A SIMULATION STUDY OF DOMESTIC HOT WATER USING TRNSYS

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DECLARATION

I declare that this project report entitled "A simulation study of Domestic Hot water using TRNSYS" is the result of my work except as cited in the references.

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Date: 17/07/2020

APPROVAL

I hereby declare that I have read this project report and, in my opinion, this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluids).

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Date: ....

DEDICATION

To my beloved mother and siblings.

ABSTRACT

The solar flat plate collector is a widely used application to harness the solar energy given by the sun for almost every industry. In this study, the flat plate solar collector used in Melaka City and the industry is investigated. The key to the successful performance of the flat plate collectors depends on the areas of the collector and also the number of collectors installed correctly into the position of the sun. The components, the inputs and the parameters affecting the performance of the flat plate collector are the temperature difference and the efficiency of the entire solar system. Thus, Transient Systems Simulation (TRNSYS) program simulation is conducted to reduce the experimentation time and avoid high experimental and design cost. The objectives of this project are to obtain the performance of flat plate solar collector by using TRNSYS as well as to determine the suitable number of collectors for domestic hot water in Melaka City by using Hottell-Whillier-Bliss equation in TRNSYS and also to find out the suitable surface areas of the flat plate solar collector according to the industry specifications and needs. A validation result of a journal studying the performance of flat plate solar collector installed in a location is carried out to find the temperature difference in the flat plate collector and also to prove that the TRNSYS simulation produce is acceptable. For the validation, the weather data of Karaikudi 2014 is generated to find out the performance of flat plate collector. The component such as the flat plate collector, the stratified tank, pump, diverter and tee piece input and parameter were inserted to produce a precise simulation outcome. The Temperature input and the Temperature Output (T_iColl and T_oColl) is compared to find out the performance. The same process is then repeated using the Melaka City weather data and simulated in terms of the T_iColl and T_oColl to find out how the flat plate collector perform in the city. To achieve the objective the temperature difference is taken with the high-temperature difference will indicate good performance level. For the second objective which is to determine the suitable number of collectors for domestic hot water in Melaka City, the annual fraction load data of Melaka city 2016 is taken. The data shows that Melaka city has an average monthly heating load of domestic hot water in Melaka. To find a suitable number of solar collectors, the normal efficiency of flat plate solar collector must be around 70%. The solar energy supply to the users is 78.42% which is higher than the optimum efficiency of the solar collector. The domestic hot water temperature that is produced using the TRNSYS is shown. A single flat plate collector of 2.5m^2 is enough for an average household in Melaka City. For the third objective, which is to find out the suitable surface areas of the flat plate solar collector according to the industry specifications and needs. The industry locations that have been chosen for this study is the Hospital Universiti Kebangsaan Malaysia in Cheras, HUKM. The simulation will use the series 5 MY-60 flat plate collector from MYSOLAR CONCEPT SDN BHD. Based on the simulation, the suitable total area needed to produce the hourly average of the storage tank water temperature is 1800m^2. This area includes a total of 360 number of panels required to be installed in the hospital with the maximum average area of 5m^2.

ABSTRAK

Pengumpul plat rata suria adalah aplikasi yang digunakan secara meluas untuk memanfaatkan tenaga solar yang diberikan oleh matahari untuk hampir setiap industri. Dalam kajian ini, pengumpul suria plat rata digunakan di Melaka City dan dalam industri diselidiki. Kunci kejayaan para pengumpul plat rata bergantung kepada bidang pemungut dan juga bilangan pemungut yang dipasang dengan betul ke kedudukan matahari. Komponen, input dan parameter yang mempengaruhi prestasi pengumpul plat rata adalah perbezaan suhu dan kecekapan keseluruhan sistem solar. Oleh itu, simulasi program Transient Systems Simulation (TRNSYS) dijalankan untuk mengurangkan masa percubaan dan mengelakkan percubaan tinggi dan kos reka bentuk. Objektif projek ini adalah untuk mendapatkan prestasi pengumpul suria plat rata dengan menggunakan TRNSYS serta untuk menentukan bilangan pengumpul yang sesuai untuk air panas domestik di Melaka dengan menggunakan persamaan Hottell-Whillier-Bliss dalam TRNSYS dan juga untuk mengetahui kawasan permukaan yang sesuai bagi pengumpul suria plat rata mengikut spesifikasi dan keperluan industri. Keputusan pengesahan jurnal yang mengkaji prestasi pengumpul suria plat rata yang dipasang di lokasi dijalankan untuk mencari perbezaan suhu pada pengumpul plat rata dan juga untuk membuktikan bahawa menghasilkan simulasi TRNSYS boleh diterima. Dalam pengesahan, data cuaca Karaikudi 2014 dijana untuk mengetahui prestasi pengumpul plat rata. Komponen seperti pengumpul plat rata, tangki bertumpuk, pam, penyongsang dan input dan parameter potongan tee dimasukkan untuk menghasilkan hasil simulasi yang tepat. Input Suhu dan Output Suhu (TiColl dan ToColl) dibandingkan untuk mengetahui prestasi. Proses yang sama kemudian diulang menggunakan data cuaca Bandaraya Melaka dan disimulasikan dari segi TiColl dan ToColl untuk mengetahui bagaimana pengumpul plat rata di bandar. Untuk mencapai objektif perbezaan suhu diambil dengan perbezaan suhu tinggi akan menunjukkan tahap prestasi yang baik. Untuk objektif kedua yang menentukan bilangan pengumpul yang sesuai untuk air panas domestik di Melaka City, data beban pecahan tahunan bandar Melaka 2016 diambil. Data menunjukkan bahawa bandar Melaka mempunyai purata pemanasan bulanan air panas domestik di Melaka. Untuk mencari bilangan pengumpul suria yang sesuai, kecekapan biasa pengumpul suria plat rata mestilah sekitar 70%. Bekalan tenaga solar kepada pengguna adalah 78.42% yang lebih tinggi daripada kecekapan optimum pengumpul suria. Suhu air panas domestik yang dihasilkan menggunakan TRNSYS ditunjukkan. Satu pengumpul plat tunggal sebanyak $2.5m^2$ *cukup untuk isi rumah purata di Melaka. Untuk tujuan ketiga, iaitu untuk mengetahui kawasan permukaan yang sesuai bagi pemungut plat rata rata mengikut spesifikasi dan keperluan industri. Lokasi industri yang telah dipilih untuk kajian ini ialah Hospital Universiti Kebangsaan Malaysia di Cheras, HUKM. Simulasi ini akan menggunakan pengumpul plat rata MY-60 siri 5 dari MYSOLAR CONCEPT SDN BHD. Berdasarkan simulasi, jumlah luas yang diperlukan untuk menghasilkan suhu setiap jam dari tangki simpanan suhu 1800m2. Kawasan ini termasuk sejumlah 360 panel yang perlu dipasang di hospital dengan purata purata maksimum* $5m^2$*.*

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CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TRNSYS	Transient Simulation Software
T_iColl	Inlet temperature of the collector
T_oColl	Outlet temperature of collector
TMY	Typical Meteorological Year
Gh	Global horizontal radiation ("GHI")
Dh	Diffuse radiation arising from the upper hemisphere reduced by the direct solar radiation from the sun's disk and its surroundings (6° aperture)
Bn	Direct normal radiation (DNI, beam) arising from a narrow solid angle of 6° centred around the sun's disk
Ta	Air temperature (2 m above ground)
Td	Dewpoint temperature
FF	Wind speed (FFE, FFN longitudinal and latitudinal part of the wind speed)
EVT	Evacuated Tube
FPC	Flat Plate Collector

LIST OF SYMBOLS

NOMENCLATURE

A = collector area, m^2

F_R = collector heat removal factor

I = intensity of solar radiation, W/m^2

T_c = collector average temperature, °C

T_i = inlet fluid temperature, °C

T_a = ambient temperature, °C

U_L = collector overall heat loss coefficient, W/m^2

Q_i = collector heat input, W

Q_u = useful energy gain, W

Q_o = heat loss, W

Greek Symbols

η = collector efficiency

τ = transmission coefficient of glazing

α = absorption coefficient of plate

Subscripts

m = mass flow rate of fluid through the collector, kg/s

CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy resources are contributing to the sustainability of energy supply which is why the usage of renewable energy is shooting up each year. The increase of renewable energy will reduce the rate of global warming issues which is because of gas emission due to energy gain from fossil fuels [1]. Malaysia has annual solar radiation of 1643kWh/m^2 and sunshine 4-5 hours per day. Currently, solar energy in Malaysia is frequently for the water pump, domestic hot water heating system crops drying [2].

Solar photovoltaic and solar thermal systems are groups of direct solar energy technology. Solar photovoltaic is used for the generation of hot air where else solar thermal systems are used for the generation of electricity. However, a photovoltaic thermal collector can carry out a simultaneous generation of both electrically and thermally. It has the advantage to increase the overall photovoltaic thermal efficiency while also saving good space.

Solar energy changes for the production of domestic hot water that includes hot water processing and water pre-heating ahead of other types of thermal intake. Until 2002, there were 10000 domestic solar water heaters used in Malaysia (most of them used are from thermosyphon type) with an annual growth rate of 10-15%.

However, for the generation of electricity in rural areas and net metering productions where the systems received a large sum, it is very much noticeable hat the solar PV implementations in Malaysia are reduced to mainly standalone PV systems [3].

The thermonuclear reaction is the energy from the sun in its core and its radiated into space which will eventually reach the earth. There are some variations in the earth atmosphere when the amount of solar radiation reaches the top of the atmosphere due to the intensity of solar radiation which is opposite to the sun distance and because of the earth distance from the sun changes during the year. The solar constant is known as the average solar radiation at the upper limits of the earth's atmosphere which usually taken to be 1,388 watts per square meter 4871 kilojoules per square meter per hour, 1.940 calories per square centimetre per minute or 1.94 langleys per minute.

Direct or beam radiation is radiation emanating within a cone which involves the sun's disc. When the radiation overcome the clouds, air particles and the floor ground it will be called as the diffused radiation. The intensity of solar radiation at a given location on the earth will vary every second. To get the full efficiency of a solar collector from the horizontal, the collector should be made 90 degrees to the solar rays all day long.

According to this study [4], another way of utilizing the solar energy is the through thermal collectors, in which solar energy is transformed into useful heat energy in many different applications by using solar collectors [5]. Finding the area and sizing of the Solar water heating system requires a huge number of input data, which is hard to get all the times. Also, the high performable designed system will always do better in providing the volume of domestic hot water. The difficulty in finding the collector areas require the amount of cold and hot water mix at a certain temperature level. In this study, solar water heating systems (SWHS) is chosen as a tool of solar thermal energy conversion., to reduce the energy usage in the considered residents. The prime objective of this study is to find out the performance of flat plate solar collector by using a simulation software called TRNSYS based on the user input data and as well to study the temperature outlet of hot water using Hottell-Whillier-Bliss equation.

1.1.1 Final energy consumption by aggregated categories in residential sector 2016.

YEAR: 2016 / UNIT: KTOE	NATURAL GAS	LPG	KEROSENE	ELECTRICITY	TOTAL
Space Cooling	-	-	-	327	327
Water Heating	-	-	-	70	70
Lighting	-	-	3	233	236
Cooking	1	538	-	117	655
Appliances	-	-	-	1,586	1,586
TOTAL	1	538	3	2,333	2,875

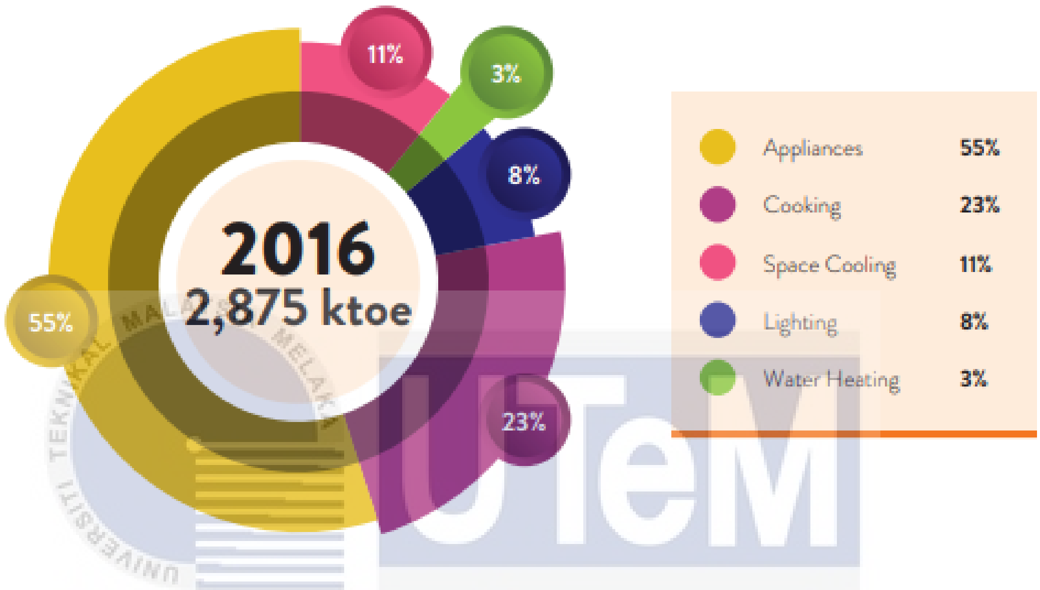

Figure 1.1.1 Adapted from National Energy Balance 2016, Malaysia Energy Commission

Based on Figure 1.1.1 the highest energy consumption for the residential sector is appliances. Cooking comes in second with 25% for the residential sector for the final energy consumption of 2016. This is followed by space cooling with 11% and lighting by 8%. Finally, domestic hot water heating comes with the lowest percentage of 3% for residential use. Mostly domestic hot water is used in homes for bathing and cleaning purpose that the reason for the usage in residential [6].

1.1.2 Final energy consumption by aggregated categories in the commercial sector.

UNIT: GWh	CATEGORY	SPACE COOLING	WATER HEATING	LIGHTING	OTHER USE	TOTAL
C1	Wholesale & Retail Trade	2,116.80	45.33	1,116.87	1,253.76	**4,532.76**
C2	Transportation & Storage	959.50	5.82	436.57	751.66	**2,153.75**
C3	Accommodation & Food Service	630.02	127.18	331.29	548.17	**1,636.83**
C4	Information & Communication	1,651.15	150.75	762.45	1,588.44	**4,152.78**
C5	Selected Services	2,270.49	-	1,254.17	1,880.72	**5,405.92**
C6	Professional, Scientific & Technical	194.35	-	118.65	272.92	**585.92**
C7	Travel Agencies & Tour	8.65	0.01	2.92	9.28	**20.86**
C8	Public Administration	2,946.31	262.71	1,418.34	2,267.82	**6,895.18**
C9	Education	1,339.60	-	673.90	1,139.99	**3,153.49**
C10	Human Health & Social Activities	2,120.27	200.57	1,103.11	1,516.59	**4,940.04**
C11	Arts, Entertainment & Recreation	343.17	40.51	223.79	284.82	**892.29**
C12	Other Service Activities	1,860.37	201.76	1,074.17	1,599.88	**4,736.19**
	TOTAL	**16,440.66**	**1,034.62**	**8,516.23**	**13,114.06**	**39,106.00**

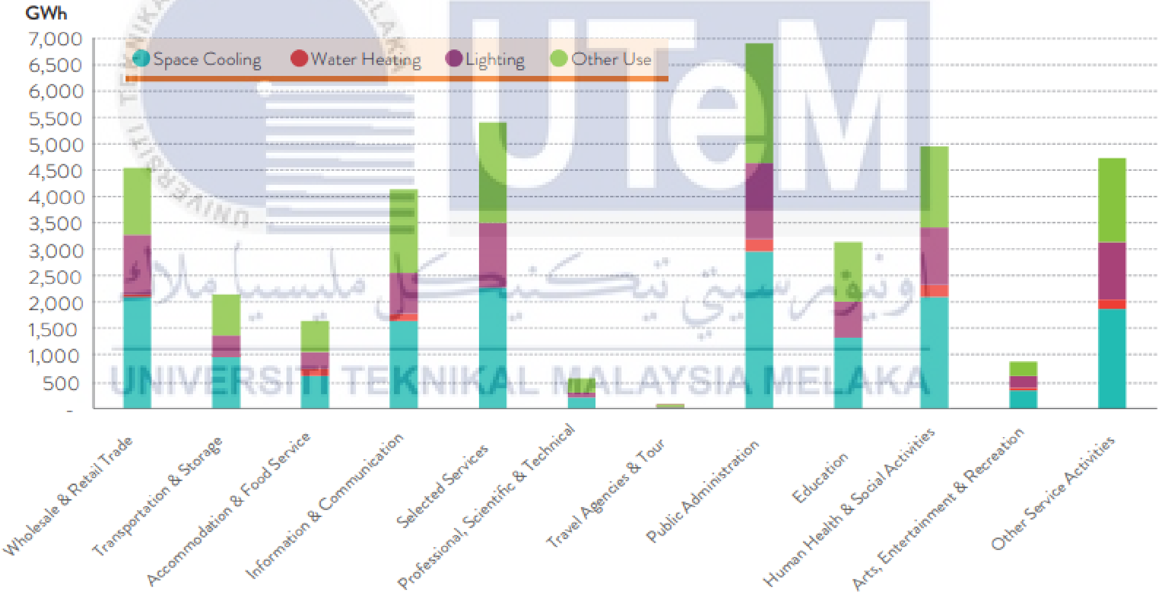

Figure 1.1.2 Adapted from National Energy Balance 2016, Malaysia Energy

Based on Figure 1.1.2 the highest energy consumption for commercial use is space cooling. Both the residential and the commercial use prefer cooling of spaces for human comfort by solar with the cooler either within the space or external to it. The domestic hot water heating is the lowest for commercial use which is the same for residential. The usage for water heating is more for public administration, human health and information and communications. Lighting comes second with 8516 of total usage.

