heat pumps
ii) 6 to7 - Solar water heaters (in-tank gas boosting)
iii) 4 to 5 - Electric storage water heater
iv) 2 to 3 - High efficiency gas
v) 1 to 2 - Standard gas

2.1.5 Choice of Ranking Scheme

The separate rating schemes developed for gas and electric water heaters was due to the lack of agreement between gas and electric supply authorities with regard to the selection of primary or metered energy as the ranking variable. The use of primary energy ranking is often presented as a valid measure of the pollution ranking of conventional gas and electric water heaters. However, this may not be correct if the life cycle efficiency of both products is considered.

A further disadvantage of gas water heaters is that the sulfur dioxide and nitrogen oxides production is distributed in the urban areas and can only be controlled by expensive maintenance and regular replacement of the burners. Meanwhile the pollution produced in electric power plants is concentrated at a few locations. It is relatively easy to reduce atmospheric pollution even though it is quiet expensive to install pollution control systems at power stations (George, 2010).

If a decision were made to reduce urban atmospheric pollution it would be cheaper to promote electric water heaters and to install pollution controls at the power stations rather than replace all gas water heaters with low pollution burner systems. As a result of these considerations a ranking scheme based on metered energy use is preferred (Morrison & Tran, 1992).

2.2 Thermal Performance Rating of SWHS in ASEAN

Halawa (2011) have studied the thermal performance rating of Solar Water Heating Systems (SWHS) in ASEAN countries. This paper is much related to the present project as the topic not only focuses on the rating method but also covers ASEAN countries.

This paper discussed about the reasons for the need of a suitable evaluation method of assessing the thermal performance of SWHS in ASEAN countries. This is because the environmental issues due to the increasing demand for fossil-fuel have become very hot issues involving the whole world and ASEAN countries consider these issues seriously by starting developing a reliable sustainability and environmental assessment method for this green technology (Halawa, 2011).

The assessment outcome for this studies is that the energy saving which delivered by the SWHS can be estimated by comparing its energy consumption with the reference system for a particular period. This should form the basis for SWH energy labeling. This can also be used as a guide for encouraging high efficient systems to enter the market through various subsidies or rebate schemes (Morrison & Tran, 1992). The outcome for this rating can be used as the basis for establishing the minimum energy performance standards (MEPS) for the SWHS.

The successful realization of the development of this evaluation method depends mainly on the establishment of reliable input data to the rating software to be employed as well as the availability of solar testing facilities for testing the main components of the systems (Morrison & Tran, 1992).

The role of the respective ASEAN government in realizing this program and running it smoothly is very crucial. ASEAN countries whether individually or as an Association need to develop the framework to assist their SWH industry to sustain in the increasingly tough global competition. Establishment of accredited solar testing facilities enable ASEAN countries to provide services to local manufacturers which helps boost their competitiveness on regional and world market (Halawa, 2011).

2.3 Economics of Domestic SHWS in Malaysia

Ali et al (2009) studied about the economics of the Solar Hot Water Heating Systems (SHWHS) with the aim to promote the solar water heater in Malaysia. They presented an economic evaluation of some solar water heating systems model uses in Malaysia marketing with different purchase price such as Aztec, Solarmate, Solarpollo, Summer, and Microsolar M80VTHE Indirect Vacum comparing with electric water heaters. The comparison between these systems was based on the direct monetary outlay of the user by calculate the annual cost method. SHWHS are generally characterized by high initial cost and low operational cost as compared with the relatively low initial costs and high operating cost of conventional Electric Water Heater Systems (EWHS).

In additional heating water with the sun also means long-term benefits, such as being protected from future fuel shortages and price increases as well as the environmental benefits (All Answers Ltd, 2003). The comparison between these systems is based on the direct monetary outlay of the end users. In order to study the economic feasibility of these systems, a different method could be used to evaluate different figures of merit of the systems. In this study, the Annual Cost Method (AC) is used to compare with the relative cost of SHWHS with EWHS (Ali et al, 2006).

The result from this research shows that the solar water heater is more economical and becomes more attractive than the electric water heater in long-term run. It is better for the family to use Solar Water Heater when compared to Electrical Water Heater (All Answers Ltd, 2003). It is the advantageous for the family to use the solar water heater at least 4 years, when compared to the electrical water heater. This is as well an option which has a renewable nature and environmental stability and it seems to be better proposition. It can also reduce the country’s dependency on foreign oil of which the price increases day after day (Ali et al, 2006). Besides that, it is more beneficial to install SHWS because of long term economical benefits, environment friendly and a way to avoid from the problem of increasing electricity bill and increasing family size (All Answers Ltd, 2003).

2.4 Optimization of SHWS through Water Replenishment

Govind et al (2008) studied about the optimization of SHWS through water replenishment, was mainly on the process inside the solar water heating system, in which the cold makeup water is added into the storage tank as soon as the hot water is drawn to serve the load. Mixing of cold makeup water with the hot water of the storage tank generates significant amount of entropy. It affects the thermodynamic quality of hot water supplied to the load. The mixing process reduces the storage temperature. The storage temperature continues to drop during draw offs over the day until enough water has been supplied. Thus water replenishment is essential to optimize the use of SHWS and increase the system efficiency.

Focus of most of the investigations was either on maintaining an optimum collector flow rate or maintaining stratification to improve system performance. The investigations also emphasis on supply of hot water at a fixed temperature from the heating source to the storage tank.

As a result compared in the present work, the appropriate water replenishment profile is determined to minimize the requirement of the collector area and the optimum water replenishment profile, the temperature of the water inside the storage tank remains constant. Based on this observation, a simply strategy for replenishing the makeup water is determined both analytically and numerically. This approximate method of water replenishment is simple to implement and near optimal (Govind et al, 2008). The work by Govind et al (2008) however has not dealt directly with the development of suitable method for rating the thermal performance of the SWHS in Malaysia.

2.5 Theory on Thermal Performance Evaluation

In theory, there are two methods in order to evaluate the thermal performance of solar hot water systems which is onsite evaluation and combined direct measurement and modeling or simulation methods (Morrison & Tran, 1992)

For the first method which is the onsite evaluation, the thermal performance is assessed during the utilization period of the system. Assessment is based on the various data recorded during the operation of the system. The outcome of the assessment only comes at the end of the system's lifetime. Although this method is more reliable in terms of its outcome since it gives more accurate results, but it is not practical to be implemented because of high cost and can not be used to regulate the market.

For second evaluation method which is the combined direct measurement and computer modeling or simulation method, the actual thermal performance of the main components of a Solar Water Heater Systems (SWHS) such as the solar collector, tank and pump is tested using standardized methods in laboratory or test field. The results from the previous test will be used as the input parameters inside the rating software called TRNSYS Simulation Program (Klein et. al, 2005) in order to calculate the system performance.

The second evaluation method is widely used because it is the most practical and easier method to be implemented and can be used to regulate the proliferation of the systems into the market by establishing the minimum performance requirements of the systems. It can also be used to estimate the systems contribution to the reduction of conventional energy use and the greenhouse gas emissions. Its main drawback based on Morrison & Tran (1992) is the need for strict observation of the implementation in the field. Its reliability or accuracy also very much depends on the input data and various assumptions behind the method. This approach also entails the need for competent computer modelers that help establish reliable computer models of each of the systems to be checked for compliance. The detailed assessment methods of SHWS thermal performance used for this project will be further explained in Chapter 3.

CHAPTER 3

METHODOLOGY

3.1 Overview of Research Methodology

Figure 3.1 shows the flow of research methodology used for this project. The steps and direction taken for the project can be seen clearly in Figure 3.1. It has been designed to fully utilize the time frame given to complete the project. The project is divided into five main stages which are first, the literature reviews and preliminaries research work. Data gathering is the next step taken for this project. The third stage is to determine the thermal performance assessment by simulating the SHWS model using TRNSYS Simulation Program. Next is to develop the thermal performance rating calculation method for SHWS using the simulation value obtained earlier. The last stage is the final documentation that compiles all the research work as well as the outcome of the project.

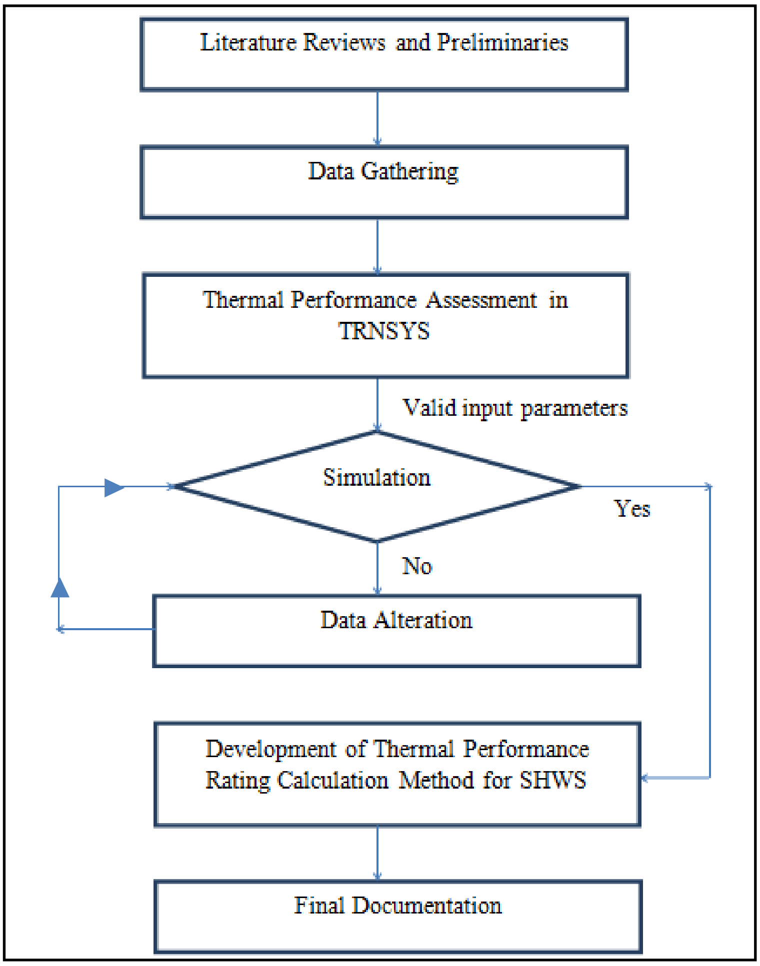


Figure 3.1: Flow of research work

3.2 Project Activities

Each stage of research methodology is discussed in detail as per Table 3.1. The project activities will give a clearer vision of what is going to be done throughout the completion of the project.