1.1.3 Types of domestic hot water applications

1.1.3.1 Electric Immersion

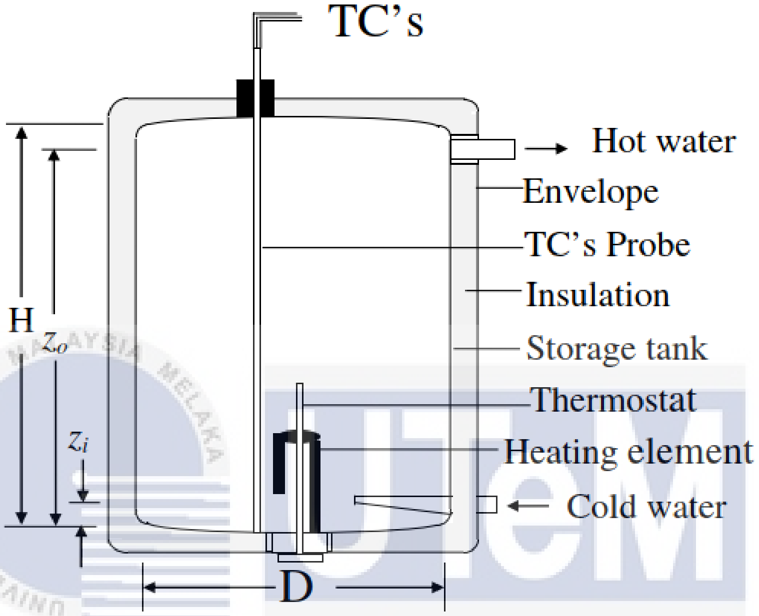

Figure 1.1.3.1: Adapted from Effect of inlet design on the performance of storage-type domestic electrical water heaters, Hegazy, Adel A. 2007

The most familiar type of domestic water heater in Malaysia which is used in both instantaneous and storage water heater. Immersion heater placed in water which transfers heat and all the electricity will be changed to heat. Immersion heaters are connected to their power supply chord via a waterproof cable. They easily switched on and off, as there's no need to heat the water constantly in your hot-water cylinder which the temperature can be controlled. Immersion heaters are usually used as a residents main source of water heater, or as a storage water heater for coil boilers for future use [7].

1.1.3.2 Gas Fired

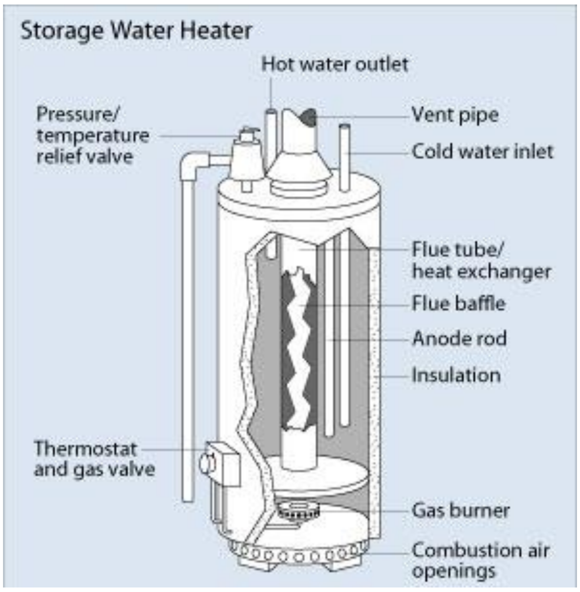

Figure 1.1.3.2: Source: US Department of Energy

It is used in immediate and storage water heaters. The continuous pilot flames ignite gas flowing through the barrier and the heat from the flame transferred to the water.

1.1.3.3 Solar

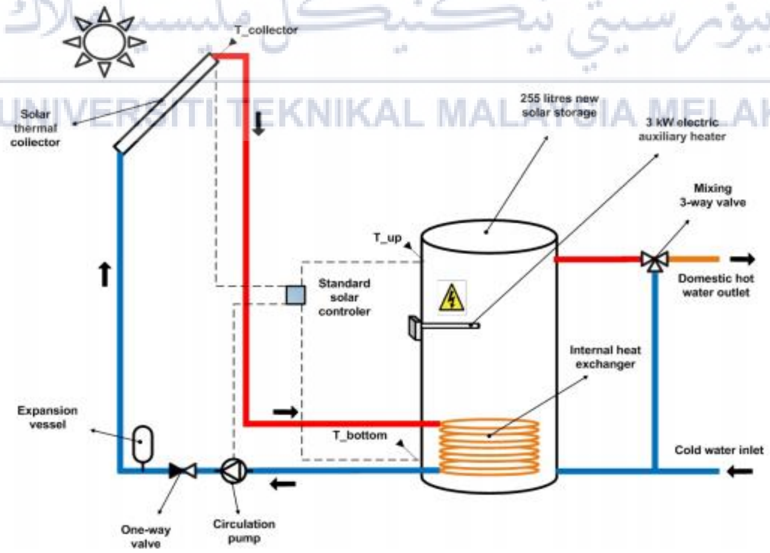

Figure 1.1.3.3: Adapted from Retrofitting domestic water heaters, A theoretical analysis, Bernardo, Luis R.Davidsson, Henrik, Karlsson, Björn 2012

It has storage tanks and solar collectors. The solar energy is used to heat water. Solar energy is converted to heat. The three temperature sensors control the pump, two placed above the tank's surface and then another at the collector outlet [8].

1.1.3 Hot water consumptions in Malaysia

In this study, Hot water consumption data in a residential building in Kuala Lumpur city are calculated based on the assessment conducted among the group of people of apartments community. This research shows a common domestic residential building with some number of person's and their water demands are considered and shown in Table 1.2.3. This table tabulates the domestic hot water consumption in different activities i.e. 60 Litre per person per day for Bathing, 10 Litre per person per day for Wash Basin, 15 litres per person per day for Kitchen Wash, 10 Litre per person per day for Clothes Wash, 10 Litre per person per day for other usages [4].

Table 1.1.3.1 Domestic Hot water Consumption

Description	Water/Person/ Day (Litre)	No of Persons (n)	Water Requirement at the site (Litre/Day)
Bathing	70	6	420
Wash Basin	15	6	90
Kitchen Wash	25	6	150
Clothes Wash	20	6	120
Others	10	6	60

1.2 Problem Statement

The solar collectors will determine the performance of the domestic hot water system and also the heat transfer of solar water heating system. The surface area of a flat plate solar collector is very much influential in determining the suitable performance of the solar system in specified locations. The surface areas of the flat plate solar collector also determine the functionality of the solar system in the industry. In this study, a flat plate solar collector is used in the solar model to determine performance by using TRNSYS simulation software. Besides that, the suitable number of solar collectors needed to be installed in Melaka City for an optimum use will find out and also the suitable surface areas of flat plate solar collectors required by the industry will be determined according to the industry specifications and requirements.

Too much heating of solar heat installations occurs when the solar energy takes in by the solar collector exceeds the potential of its heat transfer circuit to constantly cool it, which causes excessive temperatures. This is usually because of low energy demand and this phenomenon is also known as high-temperature output. It is most severe when the flow of the heat transfer fluid through the collector is stopped because of power outages or component failures which causes the production to stop.

Overheating that comes from the number of collectors that can add on in the solar collector loop when it is not taken away to a useful heating job. This can cause inconvenience and may finally lead to heating system failure at worst. Hottell-Whillier-Bliss equation is used in this study to determine the number of collectors using the domestic hot water. Solar collectors will convert solar radiation into heat and direct that heat to a medium (water, solar fluid, or air). The heat produced by solar can be used for heating water. For this study, the flat plate solar collector is used to provide heat to the domestic hot water system.

In an active system, the number of collectors and the area has to be stated to find out the performance of the solar collector system using simulation programs such as TRNSYS. It has been done in a previous model and analyses the thermal production of domestic as well as a huge number of solar water heaters. Short-term and long-term thermal performances of solar water heaters along with the auxiliary power consumption as an electric back up can be found with the help of these programs. The analysis of solar thermal water heater impacts on the distribution level water heating load profile with realistic hot water use events is still a necessity for utilities.

1.3 Objective

The objectives of this project are as follows:

1. To obtain the performance of flat plate solar collector by using TRNSYS simulation software.
2. To determine the suitable number of collectors for domestic hot water in Melaka using Hottell-Whillier-Bliss equation in TRNSYS.
3. To determine the surface areas of the flat plate solar collector for medium range temperature.

1.4 Scope of Project

The scopes of this project are:

1. Only a flat plate collector will be simulated to find out the performance using TRNSYS for this project.
2. The number of collectors of the system for this project is to be determined using Hottell-Whillier-Bliss equation in TRNSYS.

3. The area of the flat plate collectors will be figured out using TRNSYS by implementing the given specifications by the industry in the software.
4. Only the temperature axis reading will be taken to find out the performance, the suitable number of collectors and areas of the collectors.
5. For the validation purpose, the given data in [9] such as the exact components usage of weather data, stratified tank, differential controller, single-speed pump, theoretical flat plate collectors, tee-piece, flow diverter and online plotter are used in this study.
6. The exact parameters of the flat plate collectors, differential controller and single speed pump are used in this study to find out the most precise outcome exactly from the research paper. The undefine parameters and input are left in default settings.
7. The weather data taken in this study is from Meteonorm software with the average monthly and yearly data. The software can’t generate data on specific dates.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain the parameters TRNSYS simulation system used by the researcher for their study of solar collector efficiency. In recent studies, the researchers continuously studied on energy and efficiency of solar collectors. In 2.2, the TRNSYS 17 Simulation system explanation is given. The parameter used in the TRNSYS simulation system is briefed in 2.3.

2.2 TRNSYS 17 Simulation

TRNSYS 17 is a transient system simulation software which is used for simulation of the output of systems as a function of time. To simulate the system firstly the components, need to be identified based on the collective performance describes the performance of the system. TRNSED file is a more attractive feature of the TRNSYS program which creates a user-friendly input file called a TRNSED file. This will prevent the if outside conditions from influencing the system behaviour change, such as weather conditions, or if the system components themselves go through conditions the variation with time.

2.3 Advantages and Disadvantages of TRNSYS

TRNSYS have a few components that replicate the daily domestic hot water consumption that profiles with timesteps below an hour based on different standards of techniques. This is to give performance ratings and efficiency for complete solar thermal systems, the program applies computer modelling which is TRNSYS [10]. The software will be lowered to a set of interconnected subsystems modelled as TYPES [11]. TRNSYS has the capability of linking components in users preferred choice, solving the system differential equations, and producing information output in the form of .txt, .out, .dat [12].

There are some cons in using TRNSYS which are the input data not available, operational mode checks required, finding out the required parameters, linking and setting up of every component are complicated and takes a huge amount of time. The pros of daily, efficiency and compound equations are not available in the TRNSYS [13]. Linking the correct connections and justifying all of the parameters, inputs and outputs in an organized manner is a tedious task for the more advanced projects [14].

2.4 Parameter used in the TRNSYS simulation

A. Ponshanmugakumar et al, (2014) study show that the based settings to be used in the TRNSYS simulation system are the data that are used for basic solar system generation. The TMY2 Reader (Type109) used to provide a reading of weather data Tamil Nadu, India which is used to determine the performance of flat plate collectors used for domestic purposes at different geographical areas in Tamil Nadu. In the system used in this study, TMY2 reads the weather conditions constantly, and it checks the data of solar radiation to find tilted surface radiation and incidence angle for the number of surfaces. The simulation undergoes with Tamil Nadu climate condition. Type 73 and 74 are the component used as the thermal performance of a theoretical flat plate collector.

The study also states that a single-speed pump is projected as Type 3d is a which is switches on and off according to the signal received from differential controller also known as Type 2b. When the pump is ‘on’ the water flow rate will be 125 kg/hr. Type 4c is the stratified tank which stores fluid during the night time and connects to the type 2b for specifying the Tl and Tin. Type 11h is the Tee-piece has two inlet liquid streams which bonds together into a single liquid outlet stream. The Tee-piece outlet fluid will be transferred to the demand (D). Type 11f is a single inlet liquid stream flow diverter. Type 65a is used to show the variables while the simulation is ongoing also known as an online plotter. This type of component is widely used due to the variable information and allows one to see immediately if the system is performing as desired [9].

2.5 Previous studies

There are few studies have been done by researchers to study the performance and the efficiency of domestic hot water through a flat plate collector using Transient System Simulation (TRNSYS) and also, they have used the Hottell-Whillier-Bliss equations. The simulation studies are explained in 2.4.1 and the Hottell-Whillier-Bliss equations are explained in subtopic 2.4.2. The journal segregation is done in the subtopic 2.4.3 for international and 2.4.4 for Malaysia.

2.5.1 Simulation studies

All of these studies show the analysis of thermal performance in a solar system simulation processes and have not included the installation and startup costs associated with the cell, module or the array of solar collectors.

In an approach, the study carried out by Bava et al, (2010), shows that TRNSYS simulations calculate the yearly useful energy transferred to the heat exchanger was 1.2%

more than the data measured by theory, but the season base deviations were +7% and −8%, for the June to December 2013 and January till May 2014 periods, respectively [15]. Almeida et al, (2014) differentiated the performance of an energy system using TRNSYS on huge durations of a month which shows the experimental difference are less than 3% [16].

G.Fung et al, (2008) study show that the flat plate Type 1b is used in TRNSYS component libraries which shows the thermal performance of a flat- plate solar collector. The solar collector is connected in series. The number of modules and the characteristics of each module finds the thermal performance of the collector. This study performed the analysis of sensitivity for the solar hot water domestic hot water system. The outcome shows that solar domestic hot water system with a flat plate collector produce up to 80% reduction in electricity cost and emissions of GHG [17].

Based on S.Sulaiman et al, 2014, The study discussed the good rating system for solar hot water to find the total energy savings used. Different area and systems data will lead to different results in thermal performance. It is because of the weather condition of the precise location that has assessed as well as the efficiency of the system itself. According to this study, TRNSYS can be used to simulate systems from a normal domestic hot water to the modelling and simulation of high-end buildings, the equipment and others. TRNSYS provides the components called TYPEs needed to simulate solar domestic hot water systems including solar collector, tank, heater, pump, and others. It provides components for the simulation outputs such as printer and integrator to produce weather data of certain formats [18].

Y. Yaïci et al, (2012) did an experiment and simulation study on solar domestic hot water system with flat plate collectors for the Canadian climate. The study aims to optimize the crucial design parameters and to give an effective control strategy in the performance of solar collectors. The collector performance is studied by measuring heat transfer from the solar collector to heat exchanger divided by the solar energy incident on the collector. The performance of the tilted panel increased by about 13% while the solar fraction increased from 0.52 to 0.97, which is an increase of 86%. This study shows that the effect of decreasing the temperature at the collector inlet, increases its efficiency, thus improving the SDHW tank efficiency and at the same time increases the efficiency of the whole system [19].

2.5.2 Hottell-Whillier-Bliss equations.

The Transient Simulation program uses algebraic equation models for every one of its components. For example, a flat plate collector model (Type 1) uses only algebraic equations which are illustrated as follows [20]

Figure 2.5.2.1 shows the model scheme of a solar system that has a flat plate solar collector with a storage tank.

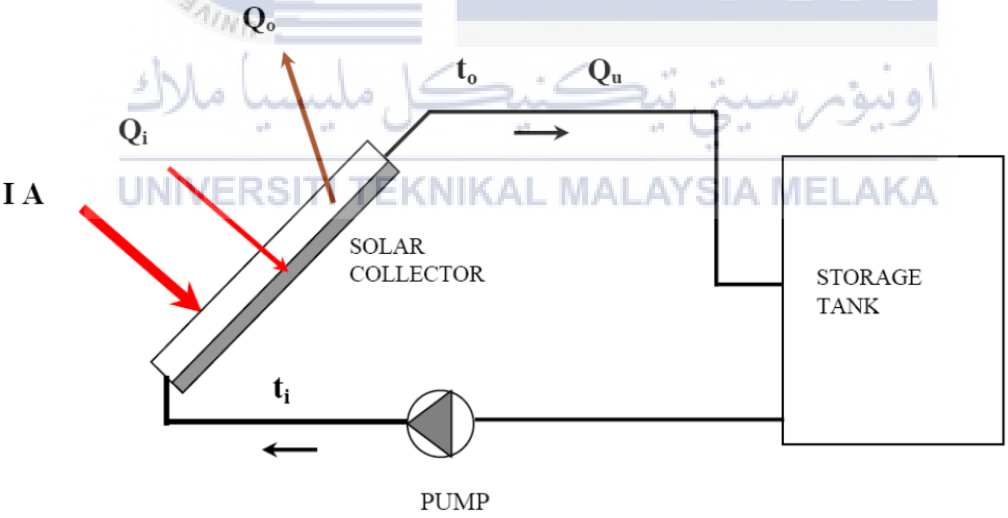

Figure 2.5.2.1: Adapted from Solar energy collection system, Analysis of a Flat-Plate Solar Collector, Klevinskis, Andrius, Bučinskas, Vytautas (2012)

I is known as the solar radiation intensity, in W/m^2, the solar collector on the aperture plane having a collector surface area of A, m^2, while the number of solar radiation collected by the collector is:

$$Q_i = I \cdot A \qquad (1)$$

In Figure 2.5.2.2, some of the radiation will reflect the atmosphere and draw up by the glazing and the rest will be carried through the glazing and will reach the absorber plate as short wave radiation. The factor of conversion shows the percentage of solar rays entering the collector's transparent cover and the percentage being absorbed.

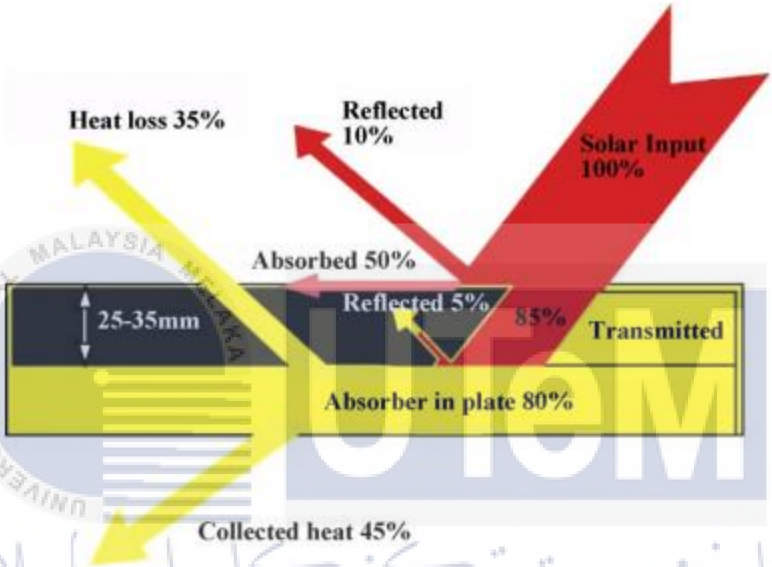

Figure 2.5.2.2: Adapted from: M.S. Hossain et al. / Renewable and Sustainable Energy Reviews 15 (2011)

This shows the product of the cover transmission rate and the absorber rate of the absorption.

Thus,

$$Q_i = I(\tau\alpha) \cdot A \qquad (2)$$

While the collector absorbs the heat, the collector temperature will get higher than the surrounding and the heat will be lost to the atmosphere by the rate of convection and radiation. The heat loss rate (Q_o) depends on the collector overall heat transfer coefficient (U_L) and the temperature of the collector.

$$Q_o = U_L A(T_c - T_a) \quad (3)$$

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

This is expressed as follows:

$$Q_u = Q_i - Q_o = I\tau\alpha \cdot A - U_L A(T_c - T_a) \quad (4)$$

The rate of extraction of heat from the collector may be measured from the amount of heat carried away in the fluid passed through it, that is:

$$Q_u = mc_p(T_o - T_i) \quad (5)$$

Equation 4 is not appropriate because of the hardness in defining the collector average temperature. Defining a quantity that relates the actual useful energy gain of a collector to the useful gain is more convenient if the whole collector surface were at the fluid inlet temperature. This quantity is “the collector heat removal factor (FR)” and is expressed as:

$$F_R = \frac{mc_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \quad (6)$$

When the whole collector is at the inlet fluid temperature that’s when maximum possible useful energy gain in a solar collector occurs. The actual **useful energy gain** (Q_u), can be calculated by multiplying the collector heat removal factor (F_R) by the maximum possible useful energy gain. This allows the rewriting of equation (4):

$$Q_u = F_R A\left[I\tau\alpha - U_L\left(T_i - T_a\right)\right] \qquad (7)$$

Equation (7) will be used for measuring the collector energy gain and is generally known as the "**Hottel- Whillier-Bliss equation**".

According to M.S.Zaman et al, (1978), for starting design purposes, U_L' F' and (*ta*) is always considered as a fixed variable throughout the whole simulation and therefore can be used into the program as parameters. The collector component receives "information" such as H_T, ṁ, T_{in}' and T_a from other components and must calculate T_{out} and Q_u to be transmitted to other components. This transfer of information into and out of a subroutine is shown in Fig. 2.4.1. It shows the number of inputs, outputs and parameters. The mass flow rate is an output but is never altered by the collector subroutine [20]. It is output so that a TRNSYS modelled system can be constructed which resembles the original flow of material in real systems.

There are four different types of solar collector modes of operation, known as 1, 2, 3, 4. This is done to give the user four choices as to the level of detail in one subroutine.

These are:

Mode 1: constant parameters

Mode 2: a function of conditions will be calculated in loss coefficient

Mode 3: a function of angle will be calculated in cover transmission

Mode 4: a mixture of mode 2 and 3.

The tank model is an instance of a component described by differential equations. A fully mixed tank is gone by the following differential equation which relates the rate of temperature rise of the tank to the net energy into the tank from the collector [20].

2.5.3 Journal segregation of related topics

No	Country	TRNSYS version	System (Open/Close)	Types of Collector	Input Load	Findings	Model	Ref
1.	Czech Republic (Prague)	2004	Closed System	Flat Plate	Heated floor area / Building volume Envelope U-value Ventilation with heat recovery Average DHW demand Qdhw Space heating demand Qsh Storage tank volume VS Solar collector area Ac	Efficiency = 81% Solar collector integration	Solar combi system model Multizone building model	[21]
2.	Iraq (Baghdad)	2016	Closed System	Flat Plate	Weather Data of Baghdad Collector Area	Average Daily ambient temperature = 600 l/day Solar Radiation= 557w/m2 Predict auxiliary energy= 300 MJ/month	Pipe focused model	[22]
3.	Malaysia (Selangor)	2017	Open System Closed System	Flat Plate	Hot Water Draw Profile Tank Storage Volume Solar Collector Area	Temperature outlet= 67°C Energy Generate= 9.5439 kWh Sensitivity	NA	[23]

					Flow Rate Solar collector			
4.	Canada (Toronto)	2016	Close System	Flat Plate	Solar Collector Area Fluid Specific Rate Tested Flow Rate Intercept Efficiency Efficiency Slope Inlet Temperature Inlet Flow Rate Ambient Temperature Collector Slope Collector Orientation Outlet Temperature Outlet Flow Rate	Energy Consumption= 1135 kg GHG emissions Energy Cost= $497.12 Sensitivity	Hybrid Model	[17]
5.	USA (Florida)	1978	Closed System	Flat Plate	Inlet Fluid Temperature Collector Fluid Flowrate Ambient Temperature Radiation per unit area on the surface collector	Collector efficiency: 50.26% Solar Percent utilization: 73.79%	Transmittance Absorptance Product	[20]

2.5.4 Malaysian journal segregation of related topics

No	Country	TRNSYS version	System (Open/Close)	Types of Collector	Input Load	Findings	Model	Ref
1.	Malaysia (Selangor)	2017	Open System Closed System	Flat Plate	Hot Water Draw Profile Tank Storage Volume Solar Collector Area Flow Rate Solar collector	Temperature outlet= 67°C Energy Generate= 9.5439 kWh Sensitivity	NA	[23]
2.	Malaysia (All States)	2016	Open System	Flat Plate	Max DC Power Max DC Voltage PV Voltage range Recommended range nominal power Max input current Max number of strings	Energy= 150kWh/day Annual output: 0.0042MW	NA	[24]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter shows the methodology in this project to get the performance of a flat plate solar collector by using TRNSYS simulation software. The flow chart of the project is shown in Figure 3.1.1. This project starts by studying and the Transient Simulation Software (TRNSYS) and to study the correct way to obtain the temperature and the heat transfer of the solar system using the temperature inlet and temperature outlet of the solar collector. Another method for the use of TRNSYS is to find out the optimum number of flat plate collectors and also to find a suitable number of flat plate collector.

After the flat plate solar collector data and single speed - no power coefficients pump data is identified, modelling of the solar system source is performed before conducting measurement for temperature and the heat transfer of the solar system using the temperature inlet and temperature outlet of the solar collector. The weather data and the load profile play a major role in simulating the results as it determines the values of the temperature input and output of the flat plate solar collector.

3.1.1 Methodology Flow chart

The summarised methodology is shown in Figure 3.1.1.

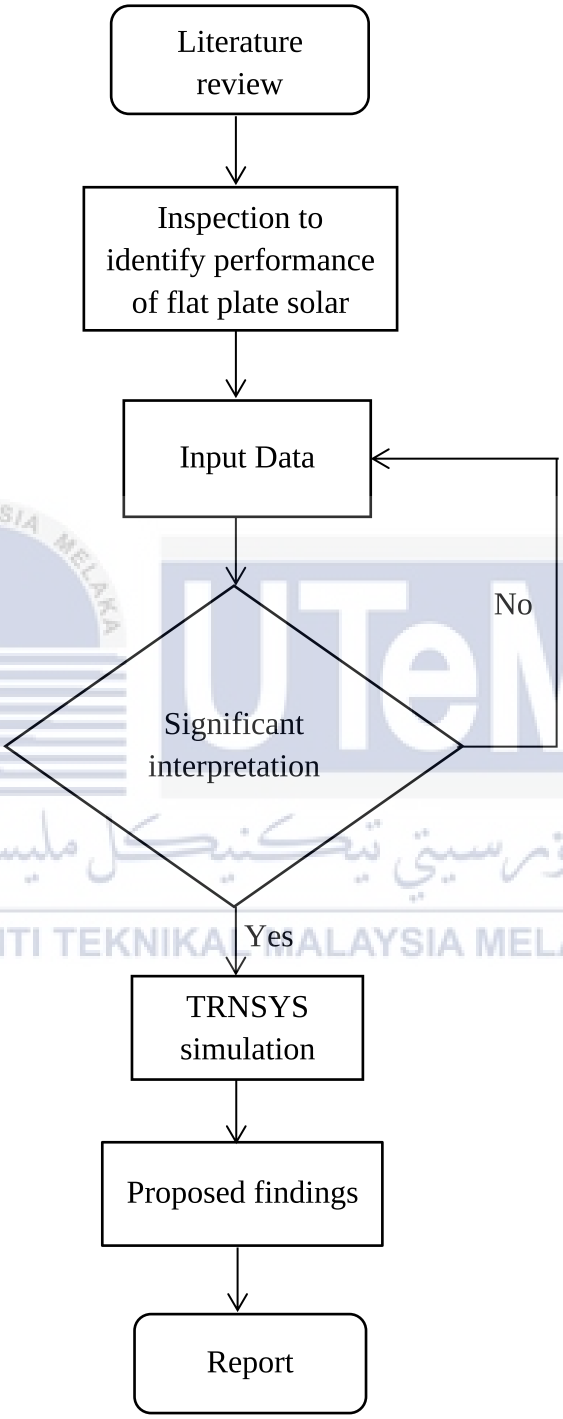

Figure 3.1.1: Flow chart of the methodology

3.1.2 Chronology of the project

To achieve this project objective, it depends on every hurdle that has been crossed throughout the research. Important aspects such as scopes, problem statement, methodology and literature review were implemented to ensure a smooth flow for this research. Objectives set for this research is to find out the performances, the suitable number of collectors in Melaka city and determine the appropriate surface areas of flat plate collectors using the specs given the industry.

The literature review is the starting point for this research as it gives a clear outlook on what the project is going to focus. It acts as a guideline for the steps taken to implement the Input and the outputs for every component in TRNSYS. Next, modelling the solar system for the flat plate solar collector is done in the software itself as it will be crucial to determine the simulations of the respective objective.

Each input and output is done to make sure the simulation is done precisely. The undefined input such as the water draw load profile is done with the try and error method to make sure the outcome is close to the literature review finding. If the simulation is not close to the literature review finding the process will be repeated. Once everything is achieved the outcomes will be written in the report.

3.2 Experimental Work and Preliminary Results

3.2.1 Experimental Work for Karaikudi

Figure 3.2.1 shows the general experimental work setup model in TRNSYS 17 for operating the solar system using flat plate collector to find out the performance. The weather data of Karaikudi, Tamil Nadu, India from 11-14 March 2014 is linked to the Type 73 which is known as the theoretical flat plate collector. The collector is connected to the stratified storage tank (Type 4c) which connects to flow diverter (Type 11f) and tee-piece (Type 11h). Both the flow diverter and the tee-piece are linked to the online plotter (Type 65a) which will produce the graph for the solar system.

The base settings to use in the TRNSYS simulation system are the components that are used for basic solar system generation. For this study, The TMY2 Reader (Type109) used to provide a reading of weather data Karaikudi, Tamil Nadu, India which is used to determine the performance of flat plate collectors is for domestic purposes at different geographic locations in Tamil Nadu. In the system used in this study, TMY2 reads the weather conditions constantly, and it checks the data of solar radiation to find radiation of tilted surface radiation and incidence angle for an arbitrary number of surfaces. The simulation undergoes with Tamil Nadu climate condition. Type 73 is the component used as the thermal performance of a theoretical flat plate collector.

The single-speed pump is projected as Type 3d act as a switch according to the signal received from differential controller also known as Type 2b. When the pump is 'on' the water flow rate will be 125 kg/hr. Type 4c known as the stratified tank which stores fluid during the night time and connects to the type 2b for specifying the Tl and Tin. Type 11h is the Tee-piece has two inlet liquid streams which mixed into a single liquid outlet stream. Tee-piece outlet fluid from the will be transferred to the demand (D). Type 11f is a single inlet liquid stream flow diverter. Type 65a is used to show the variables while the simulation is ongoing also known as an online plotter. It is widely used because it gives valuable information and allows one to see immediately if the system is performing as desired.

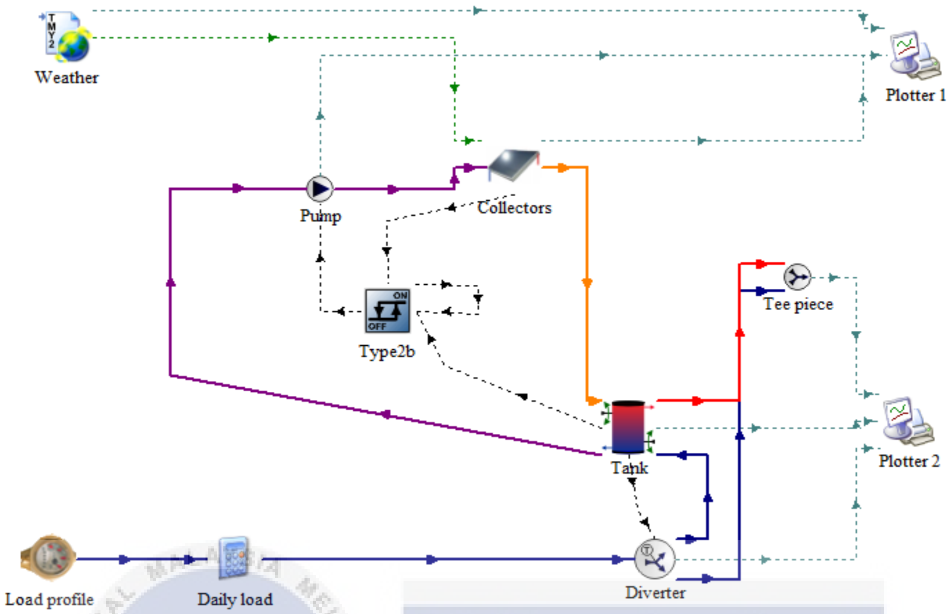

Figure 3.2.1.1: Modeling scheme of the system using Flat Plate Collector

The TRNSYS model scheme of Figure 3.2.1.1 uses the Karaikudi, Tamil Nadu, India weather data from 11-15 March 2014 specifically. The load profile used in this model is not defined in the journal. The properties of system components are modified to get the best results. It is to model a flat plate collector for domestic purposes under Tamil Nadu meteorology conditions and compare the efficiency of flat plate collector at different areas. The different inlet and outlet water flow temperature are measured hourly using flat plate collector from 11th to 15th March from seven different locations in Tamil Nadu.

Table 3.2.1.1 Flat Plate Collector parameters of the study

Data	Value	Unit
Number in series	1	
Collector area	5	m^2
Fluid specific heat	4.19	kJ/kg. K
Tested flow rate	40	$kg/hr.m^2$
Intercept efficiency	0.8	
Collector Slope	45	
Inlet Flowrate	100	kg/hr

The parameters of flat plat collector (Type 73) are adjusted in the system are shown in Table 3.2.1.1. The collector area that was chosen for the study is $5m^2$ arrange in one number of series with the intercept efficiency of 0.8.

Table 3.2.1.2 Differential Controller input parameters

High limit cut-out	100◦C
Upper input temperature T_h	T_O Coll
Lower input temperature T_l	T_{Bottom}
Monitoring temperature T_{in}	T_{TOP}

Type 2b is known as differential controller component which monitors T_{TOP} by comparing the T_oColl and T_{Bottom}. The data of this controller are shown in Table 3.2.1.2. If the T_oColl is higher than T_{Bottom}, the controller activates the pump. If the temperature T_{TOP} reaches to 1000C, the pump will be stopped.

Table 3.2.1.3 Pump Parameter used

Input	Value	Unit
Maximum Flow Rate	125	kg/hr

Table 3.2.1.3 shows the pump parameter used in the solar system TRNSYS model. Type 3d is the unit for a single speed pump will be either switch ‘on’ or ‘off’ according to

the receiving end of signal from Type 2b. The mass flow rate of water will be 125 kg/hr when the pump is 'on'.

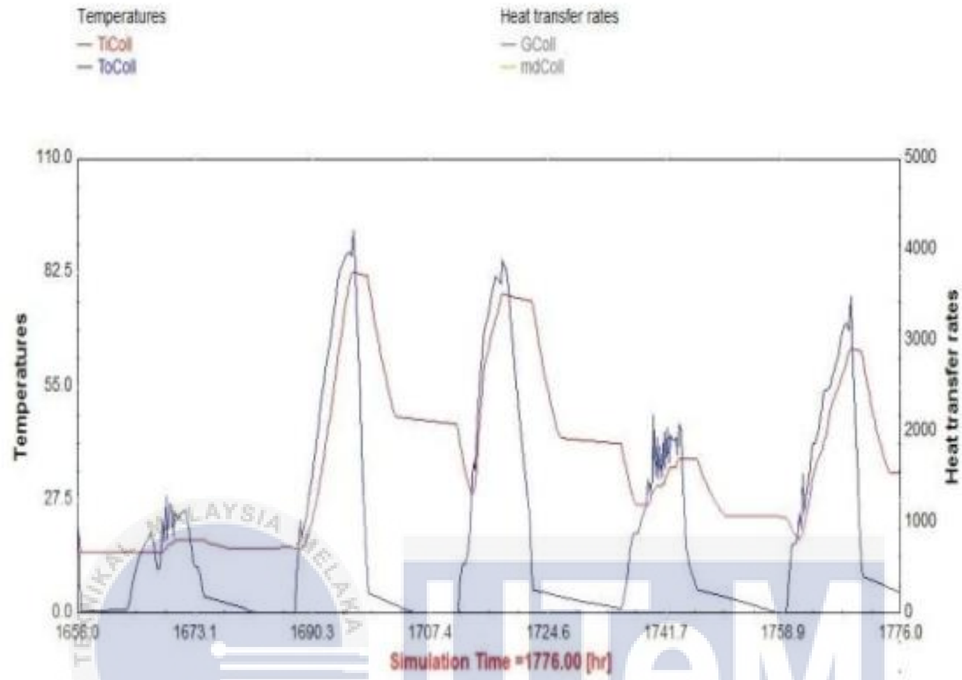

Figure 3.2.1.2 Temperature input and temperature output of collector of Karaikudi

Figure 3.2.1.2 shows temperature input and temperature output with the time of a solar collector which was produced by simulation using the theoretical flat plate solar collector with pump system using TRNSYS 17 from 11 to 15 March 2014 at Karaikudi, Tamil Nadu, India for 17 hours' time difference. T_iColl is called as the inlet temperature for solar collector, and the outlet temperature is defined as T_oColl In the starting 17 hours, the T_iColl is in a constant state of 17°c which was generated by the simulation which is the lowest temperature output that has been obtained from the system which goes together with T_oColl at 25°c. This goes by the proven study, the lower the T_iColl, the lower the T_oColl [18]. For the first 17 hours, the T_iColl is almost constant where else the T_oColl increases slightly to 27.5°c.

On the next 17 hours, the T_iColl goes increase drastically to 80°c together with the T_oColl which is at 83°c. On the third 17 hours, the reading of T_iColl and T_oColl drops massively where the T_iColl sits at 50°c and the T_oColl plunges to 0°c. On the 1724.6 hours, also known as the fourth 17 hours, both the reading of T_iColl and T_oColl increases slightly. The next 17 hours shows that the reading increases up to 27°c for T_iColl and 50°c T_oColl. At the beginning of the sixth 17 hours, the data for both the started to increase gradually where the highest point before the final calculation taken for both T_iColl and T_oColl is 60°c and 75°c respectively. The final data for the simulation for the T_iColl and T_oColl stays at 30°c and 10°c respectively.