Table 3.1: Project work descriptions

METHODOLOGY	DESCRIPTIONS
Literature Reviews and Preliminaries	Perform comprehensive study on the thermal performance assessment of SHWS as well as the rating system using outcome of the research as a guideline.
Data Gathering	Collect all required input parameters such as list of SHWS available, location for main cities, average cold water temperatures and average monthly sunshine for main cities. The details will be discussed in Section 3.3.
Thermal Performance Assessment in TRNSYS	Simulate the SHWS model using TRNSYS Simulation Program to achieve the thermal performance of the systems
Development of Thermal Performance Rating Calculation Method	Establishment of energy savings and greenhouse gas emissions reduction based on thermal performance achieved.
Final Documentation	Outcomes of the project from the beginning of the project will be documented for future use.

3.3 Gantt Chart

The Gantt chart is built as a guideline for the project timeline as shown in Figures 3.2 and 3.3. It can be changed from time to time depending on certain circumstances. It is functioned to monitor the work progress and to accurately determine whether or not the project is on schedule.

3.3.1 Final Year Project 1 (FYP 1) Milestones

No.	Detail / Work	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								MID SEMESTER BREAK							
2	Preliminary Research Work * Background Information * Literature Review on rating method for SHWS * Methodology Used															
3	Submission of Extended Proposal Defence															
4	Proposal Defence															
5	Data Gathering * Types of SHWS used in Malaysia * Weather Data for Malaysia * List of SHWS Sold by Manufacturers * Location for Main cities in Malaysia * Malaysia Weather, Monsoon Seasons * Average Monthly Cold Water Temperatures * Average Monthly Sunshine															
6	Data Analysis * Analyze data that have already been collected for TRNSYS used															
7	Submission of Interim Draft Report															
8	Submission of Interm Report															

Process

Figure 3.2: Milestones for the first semester of final year project

3.3.2 Final Year Project 2 (FYP 2) Milestones

No.	Detail / Work	1	2	3	4	5	6	7	MID SEMESTER BREAK	8	9	10	11	12	13	14	15
1	Construction of SHWS Model * TRNSYS Configuration Flow Chart	■	■	■	■	■	■	■									
2	Submission of Progress Report Draft Submission of Progress Report							■		■							
3	Simulation Process * TRNSYS Simulation Program * Achieve Thermal Performance of SHWS									■	■	■	■	■			
4	Thermal Performance Rating Calculation * Establisment of SHWS Procedures * Energy Savings using SHWS * Rating System for SHW									■	■	■	■	■			
5	Poster Presentation for Pre-SEDEX												■				
6	Submission of Dissertation Draft Submission of Technical Paper Draft													■			
7	Submission of Dissertation (Soft Bound)														■		
8	Submission of Technical Paper														■		
9	Oral Presentation															■	
10	Submission of Project Dissertation (Hard Bound)																■

■ Process

Figure 3.3: Milestones for the second semester of final year project

3.4 Data Gathering

The required data is collected in order to be put as the input parameters inside the TRNSYS Simulation Program. The data needed such as list of SHWS available in Malaysia, location for main cities in Malaysia, Malaysia weather and monsoon seasons, average monthly cold water temperatures and average monthly sunshine for main cities in Malaysia.

In order to achieve a successful evaluation for the system's thermal performance using TRNSYS software, all the appropriate input parameters needs to be obtained to be able to come out with appropriate values of the thermal systems in Malaysia. One of the important things that need to be collected is the storage tank capacity that available in Malaysia.

Table 3.2 shows the list of Solar SHWS that available in the Malaysian market nowadays. There are various types of SHWS that available in Malaysia such as the Flat Plate SHW, the Evacuated Tubes SHW with respective specifications. Storage tank capacity for each system is stated as well. The storage tank capacity shown in Table 3.2 can be further reduced into several categories such as, small capacity, medium capacity and large capacity as shown in Table 3.3.

The location for main cities in Malaysia is very important to be known as different cities will have different values of sunshine data based on their longitude and latitude of that particular location. Different location will affect the efficiency of the solar collector itself. For example high land such as in Kota Kinabalu will have higher solar radiation compared to low land which in Kuala Lumpur (See Appendix A).

Table 3.2: List of SHWS available in Malaysia

Manufacturer	Model	Collector Type	System Type	Tank Capacity, (L)
Solarela System Inc (Simon, 2003)	M328/HE	Evacuated Tubes Solar Water Heater	Closed Couple	100 – 280 L
Powerlite Global Sdn Bhd (Roy, 1999)	SP60gE	Flat Plat Solar Water Heater	Active	200 L
Green Solar Energy Sdn Bhd (Green, 2011)	S-series, P-series, T-series	Flat Plat Solar Water Heater	Active	300 L
SolarMate Sdn Bhd (Andre,1999)	MMS-60	Flat Plate Solar Water Heater	Active	227 L
Lexsun Holdings Sdn Bhd (Lexsun, 2012)	No Model	Flat Plate Solar Water Heater	Closed Couple	180 – 300 L
TC Marketing & Trading Sdn Bhd (SunFlow, 2012)	SunFlow 300FX SunFlow 180FX	Flat Plate Evacuated Tubes Solar Water Heater	Closed Couple	300 L 180 L
AUMADA Energy & Technologies (Aumada, 2012)	Solahart 300	Flat Plate Solar Water Heater	Heat Pump	300 L

Table 3.3: Storage tank capacity categories

Storage Tank Capacity	Category
Large	Tank volume equal to or greater than 300 L
Medium	Tank volume less than 300 L and greater than 200 L
Small	Tank volume equal to or less than 200 L

Apart from location, Malaysia weather data is also important in order to know which month having the very heavy rain and vice versa. Malaysia weather data is shown as per Table 3.4. The data is also one of the main input parameters to be put inside TRNSYS Simulation Program in order to get the thermal performance of the systems.

Table 3.4: Malaysia weather, monsoon seasons (Ecographica, 2008)

Season	Months	Peninsula Malaysia
Northeast Monsoon	Nov-Dec to March	Heavy Rainfall, Flooding
Southwest Monsoon	June to Sep-Oct	Less Rain, Dry In June-July
Intermonsoon Period	Apr-May	Light Winds, Clear Mornings, Thunderstorms In Afternoon
Intermonsoon Period	Oct-Nov	Light Winds, Clear Mornings, Thunderstorms In Afternoon

Monthly water cold temperature in Malaysia is also one of the important information to have in order for TRNSYS to be able to calculate the appropriate value of systems thermal performance. The data for the monthly cold water temperature is shown in Table 3.5. By having these input values, the software will evaluate whether the systems is able to supply enough hot water based on the monthly cold water temperature for each location. For example for Kota Bahru as shown in Table 3.5, the lowest water temperature is about 22.5°C from December up to January. The systems should be able to supply enough hot water on this particular month since the water temperature is quiet low. However, on May which is the highest water temperature around 34°C, systems may not be able to perform at its full capacity since the water temperature is already in high temperature, thus will save some energy from it.

Table 3.5: Monthly cold water temperature for several cities in Malaysia (El Dorado Inc, 2008)

Month	Kuala Lumpur (°C)		Kota Kinabalu (°C)		Cameron Highland (°C)		Kota Bahru (°C)	
	Lowest recorded	Highest recorded	Lowest recorded	Highest recorded	Lowest recorded	Highest recorded	Lowest recorded	Highest recorded
Jan	22.0	35.0	21.0	29.0	19.0	31.0	22.5	29.0
Feb	22.5	36.0	21.5	30.5	21.0	33.0	22.7	29.9
Mar	22.7	37.0	22.0	31.0	20.0	32.7	23.0	31.0
Apr	22.9	36.0	22.5	31.0	21.0	32.5	24.0	32.5
May	23.0	35.0	23.0	33.0	22.0	32.3	24.5	34.0
Jun	22.5	36.0	20.5	32.5	20.0	32.0	24.0	32.2
Jul	21.5	36.0	20.0	32.3	19.0	31.5	23.0	32.1
Aug	21.5	36.0	20.0	32.3	19.0	32.0	23.0	32.1
Sep	21.5	35.0	20.0	32.0	20.0	31.5	23.0	31.8
Oct	22.0	36.0	22.8	31.7	21.0	33.0	23.0	31.5
Nov	22.0	35.0	22.3	30.3	21.0	31.5	22.6	29.0
Dec	21.5	34.0	20.0	28.5	19.0	31.0	22.5	28.5

The average monthly sunshine is the most important things to be known since the primary source for the system is the solar energy which comes from the sun. Without this energy, water can not be heat up and the system will not be able to function as it is. The data for solar energy should be collected in order to calculate the amount of energy that received from one day to another as shown in Table 3.6. For example in Kota Bahru, the highest solar radiation that solar collector receives is at April which is around 9 hours per day. The lowest that it receives is on November which is only 5 hours per day. Based on these data, the systems will have low auxiliary energy rate in April compared to November since the solar energy supply in that particular month is enough to heat up the water without the used of back-up heater. As for November, the systems should used back up heater to heat up the water in order to fulfill the customer's requirement.

Table 3.6: Average daily sunshine data for several cities in Malaysia (El Dorado Inc, 2008)

Month	Kuala Lumpur, (h)	Kota Bahru, (h)	Melaka, (h)	Kuantan, (h)	Miri, (h)	Penang, (h)	Kota Kinabalu, (h)	Labuan, (h)
Jan	6.0	7.3	6.0	5.3	5.7	8.0	6.0	6.5
Feb	6.8	8.0	7.6	6.3	6.0	8.2	7.0	7.1
Mar	6.6	8.2	7.3	6.3	6.3	7.8	7.8	8.0
Apr	6.5	8.7	7.3	6.4	7.2	7.7	8.1	8.2
May	6.6	7.9	7.2	6.3	7.1	6.8	7.8	7.9
Jun	6.5	7.3	7.0	6.2	7.0	6.9	6.4	7.5
Jul	6.5	7.5	9.9	9.9	7.0	6.8	6.4	7.0
Aug	6.0	7.3	6.0	6.2	6.3	6.1	6.2	7.5
Sep	5.6	7.2	5.8	5.9	6.2	5.6	6.0	6.5
Oct	5.6	6.0	5.9	5.2	5.9	5.7	6.2	6.6
Nov	5.0	5.0	5.5	3.9	6.2	6.1	6.4	6.8
Dec	5.5	5.3	5.6	3.8	6.0	6.4	6.4	6.7

3.5 System Descriptions

Figure 3.4 shows the components configuration for a typical SHWS. The collector, which can be flat plate collector or evacuated tube type, is connected to a storage tank which stores a hot water heated by the collector. Depending on the solar collector capacity and weather conditions, the water may need further heating either inside the tank (by electric element) or before being delivered to the hot water use point. For a thermosyphon system, the tank is placed on top of the collector where the water in the tank is heated by natural convection.

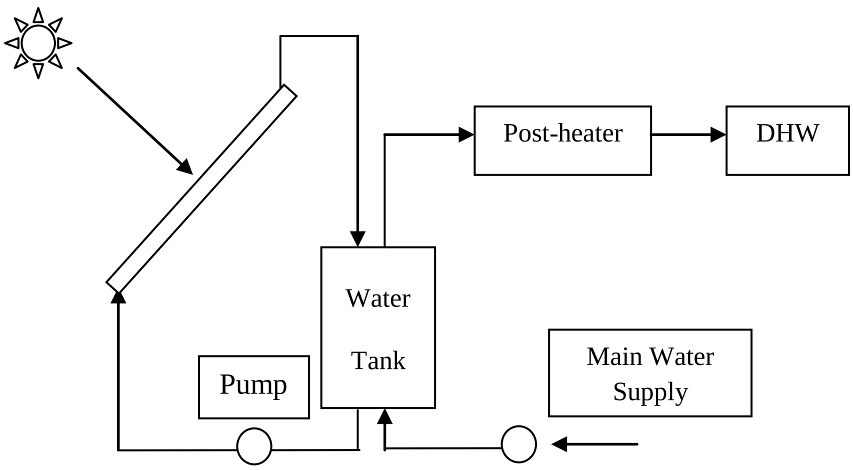


Figure 3.4: Schematic of a SHWS

As for the experimental result, the thermal performance assessment for the main components of the systems is available and can be collected from the manufacturers or suppliers in Malaysia. This is because the main components of the system need to be tested first before it can enter the industry. The data for this assessment result is already stated in the data gathering process in Section 3.4.

3.5.1 Solar Collector

Solar collector is one of the main components of SHWS. Solar collector will absorb the solar radiation from the sun and use the energy to heat up water inside the storage tank. The existing standards for evaluating the thermal performance of solar collectors such as ANSI/ASHRAE Standard 93:2003 (ASHRAE, 2003) can be used as the basis for developing such a standard in Malaysia. The thermal performance of the collector, the tank and the pump can be evaluated individually. The result of these evaluations will be used in order to calculate the thermal performance of the overall system using the computer modeling or simulation.

3.5.2 Storage Tank

A hot water storage tank is a water tank that is used for storing hot water in order for space heating or for a domestic use. A heavily insulated tank can retain heat for days (Wikimedia, 2012). The thermal performance of the storage tank depends much on the tank dimension and material of tank wall and tank insulation. Hot water tanks may have a built-in gas or oil burner system, or electric immersion heaters, or may use an external heat exchanger to heat water from another energy source such as district heating, wood-burning stove, or district system.

Water heaters for washing, bathing, or laundry have thermostat controls to regulate the temperature, in the range of 40 to 60°C, and are connected to the domestic cold water supply. Water supply has a high content of dissolved minerals such as limestone, heating the water and will causes the minerals to precipitate in the tank, a water tank may develop leaks due to corrosion after only a few years. Dissolved oxygen in the water can also accelerate corrosion of the tank and its fittings. A hot water storage tank is wrapped in heat insulation to reduce heat loss and energy consumption (Wikimedia, 2012).

3.5.3 Pump

For a forced circulation solar water heating system a pump is required to re-circulate the water between the collector and the tank. Before installing a SHWS system based on Department of Climate Change (2010), installers should consult manufacturer's instructions on minimum ventilation requirements and should also ensure that:

(a) The system can be positioned in the warmest and sunniest location.
(b) There is enough empty space around the system to allow adequate air flow.
(c) There is access to the system for installation and ongoing maintenance.
(d) There is at least 1.2 m clearance from bedroom windows to minimize the effects of the noise generated by the system.

3.6 Modeling and Simulation of the System

In order to analyze any system, a model which behaves like the real one is needed. The aims of creating the model are to know the behavior of the system and the effects of each parameter on the whole system. The model will describe what will happen at the system when it is operated thus avoid any over-designing or under-designing the system during the design state. Once the model is created, the performance, phenomena, and efficiency of the system can be analyzed. Based on this analysis, further action can be taken in order to increase the performance and to optimize the system hence will reduce cost from trial and error activities.

3.6.1 Mathematical Modeling

Mathematical model are commonly used in order to describe the system by a set of variable and equation. Figure 3.5 shows an example for a conduction heat transfer (q) through an external wall which occurs at solar storage tank. The variable which will affect the heat transfer are the thickness of the wall (l), conductance of the wall (k), inside temperature (T_i), and outside temperature (T_o).

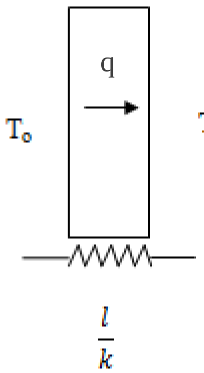


Figure 3.5: Simplified system for mathematical modeling of storage tank's wall

The mathematical model can be described as:

$$q = \frac{k}{l} A(T_o - T_i) \quad (3.1)$$

With the model, the effect of each variable on the heat transfer rate can be easily determined. In order to increase the heat transfer rate, the wall area should be increase as well as the temperature difference between inside and outside of the wall or changing the wall material with higher conductivity.

For transient condition where ΔT is changing over time due to ambient conditions, the mathematical model will be:

$$dq = \frac{k}{l} A \frac{\Delta T}{dt} \quad (3.2)$$

By solving Equation (3.2), the amount of heat transfer over period of time is achieved. Solving the equation with all possible variations of the variables is needed to determine the characteristic. In order to simplify the calculation, some assumptions are made such as there is no heat loss occurs at the storage tank.

In real condition, however, the system will be much more complex with a lot more variables and equations. The system needs to calculate the total heat transfer rate occurs at the main components. For example, the calculation need to be done at a solar collector where radiation heat transfer will occurs as well as the conduction heat transfer which occurs at storage tank. This situation happens in transient condition. Heat loss is also need to be considered since in real situation it always occurs. Hence, solving the equation will be time consuming and unstable because of human error. Due to this, solid computer model is developed to do the calculation.

Solid model is built based on a mathematical modeling. The models are usually built using programming language or other engineering software. It requires input parameters to calculate the output. Solid models will be linked to each other for the complex systems. It can be modified based on the real system. The main advantages between solid model and mathematical model are its stability since there is no human error during calculation and less time consuming. The model is constructed one time and it will take care all of the calculation later on. The accuracy of the model to describe real system will depend on the accuracy of the data input as well as the mathematical model behind the models.

3.6.2 TRNSYS Simulation Program

The software that will be used in this project would be TRNSYS Simulation Program in order to come out with the system's thermal performance as well as the heat transfer rate at solar collector and storage tank for SHWS. Microsoft EXCEL is also used in order to arrange all the input parameters that already collected in a correct manner.

TRNSYS is simulation environment software for the transient simulation of systems, including multi-zone buildings (Klein et. al, 2005). It can be used to simulate from simple domestic hot water systems to the design and simulation of multi-zone buildings and their equipment, including control strategies, occupant behavior and occupancy schedule, alternative energy system and others. TRNSYS also provide tool named weather data reader and processing to read weather data from external source or to generate weather data from weather data generator provided by TRNSYS.

In general, there are two kind of simulation which are steady state simulation (under steady state condition) and transient simulation (under transient condition).
Steady state simulation is a simulation of a system where the parameters remain unchanged (steady state condition) with time. Under steady state condition, the behavior of the system is always the same with previous observed behavior of the system. In many cases, steady state condition is achieved after certain time from the system is started. The initial condition (from the system is started till it reach steady state condition) is usually considered as transient state. Transient simulation is a simulation of the system in question where the parameters are changed with time (transient condition).

As long as the parameter used is changing, the system is on transient condition and therefore, the behavior will keep changing. As simulation software, TRNSYS can be used to do transient and steady state simulation. Other advantages of TRNSYS software are its flexibility to make any changes in the simulated system and feature to make new component if the component needed have not provided yet by the software (Klein et. al, 2005).

3.6.3 TRNSYS Model Construction

Figure 3.6 shows the flow chart of constructing a SHWS model inside TRNSYS Simulation Program. The process begins by defining the system up to the simulation and analyzing the thermal performance results from the software.

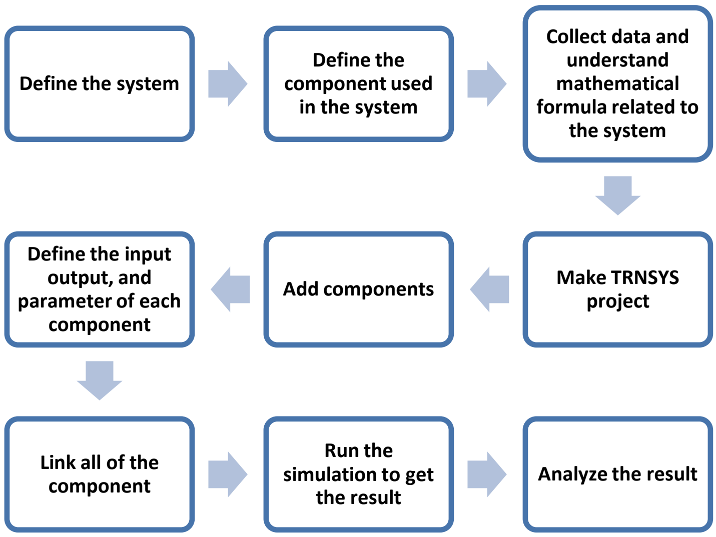


Figure 3.6: TRNSYS configuration flow chart

Below is the procedure of constructing a SHWS model inside the TRNSYS Simulation Program.