3.3.1. Experimental Work for Cyprus

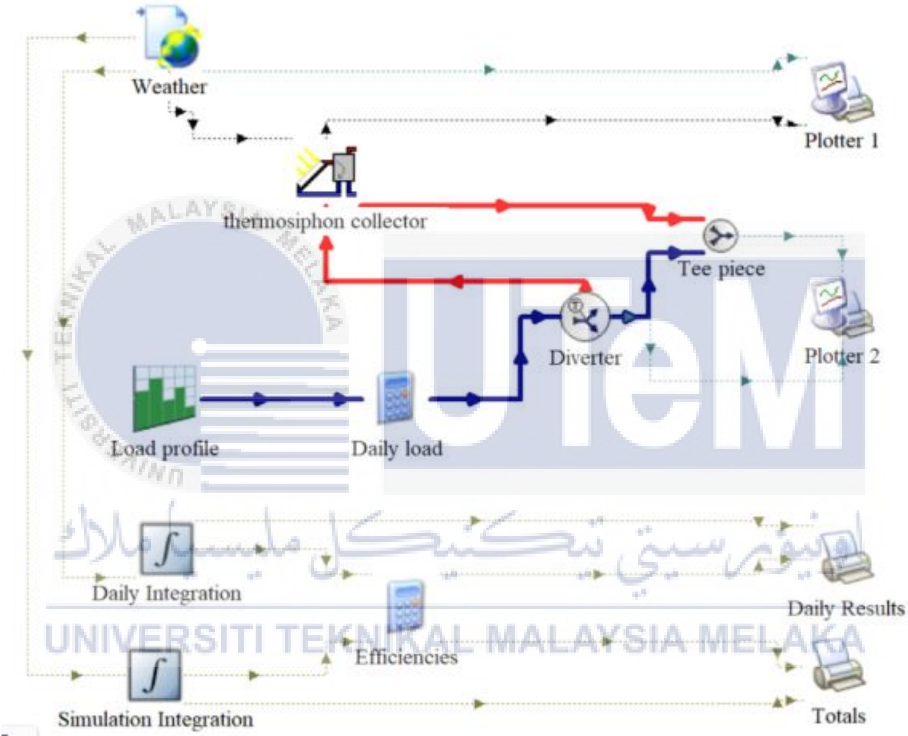

Figure 3.3.1.1 Modeling scheme for validation using thermosiphon Flat Plate Collector in Cyprus.

The above figure 3.3.1.1 shows the general experimental work setup model in TRNSYS for operating the solar system using a thermosiphon flat plate collector to analyse the energy and economic performance of low cost commercial solar thermal collectors. The weather conditions from March 2017 to May 2017 is linked to the thermosiphon flat plate collector. The collector is connected to the Tee piece. Both the flow diverter and the tee-piece are linked to the online plotter (Type 65a) which will produce the graph for the solar system.

The base settings to use in the TRNSYS simulation system are the components that are used for basic solar system generation. For this study, The TMY2 Reader (Type109) used to provide a reading of weather data in Larnaca, Cyprus which is to analyse the energy and economic performance of low cost commercial solar thermal collectors. In the system used in this study, TMY2 reads the weather conditions constantly, and it checks the data of solar radiation to find radiation of tilted surface radiation and incidence angle for an arbitrary number of surfaces. The simulation undergoes with Europe weather climate conditions.

3.3.2. Experimental Setup for Cyprus

An experimental setup was developed at the Archimedes Solar Energy Laboratory at Cyprus University to transfer the modelling scheme in the TRNSYS to the actual model. The thermosiphon solar thermal collectors were installed with the cylindrical heat storage tank (horizontal). The tank is in 47cm in diameter with a volume capacity of 100*l*. The parameters of the system energy performance are assessed experimentally. The temperature of the working fluid at the top of the storage tank is known as (T_{TKtop}), the temperature of the working fluid at the bottom of the storage tank is known as ($T_{TKbottom}$), and flow rate of the working fluid flowing in the solar loop (m). The total solar radiation per unit area incident on the solar collector was measured. The riser diameters inside the collectors are in 15mm. The solar slope is set at 35 degrees. The height of the storage tank from the collector and the distance of the collector and the storage tank details are below.

Figure 3.3.2.1 Experiment Setup (Horizontal) of Solar thermal collectors.

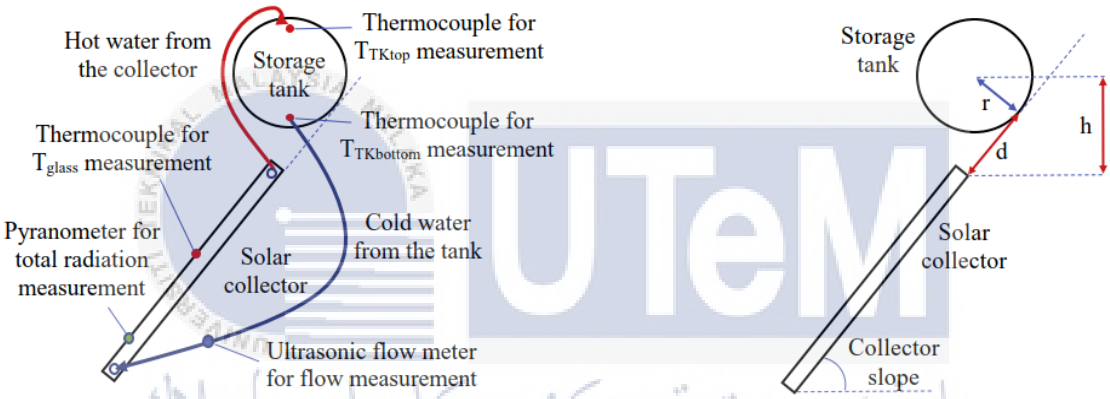

Figure 3.3.2.2 Schematics diagram of the experimental setup

Table 3.3.2.1 Flat Plate Collector parameters of the study

Data	Value	Unit
Number in series	1	
Collector area	1.52	m²
Fluid specific heat	4.19	kJ/kg. K
Tested flow rate	40	kg/hr.m²
Intercept efficiency	0.8	
Collector Slope	35	°
Distance	35	cm
Pipe Diameter	15	mm
Max Temp measured	1273	°C
Resolution	0.1	kJ/hr.m². K
Accuracy	0.5	kJ/hr.m². K²
Pyranometer constant	$9.11x10^{-6}$	V/Wm^{-2}
Larnaca collector slope	35	°
Natural Gas	0.5	₺/Nm3

The parameters of the thermosiphon flat plate collector are adjusted in the system are shown in Table 3.3.2.1. The collector area that was chosen for the study is 1.52 m² arrange in one number of series with the intercept efficiency of 0.8. The collector slope is at 35 degrees with the distance of the thermosiphon collector from the ground is at 35cm. The experiment was conducted on May 9th 2017 with a pipe diameter of 15mm for the inlet and outflow of water in the solar system.

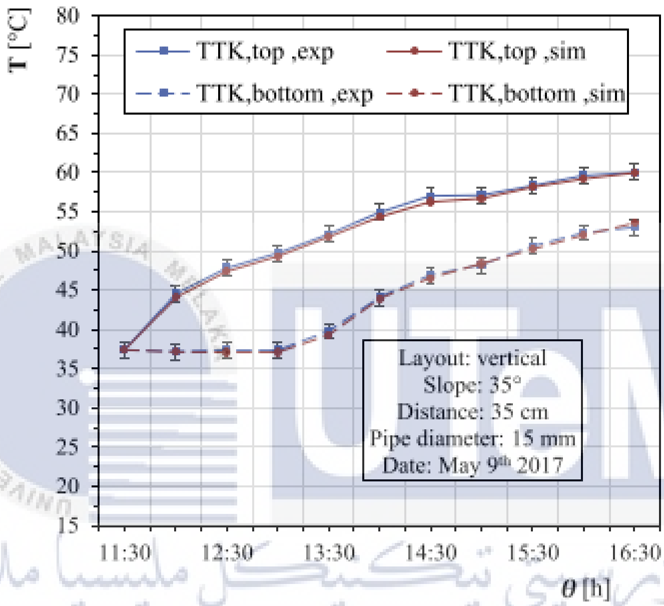

Figure 3.3.2.3 Comparison between simulated and experimental temperatures

The figure above is the simulated and experimental temperature results comparisons that have been achieved by the author of the study. The results have been concluded as a very good achievement. As the figure shows that the time history of the temperature of the working fluid at the top and the bottom of the storage tank ($T_{TK, top}$ and $T_{TK, bottom}$) is tabulated respectively. The reading was simulated and recorded live from morning 11:30 to 16:30 is the evening with a step of 30 mins. $T_{TK, top}$, the temperature of the working fluid at top of the storage tank and $T_{TK, bottom}$, the temperature of the working fluid at the bottom of the storage tank.

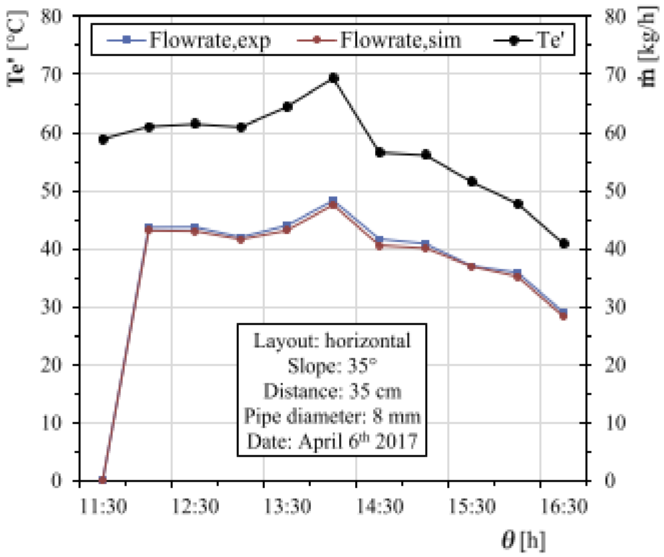

Figure 3.3.2.4 Comparison between simulated and experimental of working fluids

The figure above shows the comparison of simulated and experimental of working fluids of the mass flow rate of the solar system which uses the thermosiphon flat plate collector at Larnaca, Cyprus. The temperature is reported for comparisons purposes concerning the measured mass flow rate from the thermosiphon flat plate collector. The results for the mass flow rate for the study is low due to the thermosiphon effect that circulates the water due to no pump enhanced in the piping system if the solar system. This kind of solar system with the thermosiphon effect and without the pump will be less expensive. This is due to the lack of electrical device used in the required solar system. This system is more reliable and will have a longer lifetime as compared to any forced circulation system of solar collector systems.

3.3.3 Preliminary Results Karaikudi

3.3.3.1 Validation Flat Plate Collector for Karaikudi

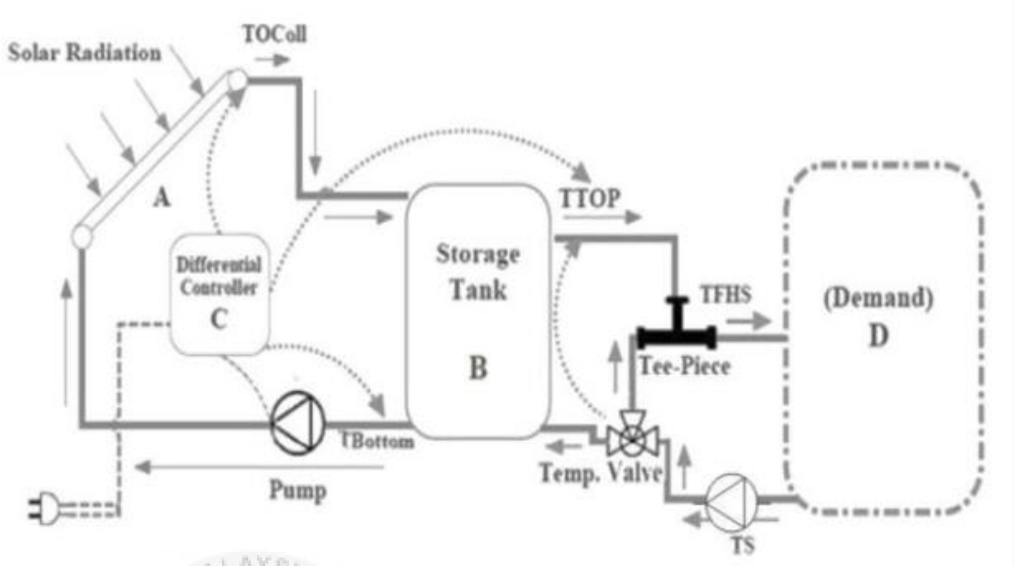

Figure 3.3.3.1(a) Actual model of Flat Plate Collector in Karaikudi.

The figure above shows the actual model of flat plate collectors in Karaikudi. The water flows from the water draw load pipe. The water will then flow through the diverter where the water will flow through the lower level of the stratified storage tank. Once the storage tank has taken the required amount of water the sensor triggers the excessive water to the tee piece where it will either end up in the demand tank or it will be released out. In the stratified storage tank, the water will wait for the sensor to trigger the pump.

Once the pump is triggered, the water enters the flat plate collector where it receives the required number of heats. Once the water has reached a certain temperature level, it enters the upper level of the stratified storage tank. The stratified storage tank has two levels of temperature, hot water above and cold water below and it has a thermocline layer in the middle where the mixture of both the hot and cold water happens in lower rate due to constant water movement at the top and the bottom.

Once the users trigger the pipe end, the heated water will flow through to the piping. Once the user is done, the excessively heated water will be stored in the demand tank (D). The demand tank act as a reservoir where if there is a second cycle to heat the water, it will use the demand water to start the process. This will lover the usage of the solar system and minimizes the work done by the system, thus saving the cost, water, energy and electricity bill.

The solar system has a temperature limit, where if the heated water reaches 100 degree Celsius the solar system will stop working and the demand tank will supply the warm water to the user, this is the reason why the temperature fluctuation used to happen during hot water usage. The temperature cut off is set to avoid any accidental water heat surge and causing mishap to the user. It is enabled for safety precaution and it is usually set up for domestic usage.

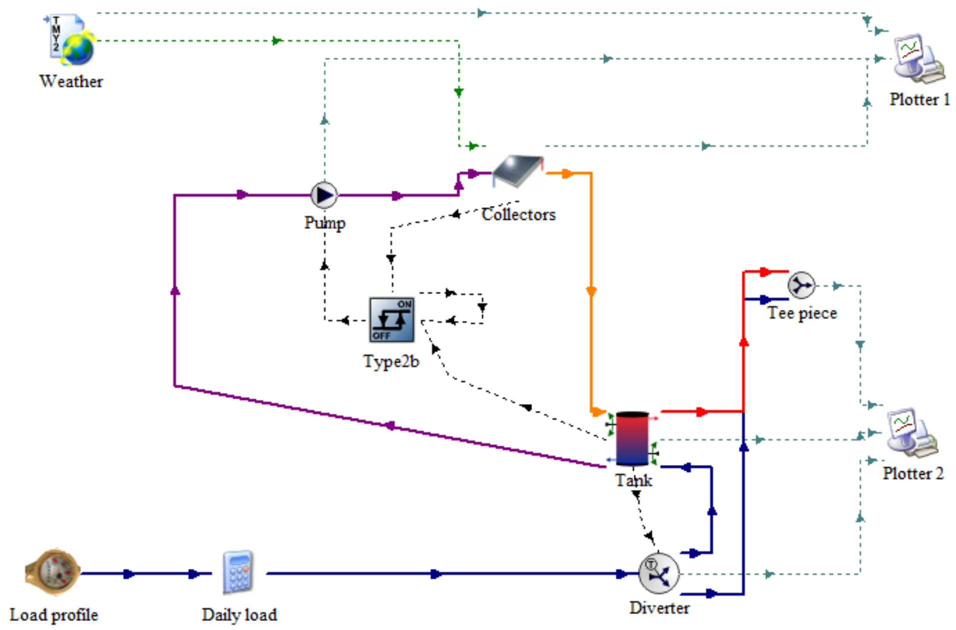

Figure 3.3.3.1(b) Modeling scheme for validation using Flat Plate Collector for Karaikudi.

As a preliminary result, a validation on the result of the journal by A.Ponshanmugakumar et al, (2014) study is carried out. The TRNSYS 17 model scheme of Figure 3.3.3.1(b) uses the Karaikudi, Tamil Nadu, India weather data from March 2014 generated from Meteonorm 7.3 software.

The specific dates of weather data of Karaikudi, Tamil Nadu, India of 11-15 March 2014 is not given in the study. The load profile used in this model is was not define in the journal. The characteristics of system components are modified to obtain the best results. The objective of this model of flat plate collector is to validate the performance of the flat plate collector at Karaikudi and match it with the original output.

The variation of inlet and outlet water flow temperature is measured hourly using a flat plate collector from March 2014 data. The linkage of each component is done with precise accuracy and the parameters for the pump, solar collector and the diverter is kept the same as given in the journal. The only difference in the validation input is the load profile and the undefined input and parameters and the weather data which might cause some variation in the output.

Table 3.3.3.1 Flat Plate Collector parameters

Data	Value	Unit
Number in series	**1**	
Collector area	**5**	**m^2**
Fluid specific heat	**4.19**	**kJ/kg.K**
Efficiency mode	1	
Tested flow rate	**40**	**kg/hr.m^2**
Intercept efficiency	**0.8**	
Efficiency slope	13	kJ/hr.m^2. K
Efficiency curvature	0.05	kJ/hr.m^2. K^2
Optical mode 2	2	
1st-order IAM	0.2	
2nd-order IAM	0	

The parameters of flat plat collector (Type 73) are adjusted in the system are shown in Table 3.3.3.1. The bold parameters are the actual parameters given in the study. The rest of it is left with the default settings.

Table 3.3.3.2 Flat Plate Collector input

Input	Value	Units
Inlet temperature	**20**	**°C**
Inlet flowrate	100	kg/hr
Ambient temperature	10	°C
Incident radiation	0	kJ/hr.m^2
Total horizontal radiation	0	kJ/hr.m^2
Horizontal diffuse radiation	0	kJ/hr.m^2
Ground reflectance	0.2	-
Incidence angle	45	degrees
Collector slope	**45**	**degrees**

Only the inlet temperature and the collector slope angle are defined in the study where else the other input is not defined. All the undefined input is left unchanged and is set at default. The bold parameters are the actual parameters given in the study.

Table 3.3.3.3 Differential Controller input parameters

Input	Value	Unit
No. of oscillations	5	-
High limit cut-out	**100**	**◦C**
Upper input temperature T_h	**20**	**◦C**
Lower input temperature T_l	**20**	**◦C**
Monitoring temperature T_{in}	**20**	**◦C**
Input control function	0	-
Upper dead-band dT	10	
Lower dead-band dT	2	

The High limit cut-out, Upper input temperature T_h, Lower input temperature T_l, Monitoring temperature T_{in} are kept the same as the study. While the other inputs are left in the default settings. The bold parameters are the actual parameters given in the study.