1. TRNSYS Simulation Program was loaded. Empty TRNSYS project function was selected from the Start Menu.

   Start > New > Empty TRNSYS Project

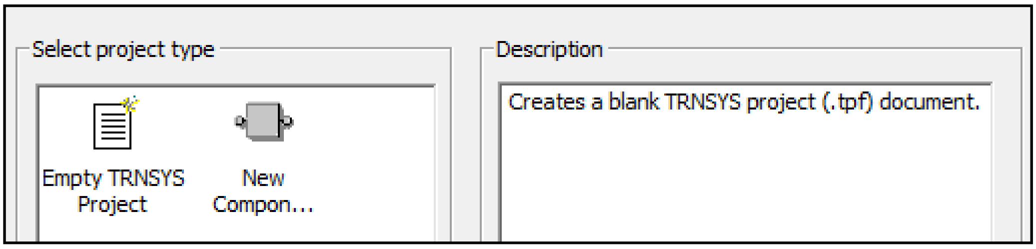


Figure 3.7: Start bar menu

2. Use arrow pointer to select components by clicking  .
3. Use direct access toolbar to select a component in the tree structure and click on the assembly panel.

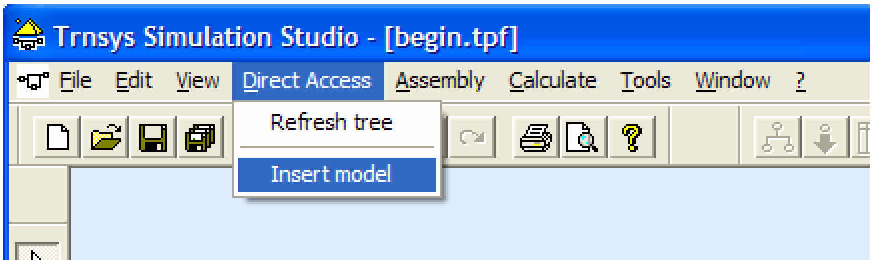


Figure 3.8: Direct access tool

4. Define weather data used.

   Weather Data Reading and Processing > Meteonorm Files > Type 15-6

Figure 3.9: Weather data used

5. Add components. Define characteristics for each component. Add solar collector.

   Solar Thermal Collectors > Flat Plate Collectors > Type 73

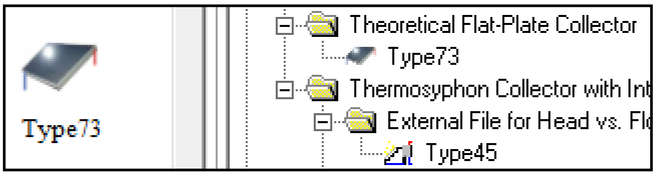
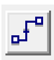


Figure 3.10: Flat plat collector added inside assembly panel

6. Add link between components by clicking .

7. Add solar controller.

   Controllers > Differential Controller > For Temperature > Control Strategy > Tybe2b

Type2b

Figure 3.11: Solar controller model

8. Add storage tank capacity.

   Thermal Storage > Variables Inlets > Uniform Losses > Type 4c

Type4c

Figure 3.12: Storage tank model

9. Define pump characteristics.

   Hydronics > Pumps > Single Speed > Type 3b

Type3b

Figure 3.13: Pump

10. Add load profile.

    Utility > Forcing Function > Water Draw > Type14b

Type14b

Figure 3.14: Load profile

11. Add daily load.

    Utility > Forcing Function > Daily Load

Daily load

Figure 3.15 Daily load

12. Add simulation integrators for calculation.

    Integrators > Quantity Integrator > Type 24

Type24

Figure 3.16: Integrator

13. Add tee piece.

Hydronics > Tee-Piece > Other Fluids > Type 11h

Type11h

Figure 3.17: Tee-Piece

14. Add printers.

Output > Printer > Formatted > TRNSYS Supplied Units > Type25d

Type25d

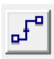
Figure 3.18: Printer

15. Add plotters.

Output > Online Plotter > Online Plotter with File > TRNSYS Supplied Units > Type65a

Type65a

Figure 3.19: Plotter

16. Link all of the components by clicking .

3.6.4 TRNSYS Configuration of SHWS Model

Based on Section 3.6.3, the TRNSYS configuration of a SHWS has been constructed as per Figure 3.20. It is the same exact configuration as the original SHWS shown in Figure 1.1 except this is the simulation process done inside the TRNSYS software. The solar collector array receives the solar radiation from the weather data supplied from various location and heat up the water at the storage tank. As for this project the Kuala Lumpur weather data used in order to assess the systems within this location. The input parameters needed for load profile, solar collector as well as storage tank.

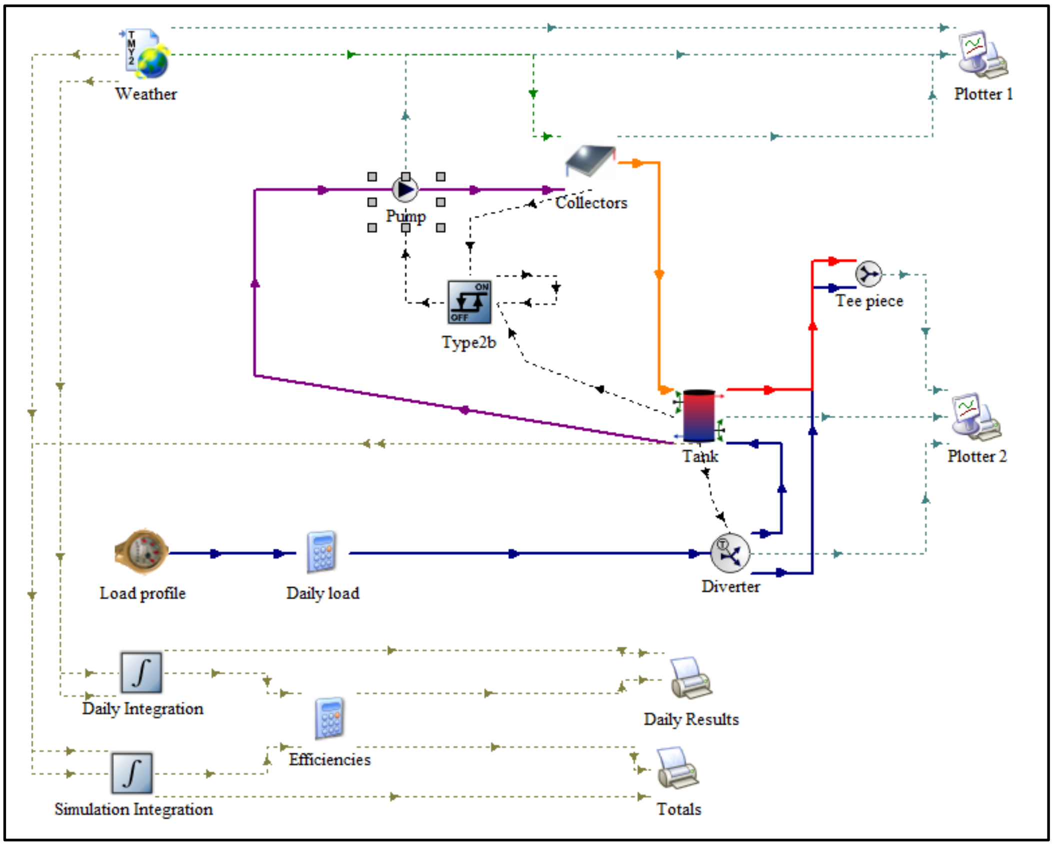


Figure 3.20: TRNSYS configuration of a SHWS model

3.6.5 Reliable Input Parameters for SHWS

The Kuala Lumpur weather data is used for this project and the data is already built-in inside the software. There is also other weather data available in TRNSYS Simulation Program depends on the location of the SHWS that need to be assessed.

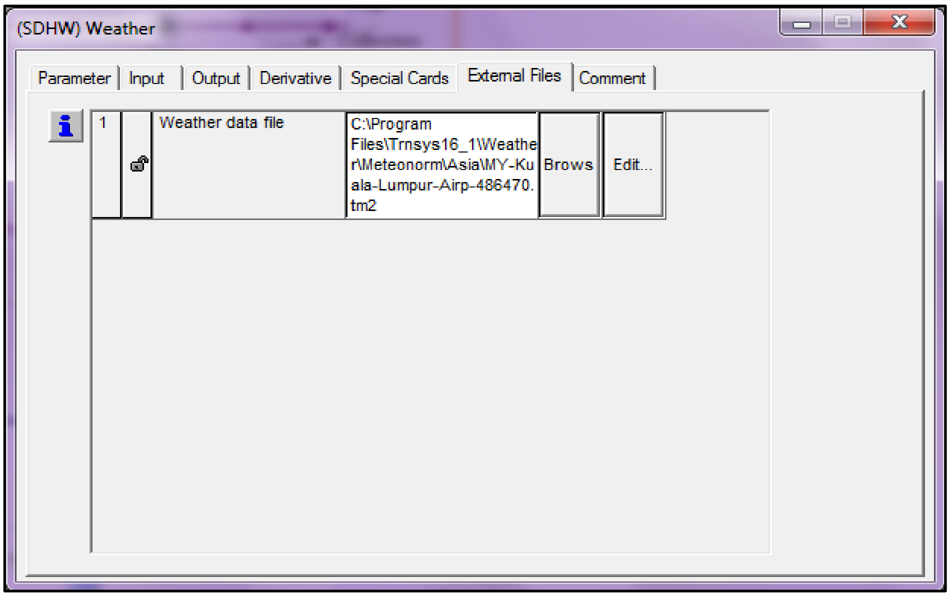


Figure 3.21: Kuala Lumpur weather data

As for solar collector, the required input parameters are inserted as shown inside Table 3.7. The thermal performance of solar collector can be affected by the collector materials, collector orientation, the slope as well as the surrounding environment of the collector such as tree, dust or wind.

Table 3.7: Solar collector inputs data

No	Parameters	Value	Unit
1	Inlet temperature	27	°C
2	Inlet flow rate	100	kg/hr
3	Ambient temperature	31	°C
4	Incident radiation	9	$kJ/hr.m^2$
5	Collector slope	0	degree
6	Incidence angle	45	degree
7	Ground reflectance	0.2	-

The thermal performance of the storage tank depends mainly on the tank dimension and the material of the tank wall. The most important parameter is the tank standing heat loss defined as the heat loss during a day from a tank. All the input parameters needed for storage tank is shown in Table 3.8.

Table 3.8: Storage tank inputs data

No	Parameters	Value	Unit
1	Variable inlet positions	2	-
2	Tank volume	0.2	m^3
3	Fluid specific heat	4.190	kJ/kg.K
4	Fluid density	1000	kg/ m^3
5	Tank loss coefficient	2.5	$kJ/hr.m^2.K$
6	Height of node-1	0.3	m
7	Height of node-2	0.3	m
8	Height of node-3	0.3	m
9	Height of node-4	0.3	m

The thermal performance of the pump depends mainly on the maximum power of the pump. This amount of power will define the maximum fluid flow rate inside the pump which can be re-circulated between the collector and the tank. All the input parameters needed for storage tank is shown in Table 3.9.

Table 3.9: Pump inputs data

No	Parameters	Value	Unit
1	Maximum flow rate	200	kg/hr
2	Fluid specific heat	4.19	kJ/kg.K
3	Maximum power	240	kJ/hr
4	Conversion coefficient	0.05	-
5	Power coefficient	0.5	-

Solar collector and storage tank components are linked into a plotter in order to show the result based on the input data given. The results from these plotters are discussed in details in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

Once the required input parameters are already in, the software will run the systems and will generate an appropriate result based on the data loaded. As a result, there are two graphs available to be analyzed since there are two plotters, one is connected to solar collector and the other is connected to the storage tank. The detailed information is discussed in Sections 4.1 and 4.2.

4.1 Results from Solar Collector

The variations of result with respect to time for solar collector are shown in Figures 4.1 and 4.2. The graph shows the temperature and the heat transfer rate occurs inside the solar collector. T_iColl is the inlet temperature for solar collector while T_oColl is the outlet temperature. GColl is the solar irradiance on the collector surface while mdColl is the solar radiations occur at solar collector surface (See Appendix B). The unit used for simulation time shown in both Figures 4.1 and 4.2 is in hour. The system is simulated to perform for a week or 7 days. Time starts when the system is started to operate at 0 hour and stop when the simulation time is 168 hour.

As for this project, the solar radiation for this solar collector is known to be about 1700 Wh/day which is the average value. The inlet temperature for solar collector is about 60°C while the outlet temperature is about 55.5°C. As shown in Figures 4.1 and 4.2, the inlet and outlet temperature is varies from one day into another depends on the weather condition of the location. The lowest inlet temperature recorded is 10°C while the highest is about 65.5°C.

As for the solar heat transfer rate, the highest value recorded is around 2000 Wh/day. This value is very much depends on the solar radiation by the sun that as been absorbed by the solar collector. The more solar energy absorbed, the better solar heat transfer rate thus will increase the efficiency of the overall systems. The lowest value recorded for solar heat transfer rate is 600 Wh/day due to insufficient solar energy for that particular day.

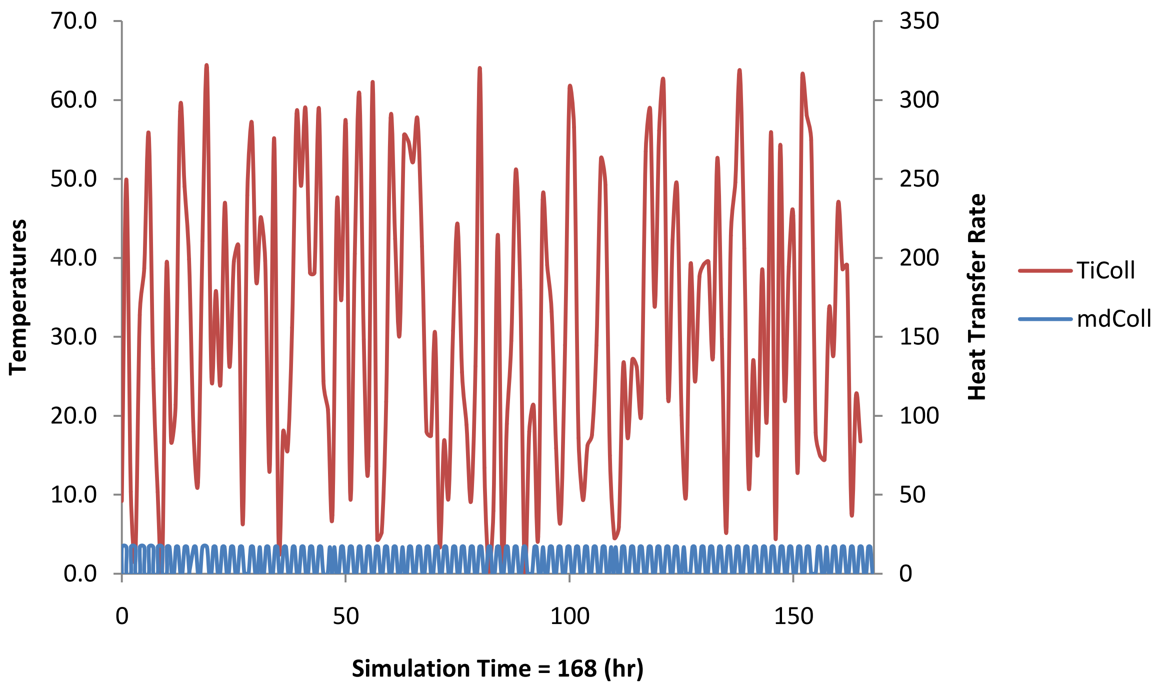


Figure 4.1: Inlet temperature and solar radiation at solar collector

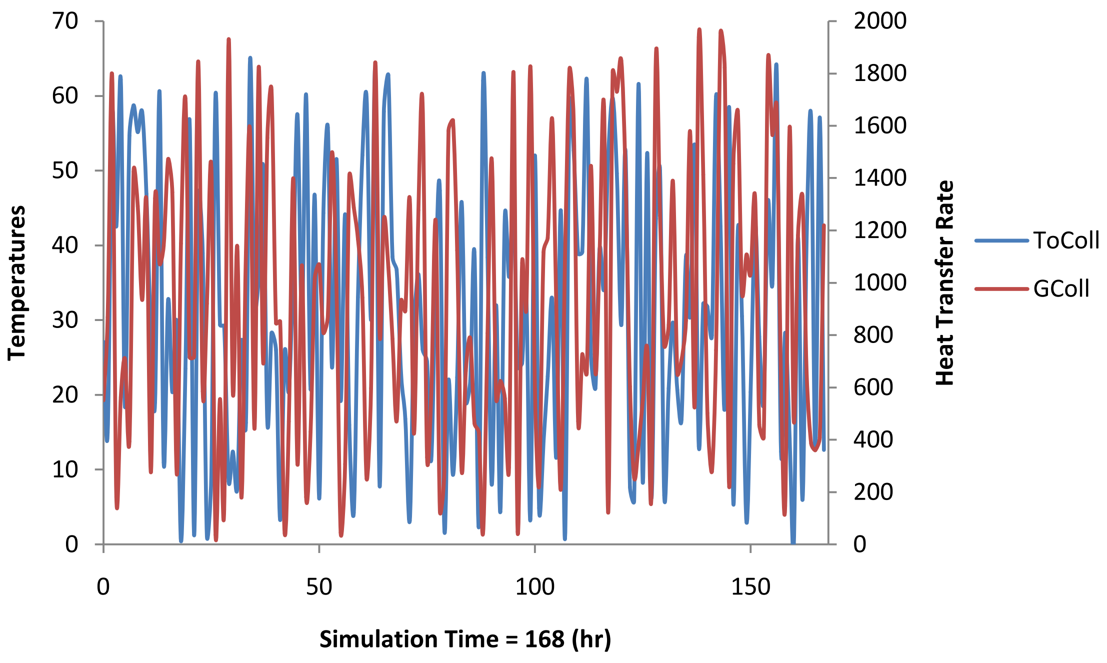


Figure 4.2: Outlet temperature and solar irradiance at solar collector

4.2 Results from Storage Tank

Figures 4.3 and 4.4 shows the variation of temperature and the heat transfer rate inside the storage tank with time. As shown, TTop is the top temperature for storage tank while the others are the indication of the temperature all around the storage tank. The most important result from this graph is QAux which is the auxiliary heat transfer rate (See Appendix B). This value is important is it will define the efficiency or the thermal performance of the overall systems. The lower auxiliary heat transfer rate will brings greater efficiency to the SHWS since the energy used from the back-up systems is fully minimized.

As for this project, the average auxiliary heat transfer rate is known to be 4500 Wh/day as per Figure 4.3 while the average top temperature for storage tank is about 59°C as per Figure 4.4. The auxiliary heat transfer rate is varies from one day into another depends on the solar radiation for that particular period of time as well as the location of the systems. The auxiliary heat transfer rate is inversely proportional with the solar radiation. It means that the higher solar radiation for a particular period of time, the lower auxiliary heat transfer rate. The lowest auxiliary heat transfer rate recorded is 500 Wh/day while the highest value is 5000 Wh/day.

As for the tank top temperature as well as the other temperature, the lowest recorded is 55°C and the highest value is 60°C. The top temperature is varies form one day into another due to the heat transfer rate at the wall of storage tank which is mainly depends on the type of insulation materials used for the systems. The more heat loss to the surrounding will reduce the top temperature thus will reduce the efficiency of the overall system.