Table 3.3.3.4 Pump input parameters

Parameters	Value	Unit
Maximum flow rate	**125**	**kg/hr**
Fluid specific heat	4.19	kJ/kg.K
Maximum power	240	kJ/hr
Conversion coefficient	0.05	-
Power coefficient	0.5	-
Inlet fluid temperature	20	◦C
Inlet mass flow rate	100	kg/hr
Control signal	1	-

The table 3.3.3.4 shows the input parameters for the differential controller. Only the maximum flow rate of the study was provided. The other parameters are kept exactly as per the default settings. The bold parameters are the actual parameters given in the study.

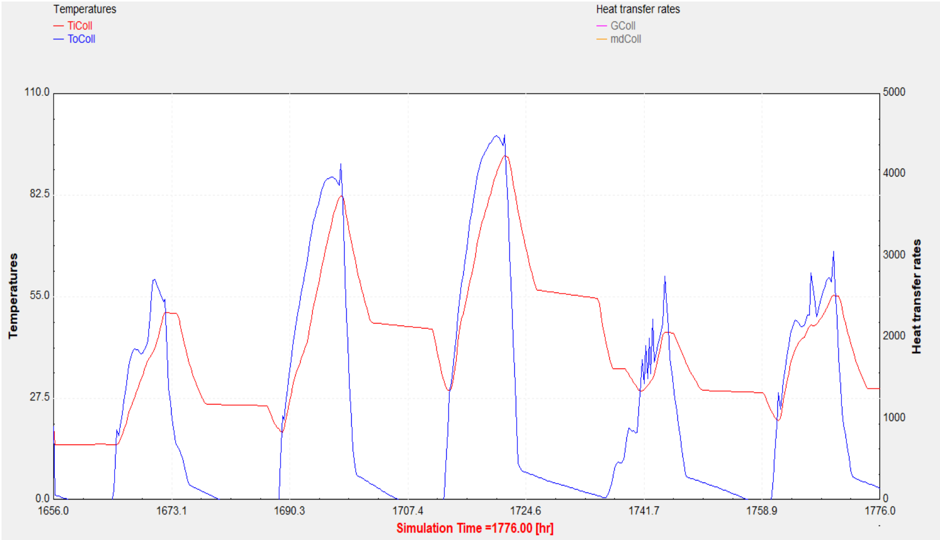

Figure 3.3.3.5: Validated temperature input and output of collector in Karaikudi

Figure 3.3.3.5 shows temperature input and temperature output with the time of a solar collector which was produced by simulation using the theoretical flat plate solar collector with pump system using TRNSYS 17 of March 2014 at Karaikudi, Tamil Nadu, India for 17 hours time difference. T_iColl and T_oColl are known as temperature input and temperature output respectively. In the starting 17 hours, the T_iColl and T_oColl started in a constant state of 17° c which was generated by the simulation which is exactly the starting point of the journal simulation.

The lowest temperature output and input that has been obtained from the system which goes with 51°c and 57°c, which is higher than the journal study. This goes by the proven study, the lower the T_iColl, the lower the T_oColl [18] which shows that the validation graph goes by this law. For the second 17 hours, the T_iColl increase drastically to 80°c which is almost the same from the journal simulation together with the T_oColl which is at 89°c slightly above from the journal.

On the third 17 hours, the reading of T_iColl and T_oColl drops massively where the T_iColl sits at 49°c which is just 1°c below the journal simulation and the T_oColl plunges to 0°c the same as the journal simulation. On the 1724.6 hours, also known as the fourth 17 hours, both the reading of T_iColl and T_oColl increases slightly.

The next 17 hours shows that the reading increases up to 40°c for T_iColl and 42°c T_oColl. At the beginning of the sixth 17 hours, the data for both the started to increase gradually same as the journal simulation where the highest point before the final calculation taken for both T_iColl and T_oColl is 50°c and 65°c respectively. The final data for the simulation for the T_iColl and T_oColl stays at 30°c and 5°c respectively which is almost the same compare the to the journal simulation where it is a simulation for the T_iColl and T_oColl stays at 30°c and 10°c respectively. It can be seen in the T_oColl with the blue line that the graph goes to 0°c in few instances, that is because the water draw point is set to zero in a specific time frame.

Besides that, the temperature inlet which is known as T_iColl will be in a constant rate and will not be hitting the 0°c because the unused or the excess output of the hot water will be stored in the demand tank. Some of the water temperatures will still be high which causes the graph to be higher than the T_oColl and it will decrease slowly and constantly.

The slight differences in the graph simulations for both the journal and the validation are because of the weather data difference. The journal uses the weather data from 11-15 March 2014 where the validation data uses on March 2014 data generated from Meteonorm 7.3. The load profile was no defined and the parameters and the inputs of the theoretical flat plate collector, pumps and the controller were left in default settings. This may be the root cause due to the minor variation of the simulation graph output. The highest percentage of error that can be noticed is at 1724 hours, where the error is at 17% where else the lowest is at 1690 hours (1.3% percentage error) at the temperature output of the collector. For the temperature input, the highest error percentage is at 1673 hours (50%) and the lowest error coming at 1724 hours (9% percentage error).

3.3.4 Karaikudi weather data

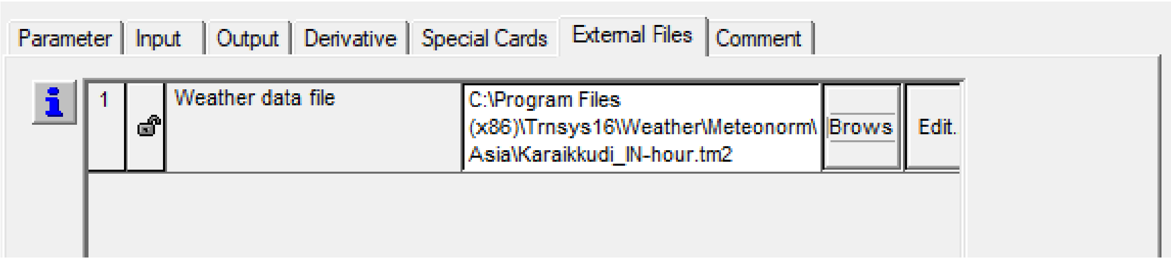

Figure 3.3.4.1 Weather data of Karaikudi in TRNSYS 17

The figure above shows the actual weather data which is used in this research in the Transient Simulation System Software. It can be seen that the Karaikudi, India 2014 weather data file is used in the system to generate the output. The exact location of the study was used to generate weather data in the TRNSYS. The weather data was generated using the Meteonorm 7.3 software.

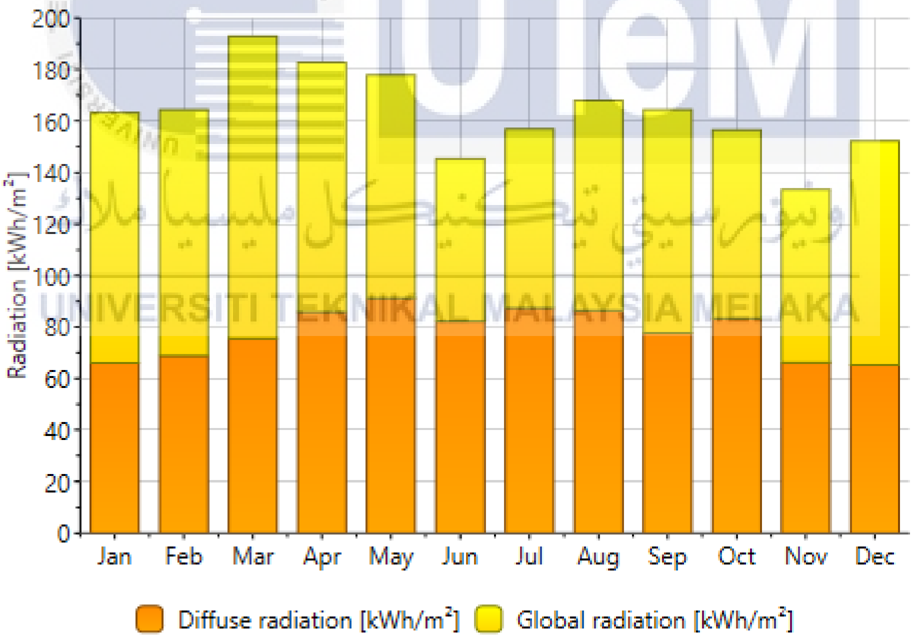

Figure 3.3.4.2 Diffuse and Global Irradiation of Karaikudi

Figure 3.3.4.2 shows the Meteonorm 7.3 generated data of Karaikudi's Diffuse and Global Irradiation of the year 2014. Direct beam radiation is the sunray that comes from the sun. Diffuse radiation is dispersed by molecules from the ground to the atmosphere of the earth. The sum of the direct beam, diffuse, and ground-reflected radiation which touches the surface is called total or global solar radiation.

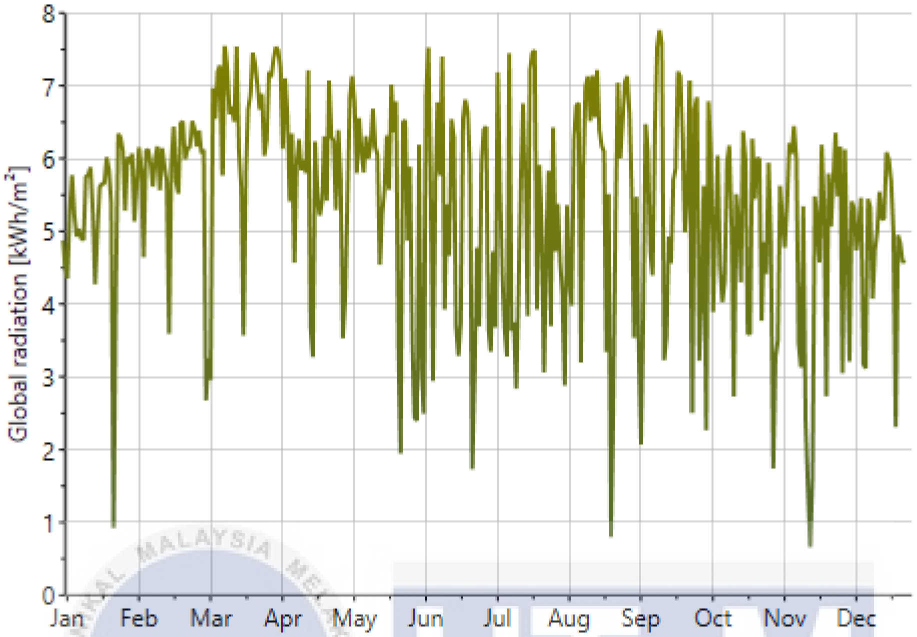

Figure 3.3.4.3 Global Irradiation of Karaikudi

Figure 3.3.4.3 shows the Meteonorm 7.3 generated data of Karaikudi's Global Irradiation of 2014. Solar irradiance can be categorized as power per unit area (watt per square meter, W/m2), it comes directly from the Sun in the form of electromagnetic radiation.

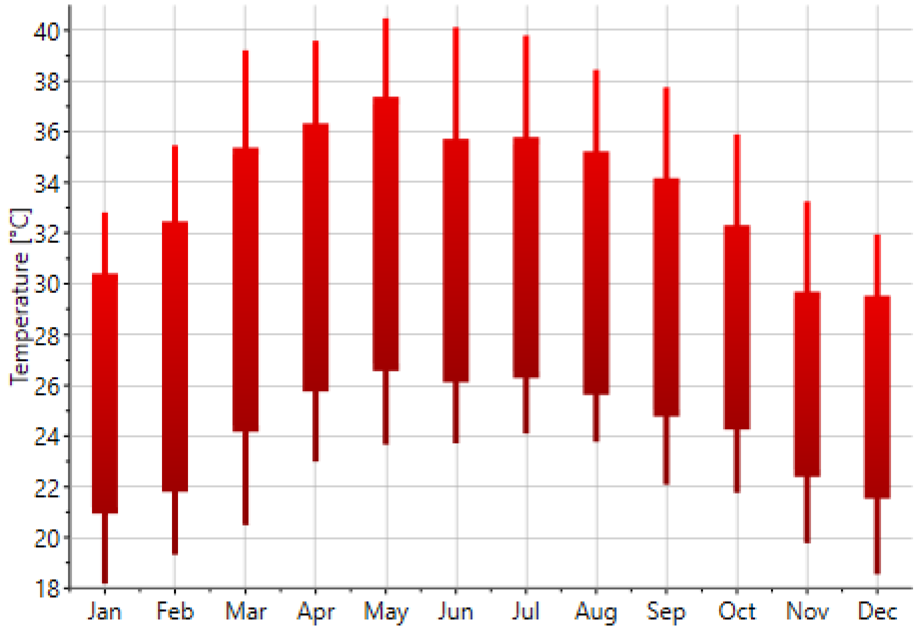

Figure 3.3.4.4 Monthly temperature of Karaikudi 2014

Figure 3.3.4.4 shows the Meteonorm 7.3 generated data of Karaikudi's Monthly temperature of 2014. The monthly temperature is the average daily mean of temperature if each day of a month.

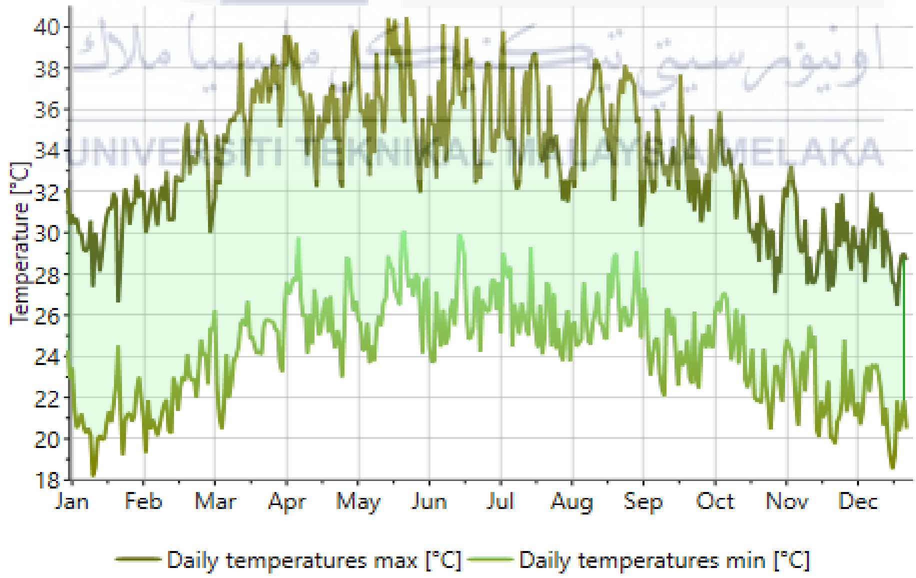

Figure 3.3.4.5 Daily min and max temperature of Karaikudi

Figure 3.3.4.5 shows the Meteonorm 7.3 generated data of Karaikudi's Daily minimum and maximum temperature in 2014. This graph portrays the maximum and minimum temperature in the course of a straight time interval of 24 hours where the highest temperature is the daily maximum temperature and the lowest temperature is the daily minimum temperature.

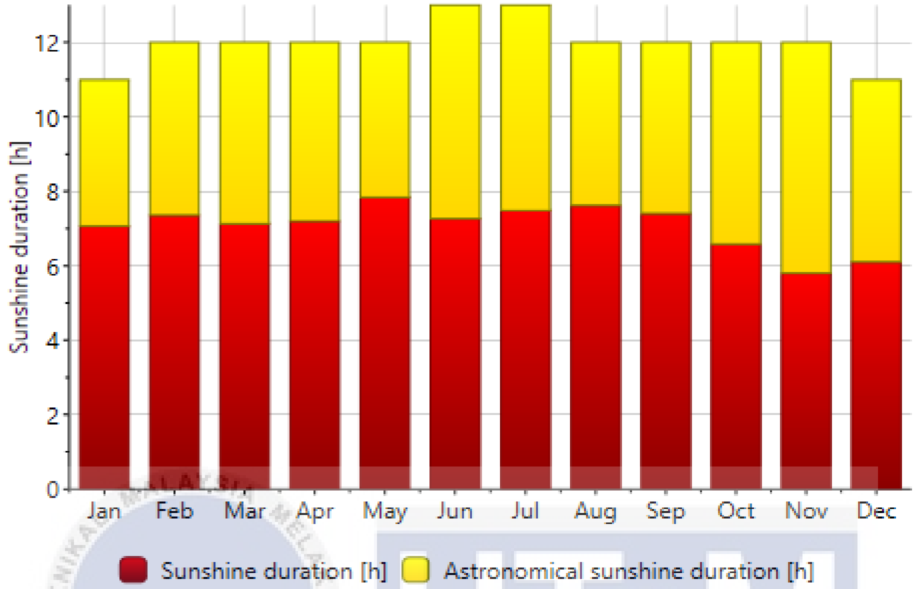

Figure 3.3.4.6 Sunshine duration of Karaikudi

Figure 3.3.4.6 shows the Metoenorrm 7.3 generated data of Karaikudi's sunshine duration and astronomical sunshine duration in 2014. Sunshine duration is the period where direct solar irradiance exceeds the threshold amount of 120 watts per square meter (W/m2). This the level of solar irradiance shortly after sunrise and shortly before the sunset without the presence of clouds.

Table 3.3.4.1 Weather data of Karaikudi 2014

Month	Gh kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	163	66	157	25.7	20.1	3.6
February	164	69	142	27.1	20.2	3.3
March	193	76	163	29.5	21.5	2.8
April	183	86	130	31.2	23.4	2.5
May	178	91	119	31.6	22.8	4.3
June	145	82	90	31.1	21.8	5.6
July	157	87	96	30.8	21.7	6.4
August	168	86	110	30.2	21.8	5.6
September	164	78	122	29.7	22.4	4.1
October	156	83	102	28.2	23.1	3.1
November	134	66	100	26.4	22.4	3.4
December	152	65	136	25.5	20.8	3.7
Year	2014	936	1466	28.9	21.8	4

The table above shows the data of Karaikudi generated from Meteononorm software for the year 2014. The data were taken with the average weather data of Karaikudi from each day and the mean are calculated to provide precise data to avoid tolerance of weather conditions.

3.3.5 Results on Increased collector area

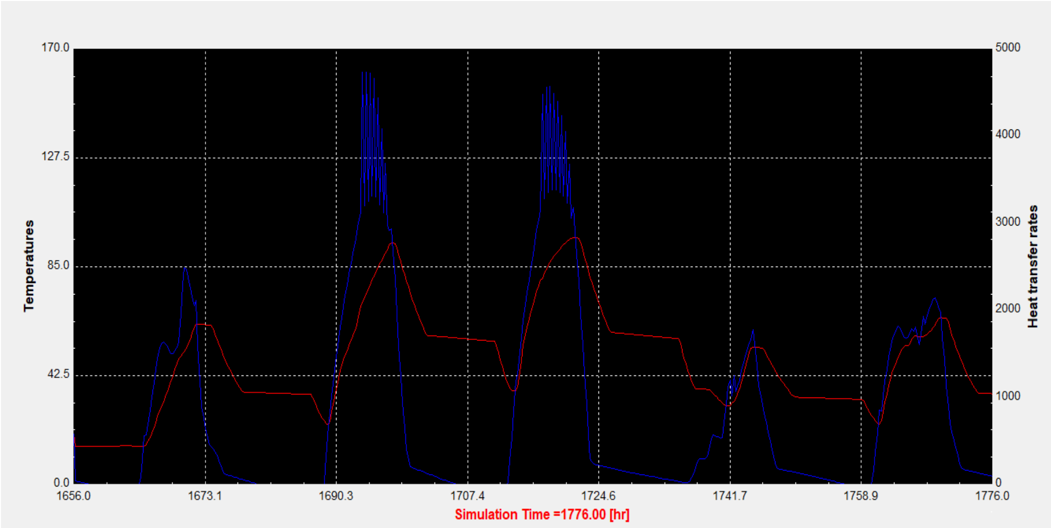

Figure 3.3.5.1 Increased results of temperature input and temperature output

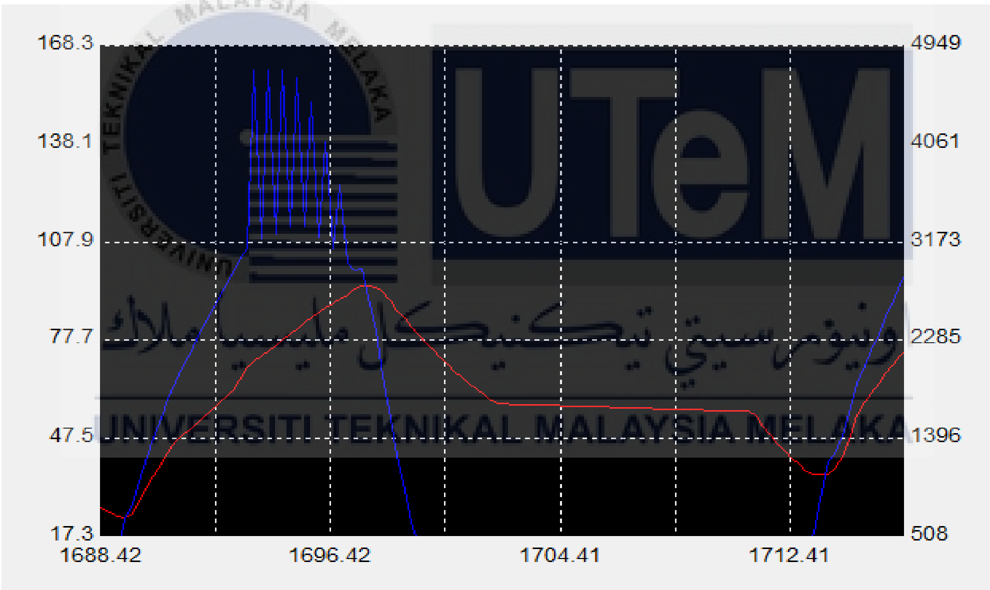

Figure 3.3.5.2 Results of 1696.4 hours

The collector area of A.Ponshanmugakumar et al, (2014) study is increased from $5m^2$ to $10m^2$ to find out the temperature difference in the input and output temperature of the collector. It can be noticed in the simulation in figure 3.3.5.2 that the temperature difference in the 3^{rd} and 4^{th} hours is more drastic.

The characteristics of a solar collector's structure is not a simple task. The area of the surface that takes in the incoming solar energy is a critical parameter since it finds out the actual heat load and temperature to be delivered to the process. The specification of uniform solar collectors depends on the combination of series and parallel arrangements [25][26].

3.3.6 Results on Increased mass flow rate

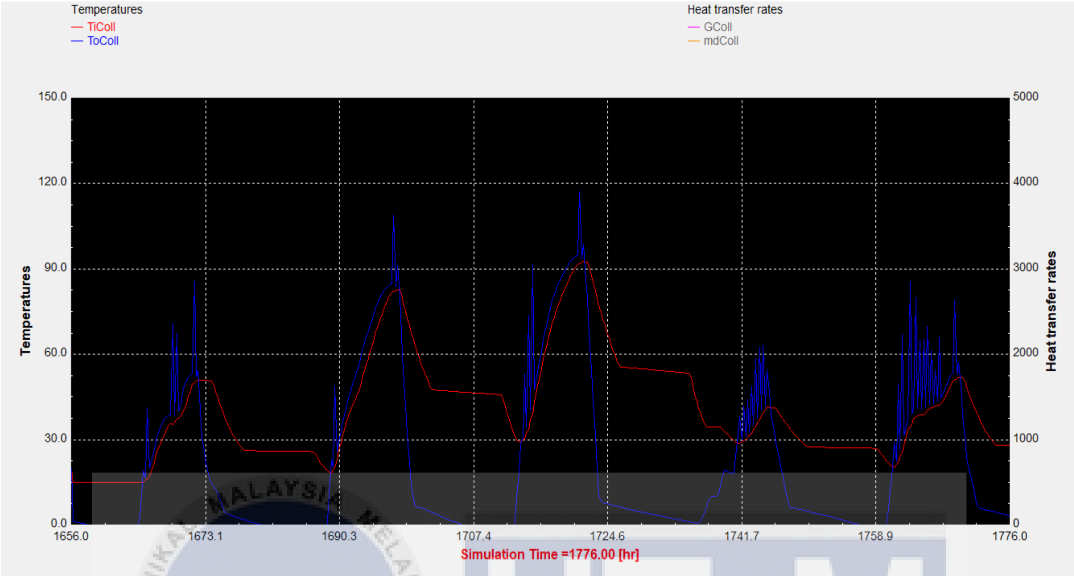

Figure 3.3.6.1 Results upon increasing the mass flow rate

The size of a flat plate solar collector also depends on the mass flow rate of the thermal fluid which determines the temperature output that will be delivered to the process [27]. The larger the mass flow rate, the larger the number of parallel arrangements whereas the higher the delivery temperature, which will produce a small temperature difference when the mass flow rate increases.

3.3.7. Preliminary Results for Cyprus

3.3.7.1 Validation and Verification of Flat Plate Collector for Cyprus

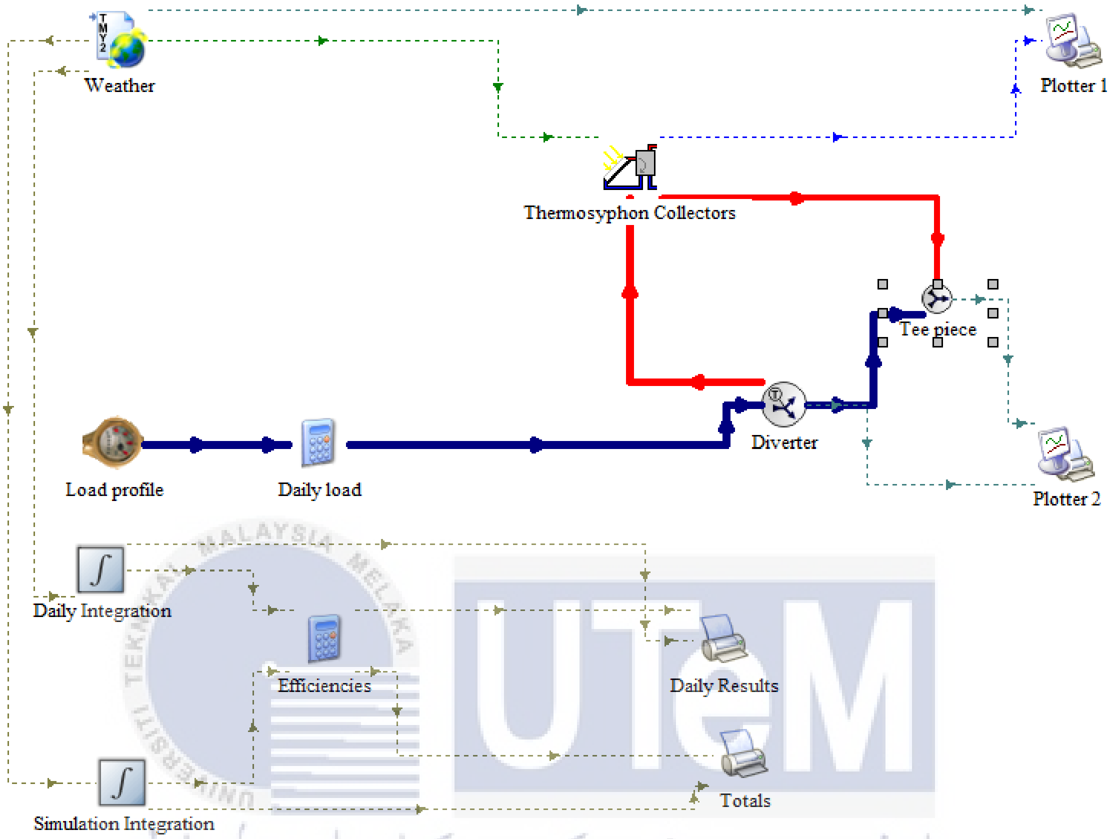

Figure 3.3.7.1(a): Modeling scheme for validation and verification.

As a preliminary result, a validation on the result of the journal by S.A Kalogirou et al, (2018) study is carried out. The TRNSYS model scheme of Figure 3.3.7.1 (a) uses the Larnaca, Cyprus weather data from 15 October 2017 – 15 April 2018 generated from Meteonorm 7.3 software.

The load profile used in this model did not define in the journal. The characteristics of system components are modified to obtain the best results. The objective of this model of flat plate collector is to validate the temperature comparisons of simulated and experimental temperatures.

The variation of inlet and outlet water flow temperature is measured hourly using a flat plate collector from 15 October 2017 – 15 April 2018 data. The linkage of each component is done with precise accuracy and the parameters for the diverter, solar collector and the tee piece is kept the same as given in the journal. The only difference in the validation input is the load profile and the undefined input and parameters and the weather data which might cause some variation in the output. The inlet of the water flow is known as the bottom of the storage tank and outlet is known as the top of the storage tank as in Figure 3.3.7.1(b) below.

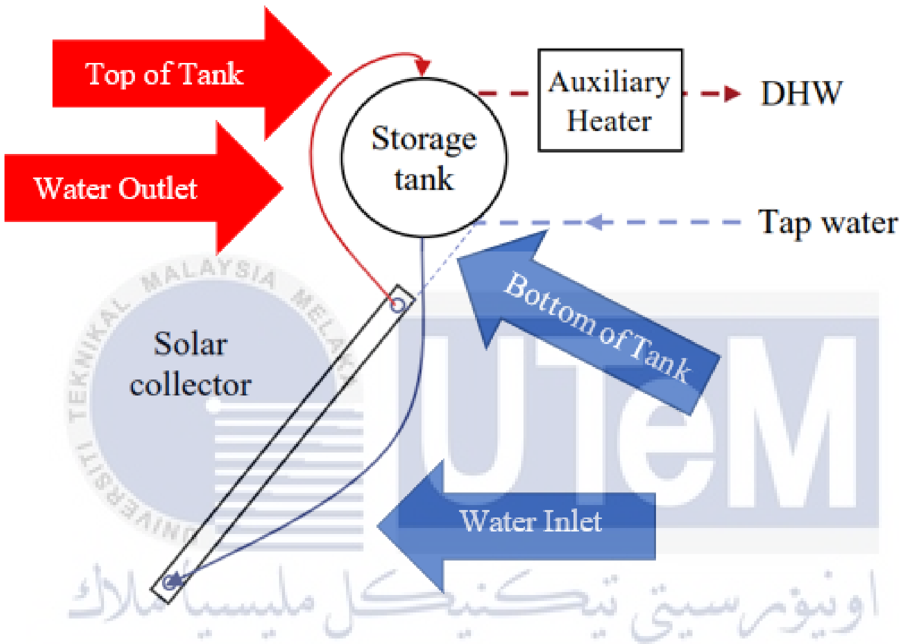

Figure 3.3.7.1(b): Modeling of the storage tank and flat plate collector.

Table 3.3.7.1 Thermosiphon Flat Plate Collector parameter

Data	Value	Unit
Number in series	1	
Collector area	1.52	m²
Fluid specific heat	4.19	kJ/kg.K
Efficiency mode	1	
Tested flow rate	40	kg/hr.m²
Max Temp measured	1273	°C
Resolution	0.1	kJ/hr.m². K
Accuracy	0.5	kJ/hr.m². K²
Pyranometer constant	$9.11x10^{-6}$	V/Wm^{-2}
Larnaca collector slope	30	°
Natural Gas	0.5	£/Nm3

The parameters of the thermosiphon flat plate collector are adjusted in the system are shown in Table 3.3.7.1. Across all the case studies the relevant data for TRNSYS 17 is using the parameters shown in the above table. The resolution and the accuracy are set with the exact given data from the study to make sure close to or precise simulation outputs are achieved.

Table 3.3.7.2 Thermosiphon Flat Plate Collector input

Input	Value	Units
Inlet temperature	20	◦C
Inlet flowrate	100	kg/hr
Ambient temperature	10	◦C
Incident radiation	0	kJ/hr.m^2
Total horizontal radiation	0	kJ/hr.m^2
Horizontal diffuse radiation	0	kJ/hr.m^2
Ground reflectance		-
Incidence angle	30	degrees
Collector slope	30	degrees

The inputs of thermosiphon flat plate collector are adjusted in the system are shown in Table 3.3.7.2 above, across all the case studies the relevant data for TRNSYS 17 is using a shown in the above table. The inlet temperature and inlet flowrate are set with the exact given data from the study to make sure close to or precise simulation outputs are achieved.

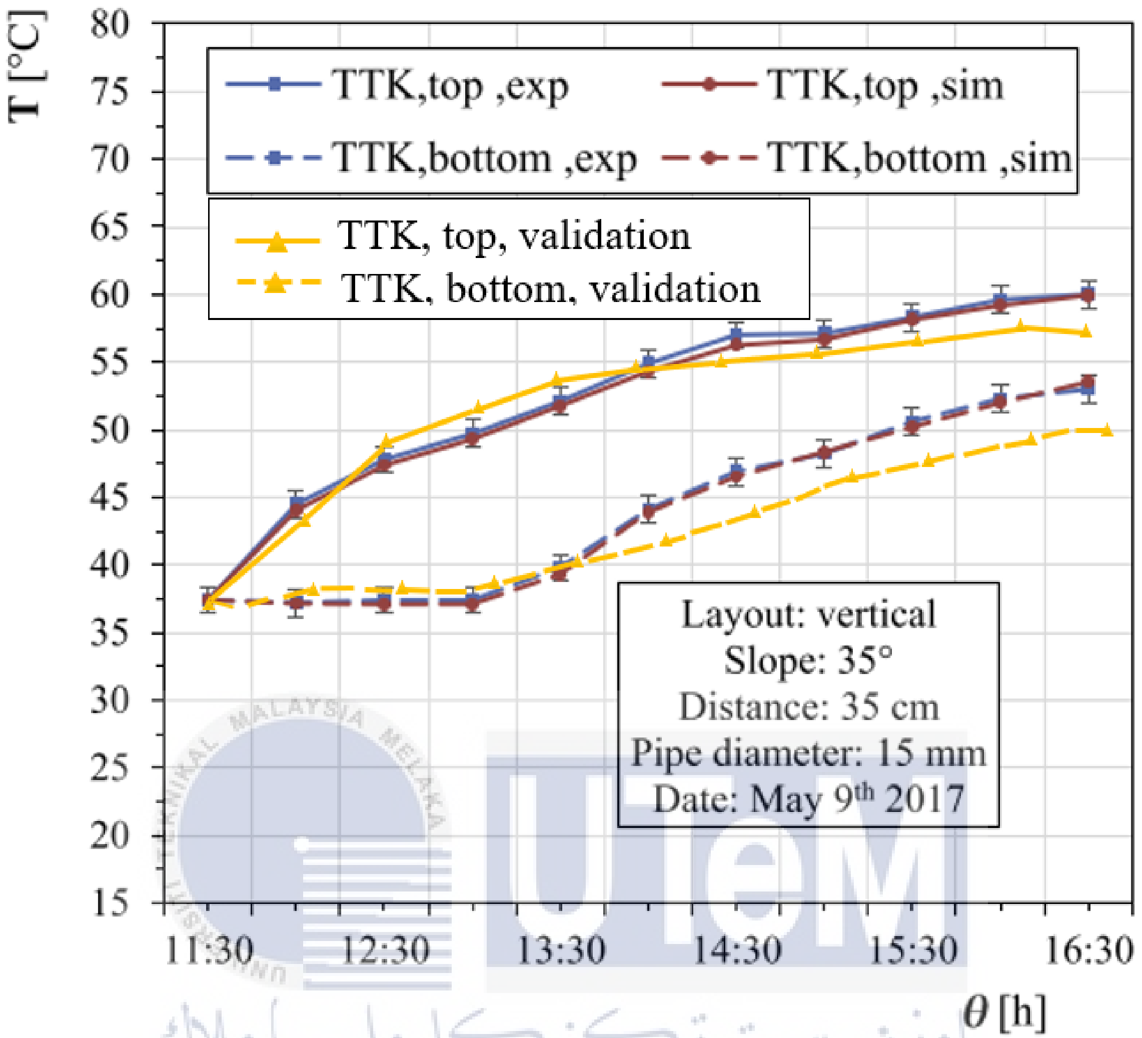

Figure 3.3.7.2: Comparison between simulated, experimental and validation temperature.

The figure above shows the comparison of the simulated, experimental and validation of the time history temperature of working fluid at the top and bottom of the storage tank ($T_{TK,\ top}$ and $T_{TK,\ bottom}$ respectively). The result is measured from 11:30 to 16:30 with a timestep of 30 mins. The highest error observed between the temperature at the top of the storage tank ($T_{TK,\ top,\ experiment}$ and $T_{TK,\ top,\ sim}$) is 1.3% at the timestep of 14:30. The highest error observed between the temperature at the top of the storage tank ($T_{TK,\ top,\ sim}$ and $T_{TK,\ top,\ validation}$) is 2.3% at the timestep of 14:30 which is almost similar to the experimented outcome.