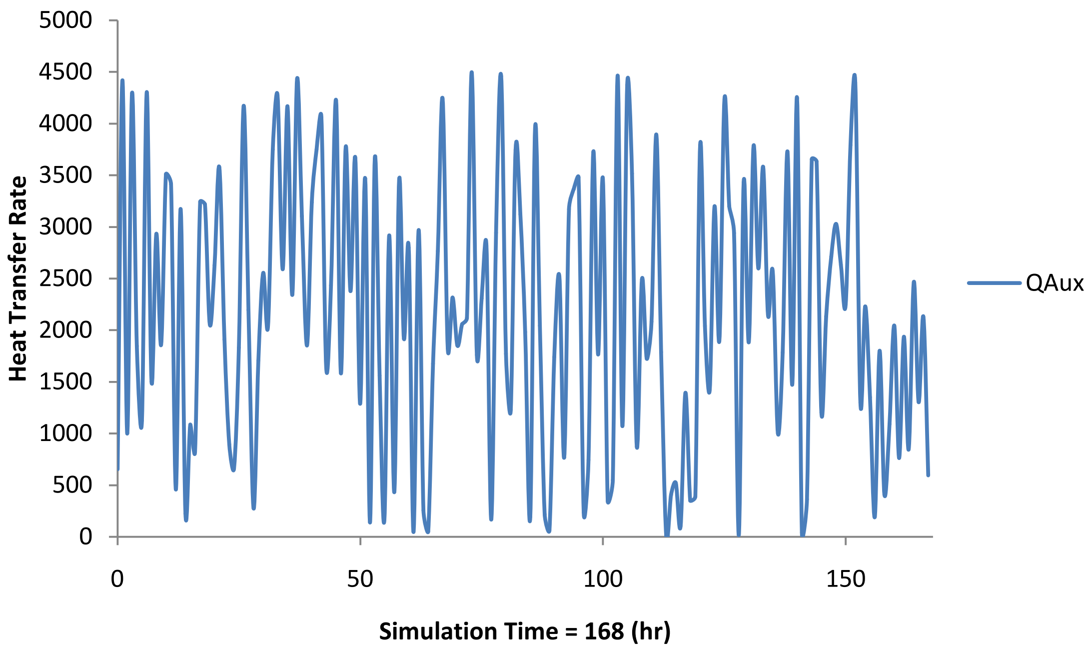


Figure 4.3: Auxiliary heat transfer rate at storage tank

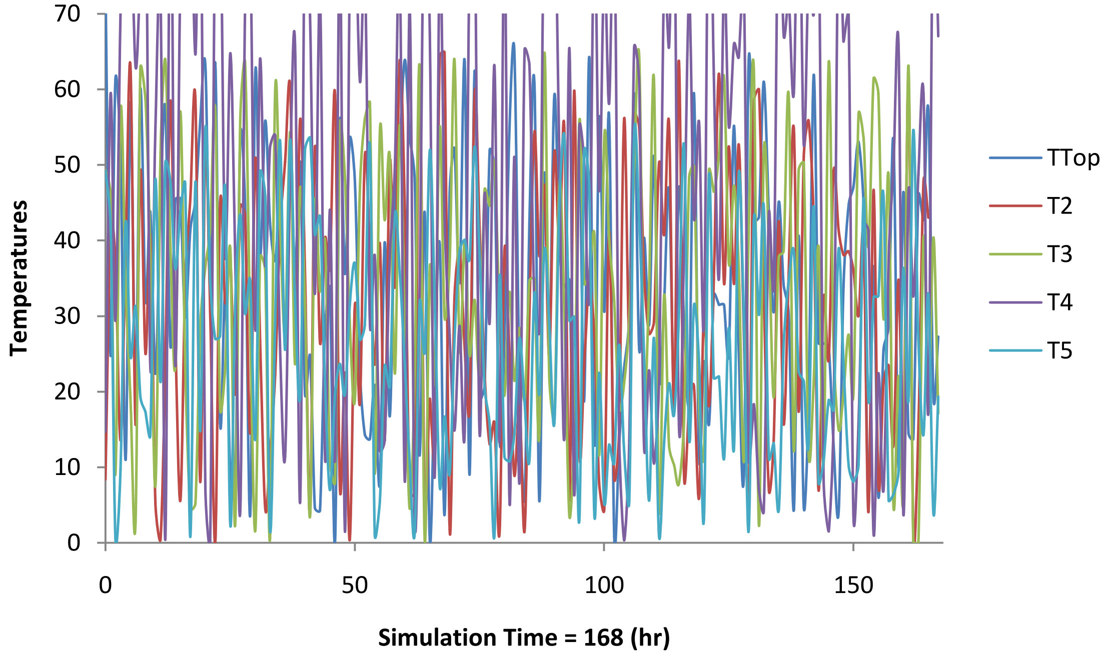


Figure 4.4: Variation of temperature in storage tank

Based on the results obtained in Figures 4.3 and 4.4, the thermal performance of the systems is mainly depends on the auxiliary heat transfer rate at storage tank which is 4.5 kWh/day. Thus, the rating calculation for the systems is shown in Sections 4.3 and 4.4.

4.3 Introduction to Rating Method of SHWS in Malaysia

This methodology is to be used to calculate the renewable energy savings for a Solar Hot Water System (SHWS) with a volumetric storage capacity up to 300 L for the household purposes.

The annual energy savings for a Solar Hot Water System is calculated by subtracting the energy used by SHWS that deliver to the specified purposes from the electrical energy consumption of an electric water heater (conventional water heater) which deliver the equivalent load. This needs to be calculated for each of the zones which energy savings are to be claimed.

4.3.1 Proposed Thermal Performance Rating Calculation Method

Thermal performance rating calculation method is used to calculate the annual energy savings and greenhouse gas emission reduction by using SHWS with a volumetric water storage tank up to 300 L for the domestic purposes. The method is as follows:

i) Use TRNSYS input parameters in order to calculate the auxiliary boost energy for a Solar Hot Water System using TRNSYS Simulation Program.
   a) Solar collector efficiency parameters determined in accordance with ISO Standards-ICS 97.030
   b) Tank heat loss is determined in accordance with ISO Standard-ICS 97.030
   c) Modeling shall be carried out using a simulation time step of 0.1 hr or less
   d) Use Table 4.1 to determine the hot water load (small, medium or large) based on the size of the solar storage tank
   e) Peak loads for each zone is provided in Table 4.2
   f) Monthly usage patterns are provided in Table 4.3
   g) Monthly cold water temperatures for each zone are provided in Table 3.5

ii) Weather data to be used for each zone can be obtained in Table 3.4. Further documentation of weather data is available at http://www.met.gov.my

iii) By default, TRNSYS simulation software reports auxiliary energy as average daily for each month. The unit would be in kJs. Multiply average daily kJ by the number of days in each corresponding month. Sum the monthly totals to determine total auxiliary energy.

iv) From Table 4.1 look up the size of the equivalent conventional water heater (small, medium or large) using peak load delivery capacity of the solar water heater (kJ/day).

v) From Table 4.4 look up the electrical energy consumption of an equivalent sized (small, medium or large) electric water heater

vi) Subtract the total annual auxiliary energy of the solar water heater from the equivalently sized (small, medium or large) electric water heater to determine the annual saving of input energy

vii) Multiply this calculated annual saving by 10 to determine the 10 year renewable energy savings allocation

viii) The savings calculated above should be rounded down to an integer value.

Table 4.1: Hot water rating loads

Hot water load	Single tank product with solar & auxiliary inputs to the one tank	Solar preheat product with series connected instantaneous booster and two tank products
Large	Tank volume equal to or greater than 300 L	Preheat tank volume equal to or greater than 200 L
Medium	Tank volume less than 300 L and greater than 200 L	Preheat tank volume less than 200 L and greater than 100 L
Small	Tank volume equal to or less than 200 L	Preheat tank volume equal to or less than 100 L

Table 4.2: Peak energy load for each zone

System Size	Peak Load (MJ/day)			
	Kuala Lumpur	Kota Kinabalu	Cameron Highland	Kota Bahru
Large	41.3	45.0	47.8	42.7
Medium	31.5	34.5	35.0	32.0
Small	20.2	22.0	22.5	20.0

Table 4.3: Monthly hot water usage patterns for each zone

Month	Monthly Usage Patterns (Ratio of peak month)			
	Kuala Lumpur	Kota Kinabalu	Cameron Highland	Kota Bahru
Jan	0.44	0.69	0.68	0.55
Feb	0.50	0.65	0.68	0.55
Mar	0.58	0.74	0.73	0.57
Apr	0.69	0.74	0.81	0.64
May	0.86	1.00	0.92	0.77
Jun	0.75	0.8	0.97	0.75
Jul	0.61	0.87	0.95	0.70
Aug	0.53	0.90	0.89	0.70
Sep	0.49	0.87	0.81	0.70
Oct	0.47	0.84	1.00	0.70
Nov	0.47	0.80	0.76	0.53
Dec	0.44	0.76	0.70	0.55

Table 4.4: Standard electric energy consumption for conventional systems

System Size	Hot Water Delivery (L/day)	Average Person	Hot Water/Person/ Day	Capacity (MWh/a)
Large	100	1.3	92	4.93
Medium	200	2.5	80	3.72
Small	300	4.4	68	2.44

4.3.2 SHWS Rating Calculations

Using the auxiliary heat transfer rate value obtained from the TRNSYS Simulation Program shown in Figures 4.3 and 4.4, the system thermal performance is known to be 4.5kWh/day based on the input energy load which is 20.2 MJ/day shown in Table 4.2 for small capacity and Kuala Lumpur zone.

Based on the proposed rating calculation method in Section 4.3.1, the total auxiliary energy used for SHWS in a year can be calculated to be 1.644 MWh/year (See Appendix C).

Using the equivalent data for conventional electric water heaters shown in Table 4.4, the energy consumptions would be 2.44 MWh/year. Thus, the energy savings by using SHWS is calculated and found to be 0.796 MWh/year or 2.866 GJ/year.

In 10 years, the amount of energy that can be saved would be 7.96 MWh. This huge amount of energy is saved by using the SHWS instead of electric water heaters systems. The amount of greenhouse gas emissions can also be quantified.

4.4 Proposed SHW Rating Systems

Based on the annual energy savings calculation in Section 4.3.2, the same calculation process is done using the other different locations which is in Kota Kinabalu, Cameron Highland and Kota Bahru. The annual energy savings for different location is shown in Figure 4.5.