The fluctuations in the time history temperature of working fluid at the top and bottom of the storage tank between ($T_{TK,\ top}$ and $T_{TK,\ bottom}$ respectively) for simulations and validations is due to the load profile which was not defined in the journal. The temperature at the bottom of the tank ($T_{TK, bottom}$) has a maximum error of 2.3% at the 15:30 hours. The max error observed between the temperature at the top of the storage tank ($T_{TK, bottom, sim}$ and $T_{TK, bottom, validation}$) is 6.0% at the timestep of 14:30. The error is not similar to the maximum error observed between the temperature at the top of the storage tank ($T_{TK, bottom, sim}$ and $T_{TK, bottom, validation}$). This is due to the undefine load profile in the modelling scheme of the solar system.

The other factor that might contribute to the variation of the temperature at the top of the storage tank ($T_{TK, bottom, sim}$ and $T_{TK, bottom, validation}$) and the temperature at the top of the storage tank ($T_{TK, top, sim}$ and $T_{TK, top, validation}$) is the weather data date. The experiment and the simulation were conducted on the 9th of May 2017 while the simulation for the validation was done by taking the average weather data of May 2017. The variation of solar radiation and irradiation will cause a change in the simulation output.

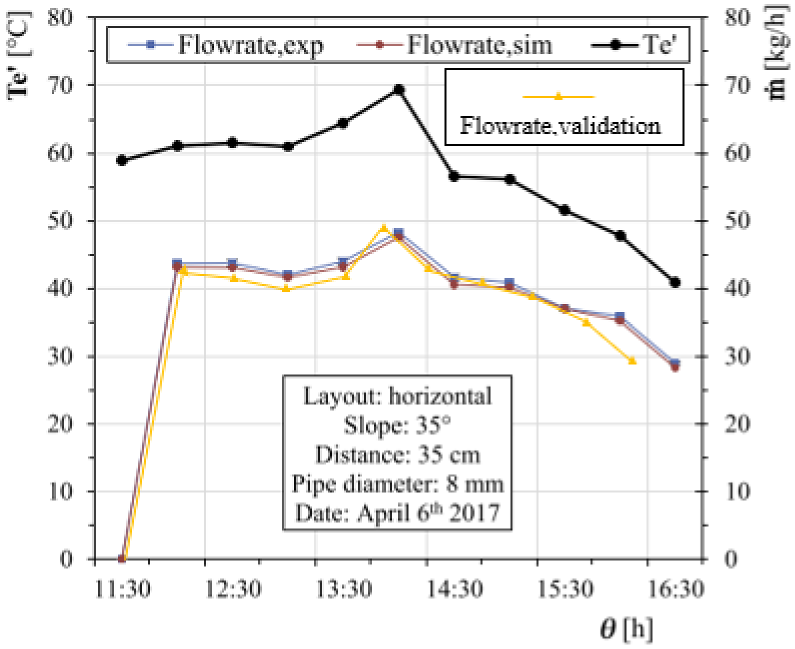

Figure 3.3.7.3: Comparison between working fluid mass flow rate

The figure above shows the time history of working fluid mass flow rate (ṁ). The result is measured from 11:30 to 16:30 with a timestep of 30 mins which is the same as the study.

The maximum detected an error for the experimented and the simulated outcome from the study is 2.6% at 14:30. The maximum error between the simulation and the validation came at the latter stages of the simulation. The max error came at 16:00 hour with 4% outcome. The validation graph ended a few minutes earlier than the simulated graph. The time history SolAir temperature (Te') has a comparison purpose concerning the measured thermosiphon mass flow rate (ṁ) of the working fluid.

The mass flow rate is always in phase with Te'. The experimented, simulated and validated outcome of the flow rate is low due to the thermosiphon effect produce by the thermosiphon flat plate collector which circulates the water that is not enhanced by a pump. This shows that the solar system with a thermosiphon flat plate collector without the pump will be less expensive as there is not an electric device and supply required. This system is more reliable and will last longer than the solar system with an added pump and forced circulation systems [28].

The experiment and the simulation were conducted on the 6th of April 2017 while the simulation for the validation was done by taking the average weather data of April 2017. The variation of solar radiation and irradiation will cause a change in the simulation output.

3.3.8 Cyprus weather data

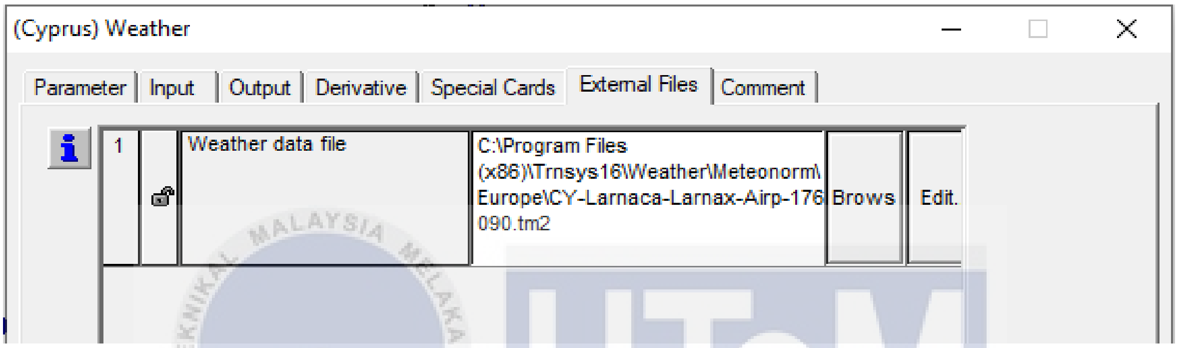

Figure 3.3.8.1: TRNSYS weather data

The figure above shows the actual weather data which is used in this research in the Transient Simulation System Software. It can be seen that the Cyprus, Larnaca 2017 weather data file is used in the system to generate the output. The exact location of the study was used to generate weather data in the TRNSYS.

The weather data was generated using the Meteonorm software. The software was used to generate the 2017 data of Cyprus for May and April for the comparison between simulated, experimental and validation temperature and also the comparison between experimental, simulated and validation data of working fluid mass flow rate.

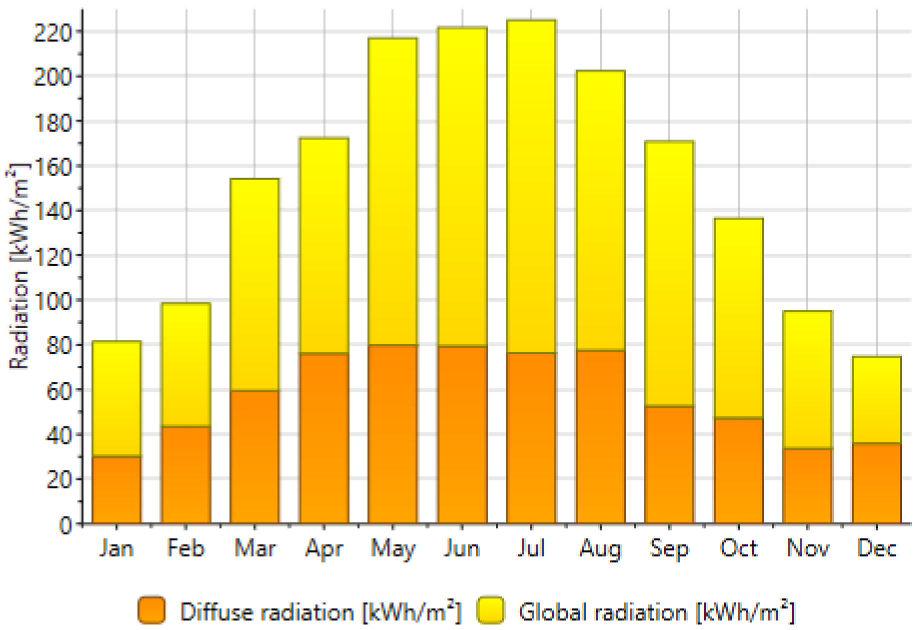

Figure 3.3.8.2: Diffuse data and global radiation

Figure 3.3.8.2 shows the Meteonorm 7.3 generated data of Cyprus's Diffuse and Global Irradiation of the year 2017. Direct beam radiation is the sunray that comes from the sun. Diffuse radiation is dispersed by molecules from the ground to the atmosphere of the earth. The sum of the direct beam, diffuse, and ground-reflected radiation which touches the surface is called total or global solar radiation.

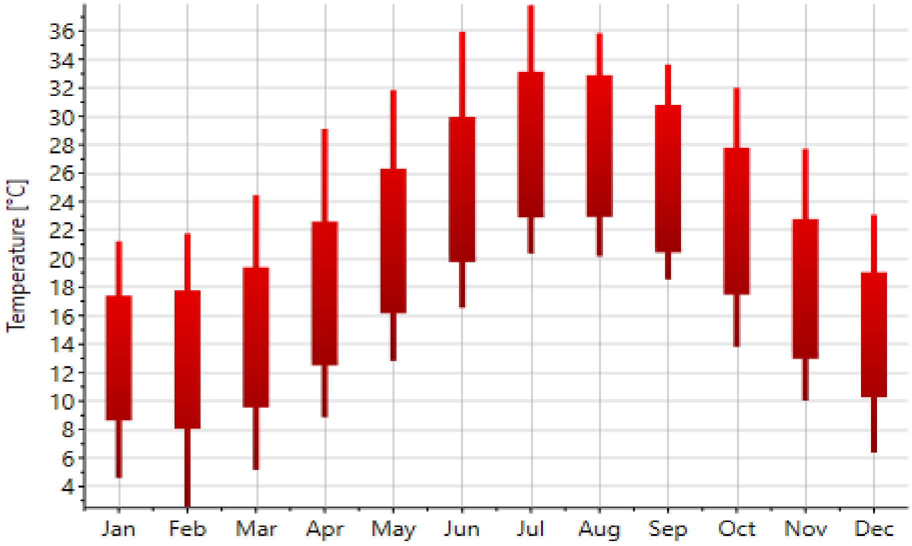

Figure 3.3.8.3: Monthly temperature

Figure 3.3.8.3 shows the Meteonorm 7.3 generated data of Cyprus's monthly temperature of 2017. The monthly temperature is the average daily mean of temperature if every day of a month.

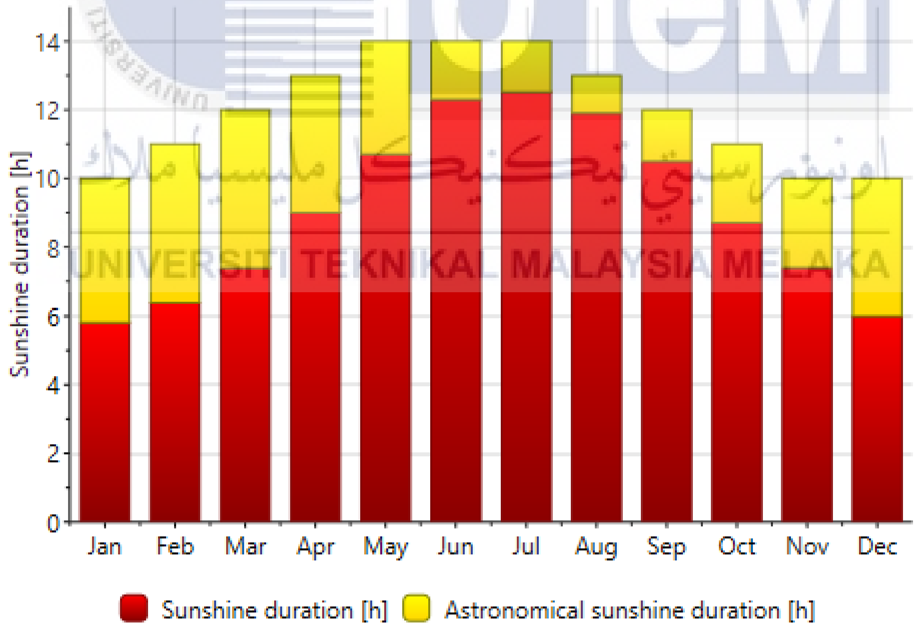

Figure 3.3.8.4: Sunshine Duration

Figure 3.3.8.4 shows the Meteonorm 7.3 generated data of Cyprus's sunshine duration and astronomical sunshine duration in 2017. Sunshine duration is the period where direct solar irradiance exceeds the threshold amount of 120 watts per square meter (W/m^2).

This the level of solar irradiance shortly after sunrise and shortly before the sunset without the presence of clouds.

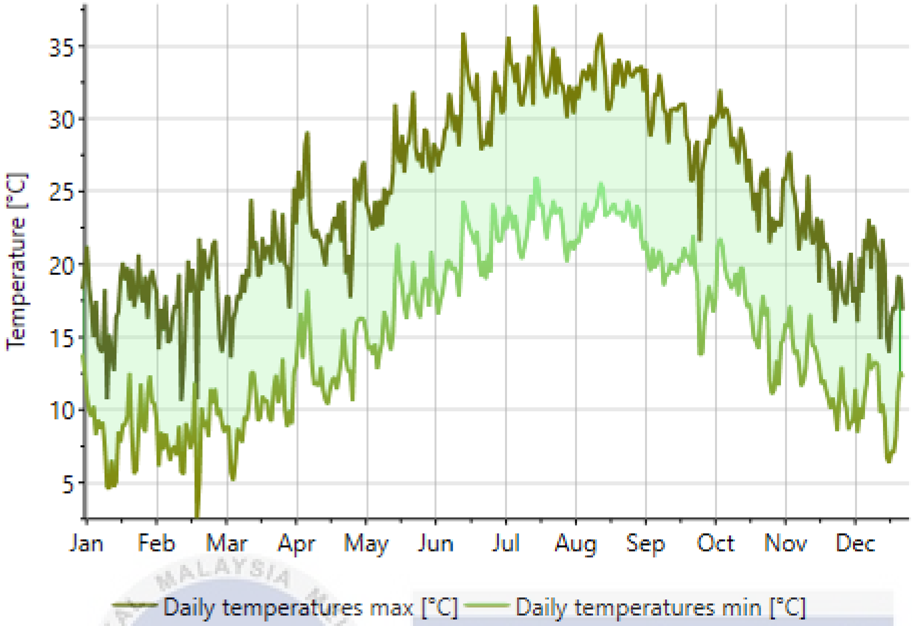

Figure 3.3.8.5: Daily max and min temperature

Figure 3.3.8.5 shows the Meteonorm 7.3 generated data of Cyprus's Daily minimum and maximum temperature in 2017. This graph portrays the maximum and minimum temperature in the course of a straight time interval of 24 hours where the highest temperature is the daily maximum temperature and the lowest temperature is the daily minimum temperature.

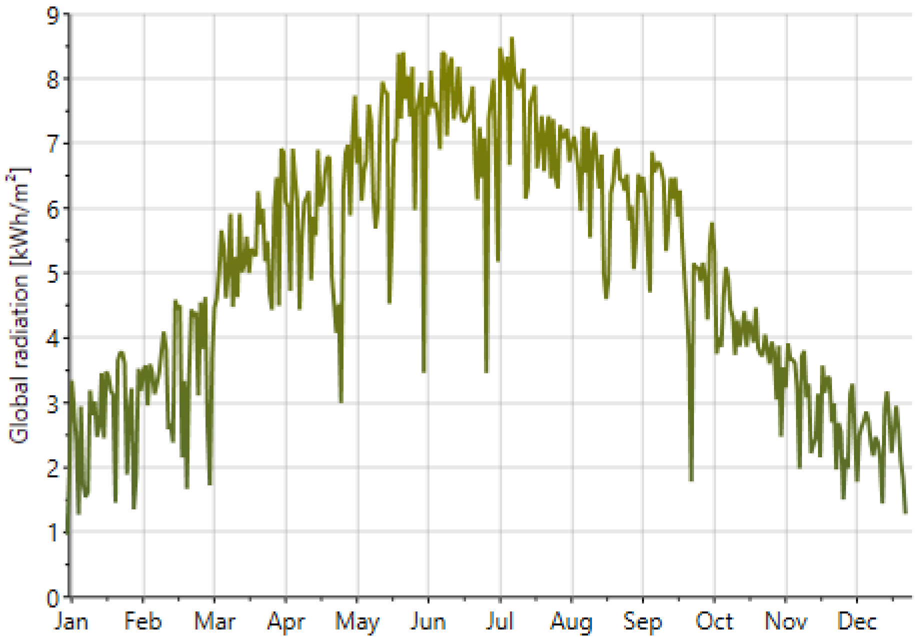

Figure 3.3.8.6: Global Irradiation

Figure 3.3.8.6 shows the Meteonorm 7.3 generated data of Cyprus's Global Irradiation of 2017. Solar irradiance can be categorized as power per unit area (watt per square meter, W/m2), it comes directly from the Sun in the form of electromagnetic radiation.

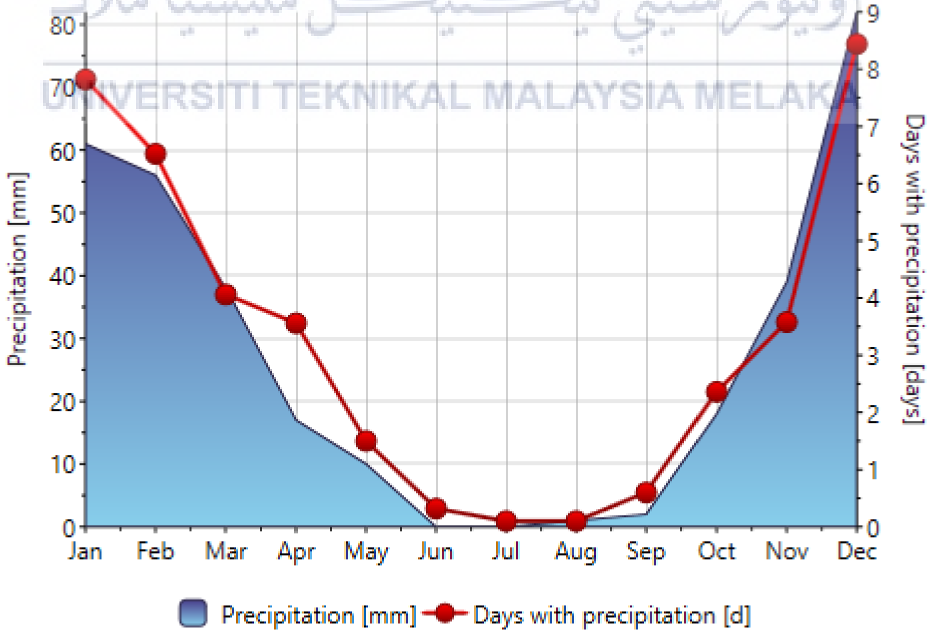

Figure 3.3.8.7: Precipitation

The figure above shows the precipitation in the Cyprus weather condition of 2017. It is knowing as the weather condition from the sky such as rain, snow, hail or sleet that occurs in certain conditions.