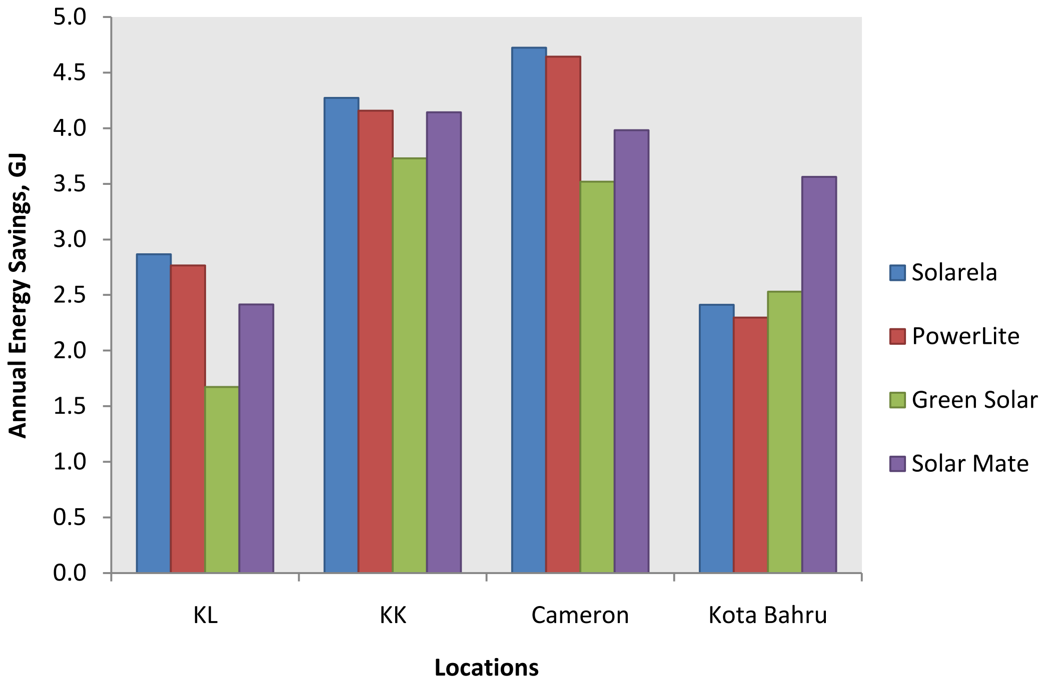


Figure 4.5: Annual savings energy in GJ for various locations in Malaysia

Based on the calculation in Section 4.3.2, the SHWS can be rate into several schemes based on their thermal performance as well as the energy savings and the greenhouse gas emission reduction for each system.

The comparative performance information in Figure 4.5 clearly differentiates between SHWS and the conventional water heaters based on the energy savings and if presented as a 10 point star rating system with six stars reserved for future developments, ranking would apply based on Equation (2.1):

The proposed ranking systems would be as follows:

i) 4 – Green Solar Energy Sdn Bhd
ii) 2 – SolarMate Sdn Bhd
iii) 1 – PowerLite Global Sdn Bhd and Solarela System Inc

Based on the proposed rating systems of solar hot water, it will provide guideline and safety awareness to the manufacturers or suppliers in order to come out with a proper SHWS that will lead to the green technology. This is because the thermal performance claimed by the manufacturers or suppliers can be assessed using the proposed method mentioned in this project. By doing so as well, the amount of energy savings of using SHWS instead of conventional electric water heater is quantified. This assessment method will help the consumers to assess the economical feasibility for this system.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The main objective for this project is to study the thermal performance assessment of SHWS in Malaysia by using combined direct measurement and computer modeling or simulation method. Based on the results presented in Chapter 4, the objective for this project has been achieved.

5.1 Conclusions

This report discussed about the proper rating system for solar hot water in order to quantify the overall energy savings used. In order to develop this rating system, a study on thermal performance assessment of SHWS in Malaysia is required. Although the proposed thermal performance rating calculation method has not been certified and endorsed by Malaysian government, yet the development of this rating method is the first and crucial step that leads to minimize the energy performance of the SHWS itself. The proposed thermal performance rating method will also help to quantify the energy savings and greenhouse gas emissions reduction of the system. Different location and systems characteristics will lead to the different result of thermal performance. This is due to the weather condition of the particular location that been assessed as well as the efficiency of the system itself. This shows the importance of the proposed thermal performance rating method discussed in this report.

The proper thermal performance rating produced will be used to provide helpful information to consumers, in order to verify the claimed energy performance and greenhouse gas emissions reduction of the system, to provide basis for comparison of greenhouse impact of all forms of water heating appliances in Malaysia as well as to provide the references and guidelines for supporting program.

5.2 Recommendations

Successful realization of the development of SHWS thermal performance evaluation method mainly depends on reliability of the input parameters of the TRNSYS Simulation Program. Invalid input parameter will lead to inappropriate value of thermal performance thus will affect the annual energy savings calculation and the systems rating. For example, different weather data used for a different location will cause inappropriate thermal performance value obtained thus will affect the rating of the system. An in-depth research should be done in order to collect a reliable and relevant input data for this project. The data should come from the satisfied source with appropriate references as shown in the project.

In order to avoid future chaos in the SHWS industry due to the establishment of method, gradual and smooth introduction of the proposed rating methodology should be well planned by the government itself. This can be realized through the formulation of immediate action plans. The immediate plan should include briefing to SHWS industry on the importance, potential benefits and impacts of a rating program on the industry and the government policy in order to minimize the impacts.

The role of Malaysian government in realizing this project is very important. In order to make the proposed thermal performance rating calculation method a success, the certification and endorsement by Malaysian government (SIRIM) is very essential and crucial step. This is the first step that leads to the establishment of minimizing the energy performance of the SHWS. The proposed thermal performance rating method will help to quantify the energy savings and greenhouse gas emissions reduction of the system. Table 5.1 shows the milestone of the past works that already been done as well as the future recommendations in order to make this project a success.

Table 5.1: Summary of the work done and recommendations for future purposes

WORK DONE INTHE PROJECT		**RECOMMENDATIONS FOR FUTURE PURPOSES**
i. Preliminaries research work ii. Literature review on rating method for SHWS iii. Research methodology iv. Data gathering for input parameters v. Model construction of SHWS in TRNSYS Simulation Program	i. Run TRNSYS Simulation Program in order to achieve thermal performance for SHWS ii. Introduction to rating method for SHWS iii. Proposed rating calculation method for SHWS to calculate energy savings iv. Propose rating systems for SHWS based on energy saved by the systems	i. Deep research on the rating method for SHWS in Malaysia ii. Proposed rating calculation method need to be certified by SIRIM before the establishment the guideline iii. More reliable input parameters needed

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APPENDIX A

Table A1: Latitudes and longitudes of main cities in Malaysia

Main Cities	Location	Latitude	Longitude
Kuala Lumpur	Kuala Lumpur	3.16°N	101.71°E
George Town	Penang	5.30°N	100.27°E
Ipoh	Perak	4.60°N	101.07°E
Kuching	Sarawak	1.48°N	110.33°E
Johor Bahru	Johor	1.48°N	103.75°E
Kota Kinabalu	Sabah	5.93°N	116.05°E
Kota Bharu	Kelantan	6.17°N	102.28°E
Shah Alam	Selangor	3.07°N	101.52°E
Malacca Town	Malacca	2.27°N	102.25°E
AlorSetar	Kedah	6.11°N	100.36°E
Miri	Sarawak	4.33°N	113.98°E
Kuala Terengganu	Terengganu	5.33°N	103.13°E
Kangar	Perlis	6.43°N	100.20°E
Kuantan	Pahang	3.62°N	103.22°E
Labuan	Labuan	5.30°N	115.25°E

APPENDIX B

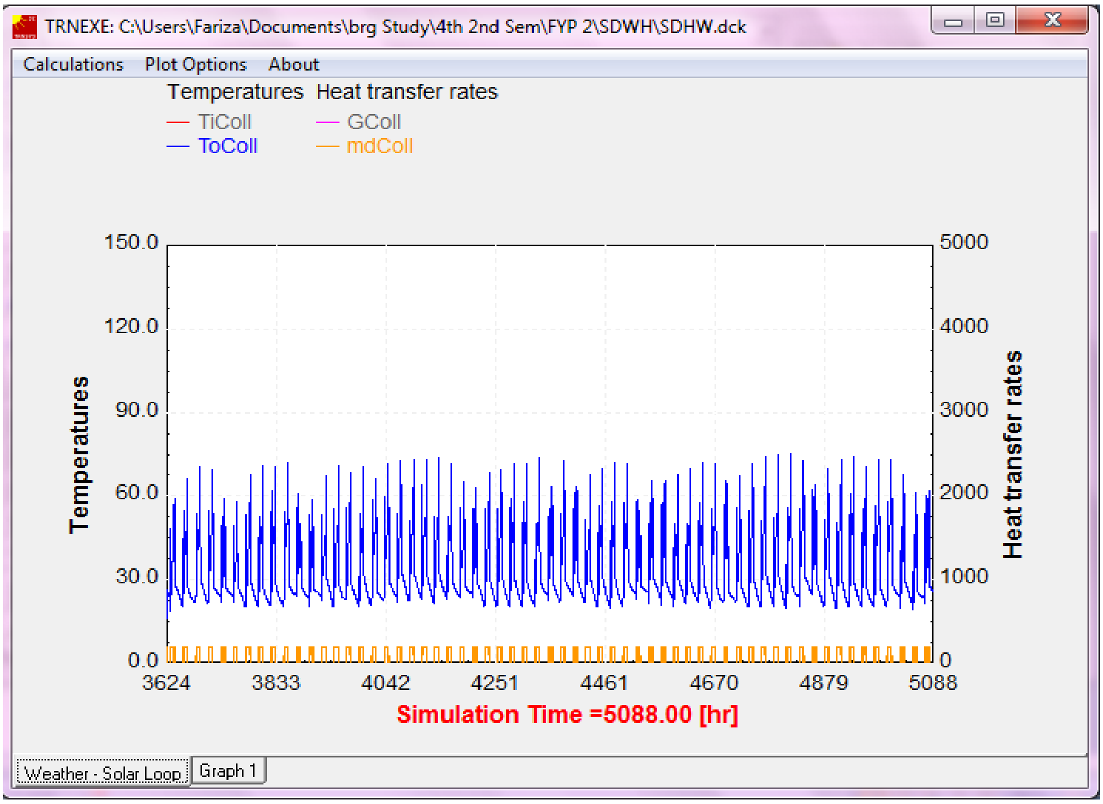

Figure B1: Inlet temperature and solar radiation at solar collector

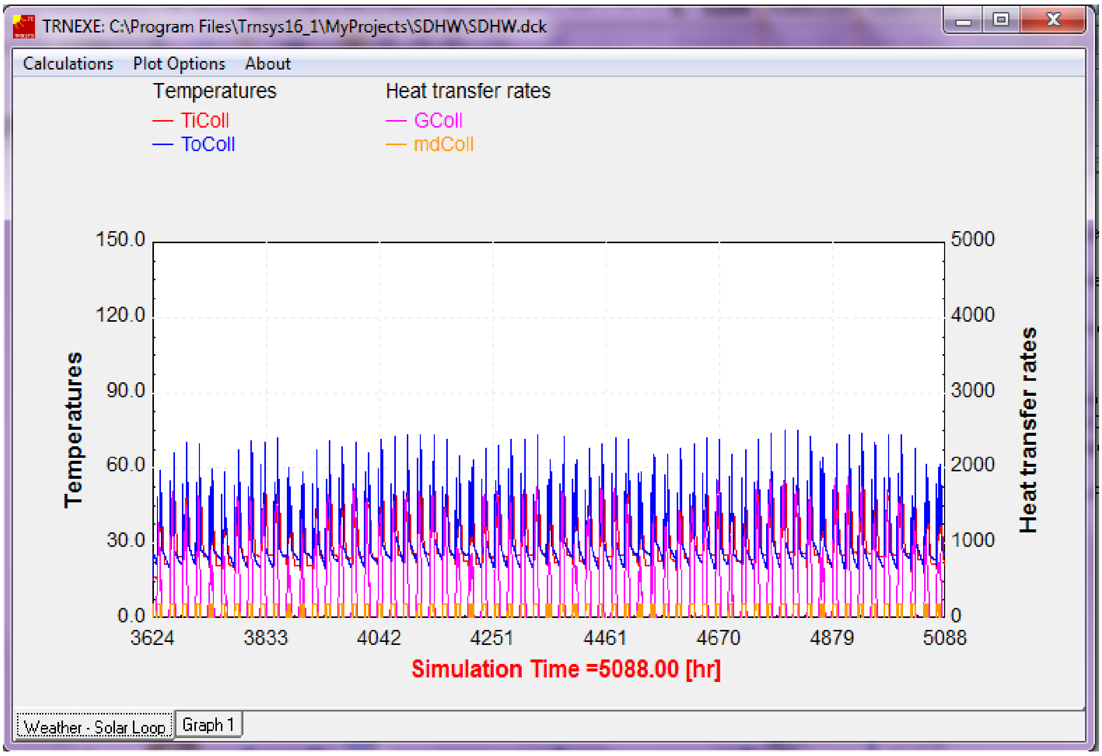

Figure B2: Outlet temperature and solar irradiance at solar collector

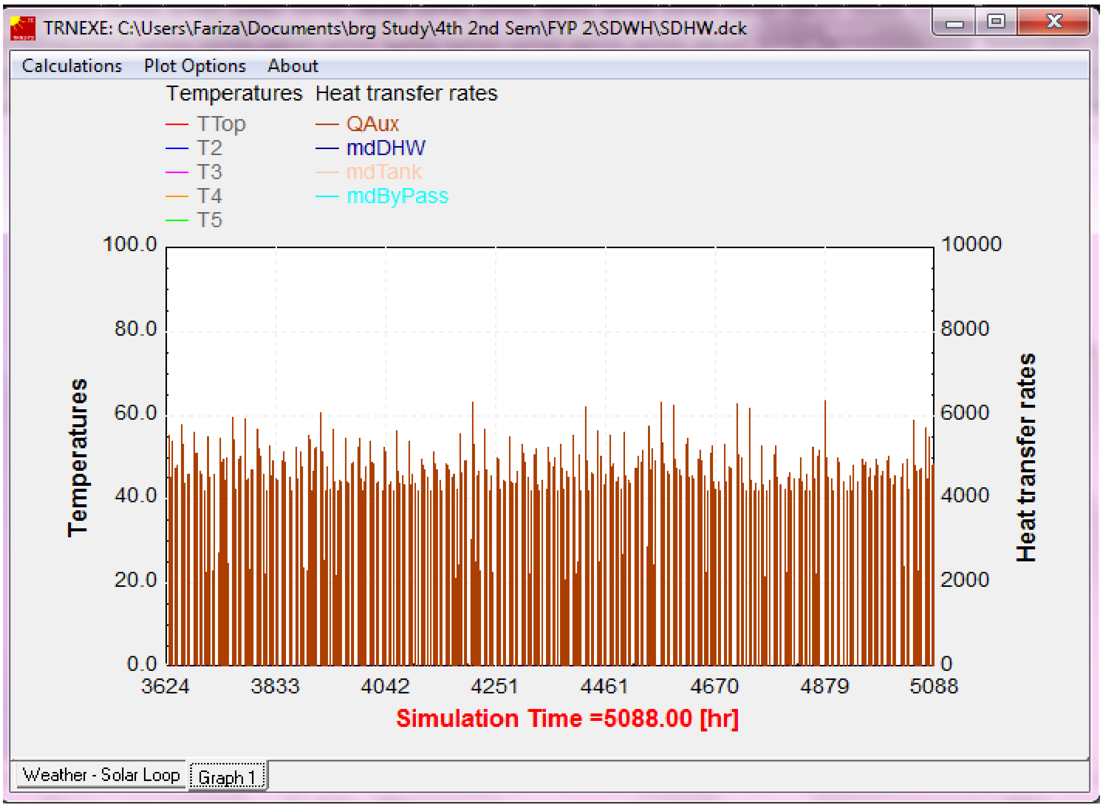

Figure B3: Auxiliary heat transfer rate at storage tank

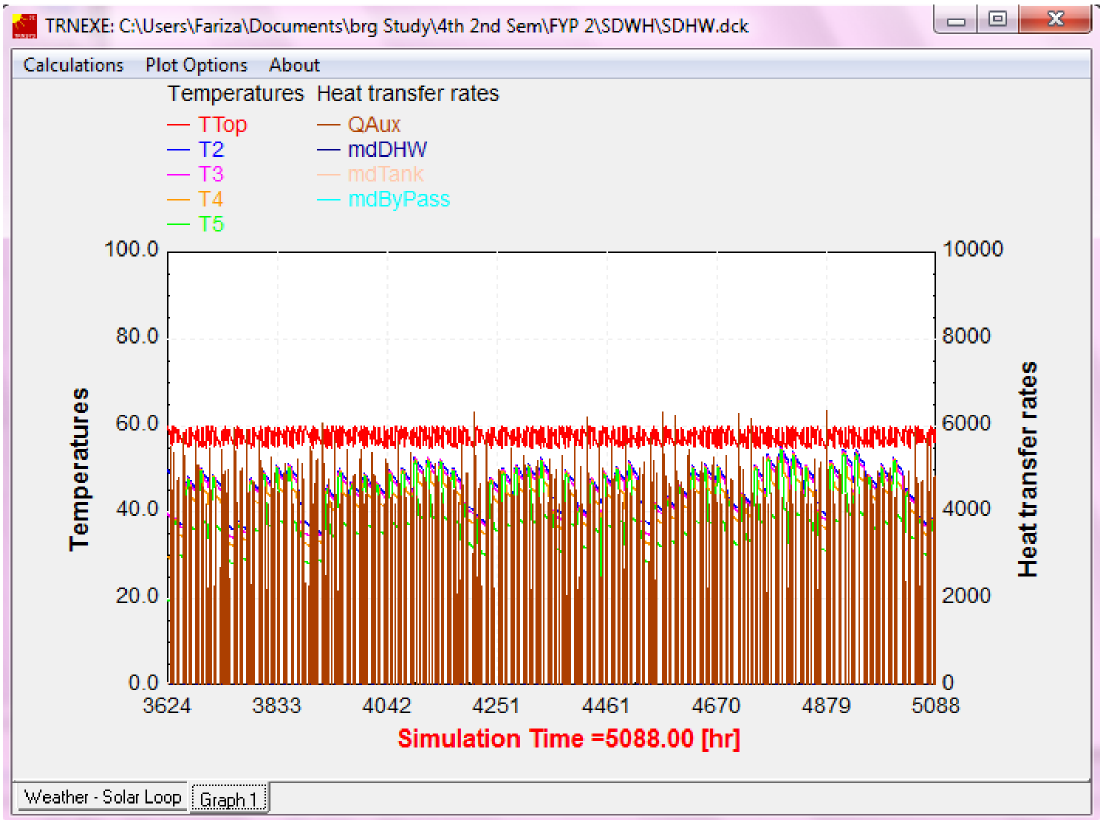

Figure B4: Variation of temperature in storage tank

APPENDIX C

Thermal Performance Rating Calculation Method

Average Auxiliary Energy $= \frac{4.5\ kWh}{day} \text{ x } \frac{3600\ s}{1\ h} \text{ x } \frac{1\ J}{1\ s} = \frac{16200\ kJ}{day}$

$$= \frac{16200\ kW}{day} \text{ x } no\ of\ days\ for\ every\ month$$

$$= \frac{\mathbf{5913000\ kJ}}{\mathbf{year}}$$

Total Auxiliary Energy $= \frac{5913000\ kJ}{1\ year} \text{ x } \frac{0.000278\ Wh}{1000\ M}$

$$= \frac{\mathbf{1.644\ MWh}}{\mathbf{year}}$$

Annual Energy Savings $= \frac{2.44\ MWh}{year} - \frac{1.644\ MWh}{year}$

$$= \frac{0.796\ MWh}{year}$$

$$= \frac{0.796\ MWh}{year} \text{ x } \frac{3600\ s}{1\ h} \text{ x } \frac{1\ J}{1\ s} \text{ x } \frac{1\ G}{1000\ M}$$

$$= \frac{\mathbf{2.866\ GJ}}{\mathbf{year}}$$