Table 3.3.8.1: Weather Data of Cyprus

Month	Gh kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	81	30	123	12.5	8.1	4.3
February	98	44	109	12.8	8.3	4.3
March	154	60	157	14.1	9.7	4.2
April	172	76	146	17.6	12.6	4.4
May	217	80	196	21.2	16	4.3
June	222	79	200	25.1	19.5	4.4
July	225	76	211	27.7	21.5	4.6
August	202	78	181	27.6	21.7	4.4
September	171	53	190	25.6	20.1	4
October	137	47	162	22.2	17.5	3.8
November	95	34	135	17.7	13	3.9
December	75	36	99	14.1	10.4	4
Year	2017	692	1908	19.9	14.9	4.2

The table 3.3.8.1 shows the data of Cyprus generated from Meteonorm software for the year 2017. The data were taken with the average weather data of Cyprus from every day and the mean are calculated to provide precise data to avoid tolerance of weather conditions.

3.3.9. Preliminary Results for HUKM

3.3.9.1 Validation and Verification of Flat Plate Collector for HUKM

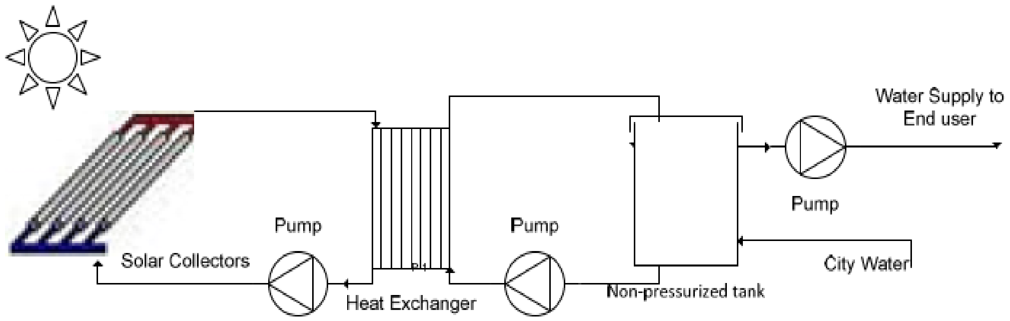

Figure 3.3.9.1: Solar model of HUKM with evacuated tubes

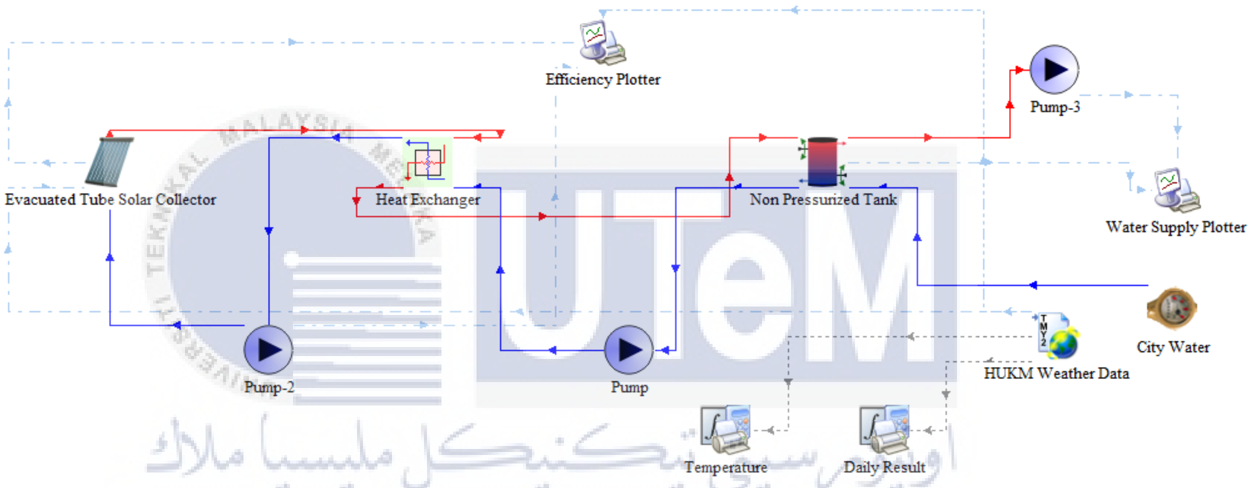

Figure 3.3.9.2: Solar model of HUKM with evacuated tubes

The figures above show the actual solar system in TRNSYS modelling that is installed in HUKM. The solar collectors that are being used in this system are the evacuated tube. The city water will be drawn into the non-pressurized tank where the water will be stored. The water will be at 20 – 40 degrees. The pump will transport the water into the heat exchanger. In the heat exchanger, both the cooling and heating process will take place. The weather data that has been generated by Meteornorm software is the actual weather data of August 2011

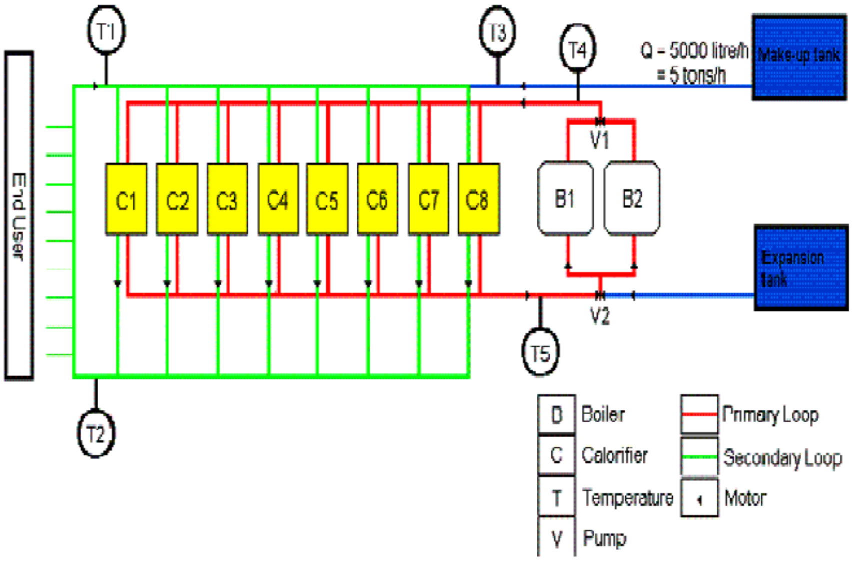

Figure 3.3.9.3: Solar model of HUKM with evacuated tubes

The figure above shows the hot water heating in HUKM, there is no temperature limit or cut off limit in this system as the hospital needs different temperature levels for laundry, kitchen, wards, toilets, etc. The consumed water will be replaced by the water stored in the tank. The average water temperature needed for kitchen and wards is 50 – 60 degree Celsius. While the hot water for washing, laundry, sterilization, etc. will be having a temperature at 90 degrees Celsius which is at the point of T4. When there is a temperature drop in the system the pump will feed in hot water with the required hot water temperature.

The boiler will work simultaneously will start to burn water until the water flow in the secondary loop reaches 60°C. There will be some water losses in the boiler during this process but it will be replaced by the expansion tank. The water used in the calorifier will be replaced by the makeup tank. The boiler 1 will be in standby mode where the water will be hot when the system is not in use and the boiler 2 act as a backup if the boiler 1 doesn't perform appropriately.

Table 3.3.9.1: Collector Parameter of HUKM

Data	Value	Unit
Fluid specific heat	4.19	kJ/kg.K
Collector fin efficiency factor	0.7	
Bottom edge loss coefficient	3.0	kg/hr.m².K
Absorber plate emittance	0.7	
Absorptance of the absorber plate	0.8	
Number of covers	1	
Index of refraction of cover	1.526	
Extinction coefficient thickness product	0.0026	

The table 3.3.9.1 shows the flat plate solar collector used in the TRNSYS simulation software for HUKM. The fluid specific heat is used for water which is 4.190 kJ/kg.K with several covers of one. The other parameters a left with the default settings.

Table 3.3.9.2: Input of Flat Plate Collector

Input	Value	Units
Inlet temperature	20	◦C
Inlet flowrate	100	kg/hr
Ambient temperature	10	◦C
Incident radiation	0	kJ/hr.m^2
Total horizontal radiation	0	kJ/hr.m^2
Horizontal diffuse radiation	0	kJ/hr.m^2
Ground reflectance	0.2	-
Incidence angle	45	degrees

The collector inlet temperature is set at 20°C as the water draws from the city water will be a range of 15°C to 25°C cold. The inlet flow rate will be at 100kg/hr. The ambient temperature will be set to 10°C surrounding the system.

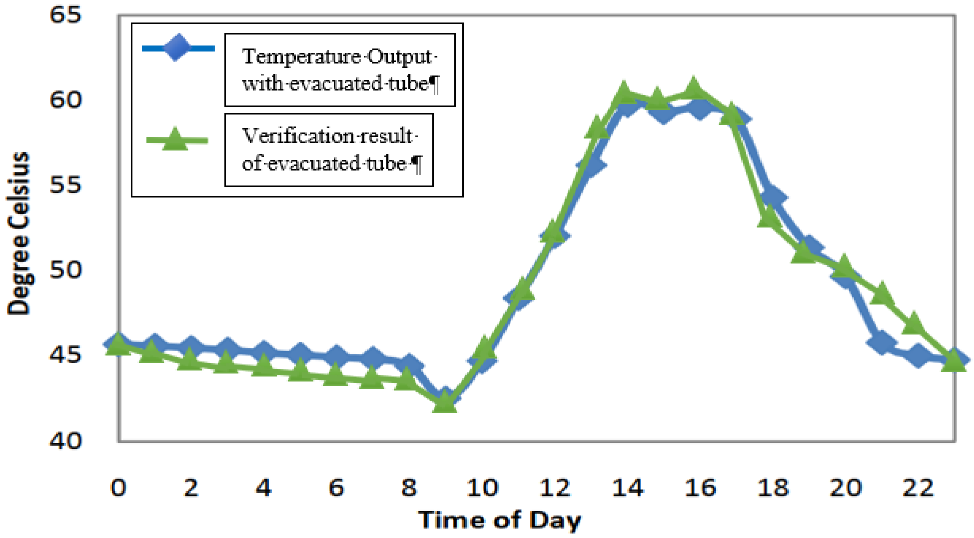

Figure 3.3.9.41: Comparison between verification and actual output

The figure above shows the comparison between the evacuated tube and the temperature output of the evacuated tube in a simulation verification. By comparing the temperature output between the two graphs, a very good agreement was achieved. The results that have been recorded from the simulation is for 24 hours and each hour of the point is also recorded. It can be noted that the temperature output started at 45°C for both outputs.

The highest error produces between the verification result (green) and the temperature output of the evacuated tube (blue) is during 9 PM. The error that was recorded is 6.6%. The lowest error recorded between the verification result and the temperature output of the evacuated tube is from 1 pm where the error was at 0.5%.

It can be noted that the starting time and the finishing time is the same between the verification result and the temperature output of the evacuated tube. Besides that, the temperature didn't drop below 40°C and the temperature output between 10 am to 10 pm is high. The simulated results of the verification result and the temperature output of the evacuated tube is subject within the confidence interval of the system.

3.3.10 HUKM weather data

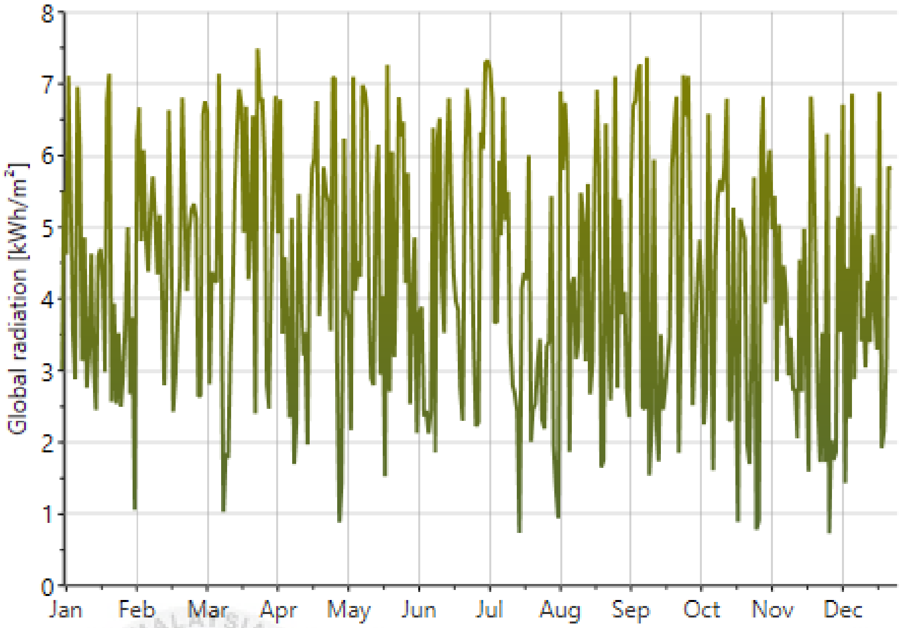

Figure 3.3.10.1: Global Irradiation

Figure 3.3.10.1 shows the Meteonorm 7.3 generated data of HUKM Global Irradiation of 2011. Solar irradiance can be categorized as power per unit area (watt per square meter, W/m2), it comes directly from the Sun in the form of electromagnetic radiation.

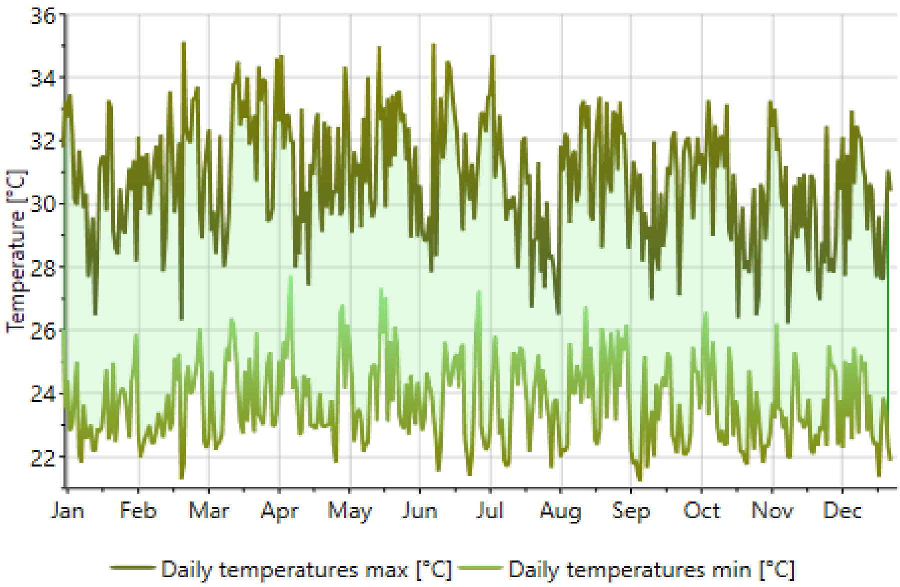

Figure 3.3.10.2: Max and Min Temperature

Figure 3.3.10.2 shows the Meteonorm 7.3 generated data of HUKM's Daily minimum and maximum temperature in 2011. This graph portrays the maximum and minimum temperature in the course of a straight time interval of 24 hours where the highest temperature is the daily maximum temperature and the lowest temperature is the daily minimum temperature.

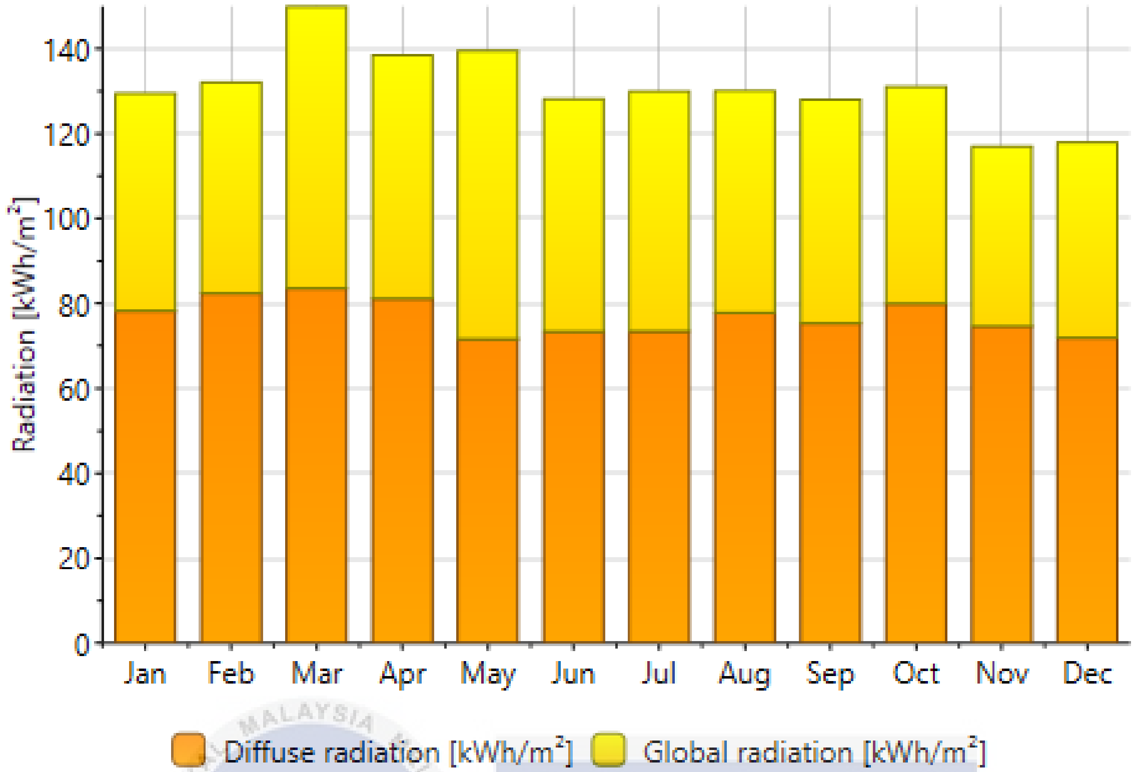

Figure 3.3.10.3: HUKM's Diffuse and Global Irradiation

Figure 3.3.10.3 shows the Meteonorm 7.3 generated data of HUKM's Diffuse and Global Irradiation of the year 2011. Direct beam radiation is the sunray that comes from the sun. Diffuse radiation is dispersed by molecules from the ground to the atmosphere of the earth. The sum of the direct beam, diffuse, and ground-reflected radiation which touches the surface is called total or global solar radiation.

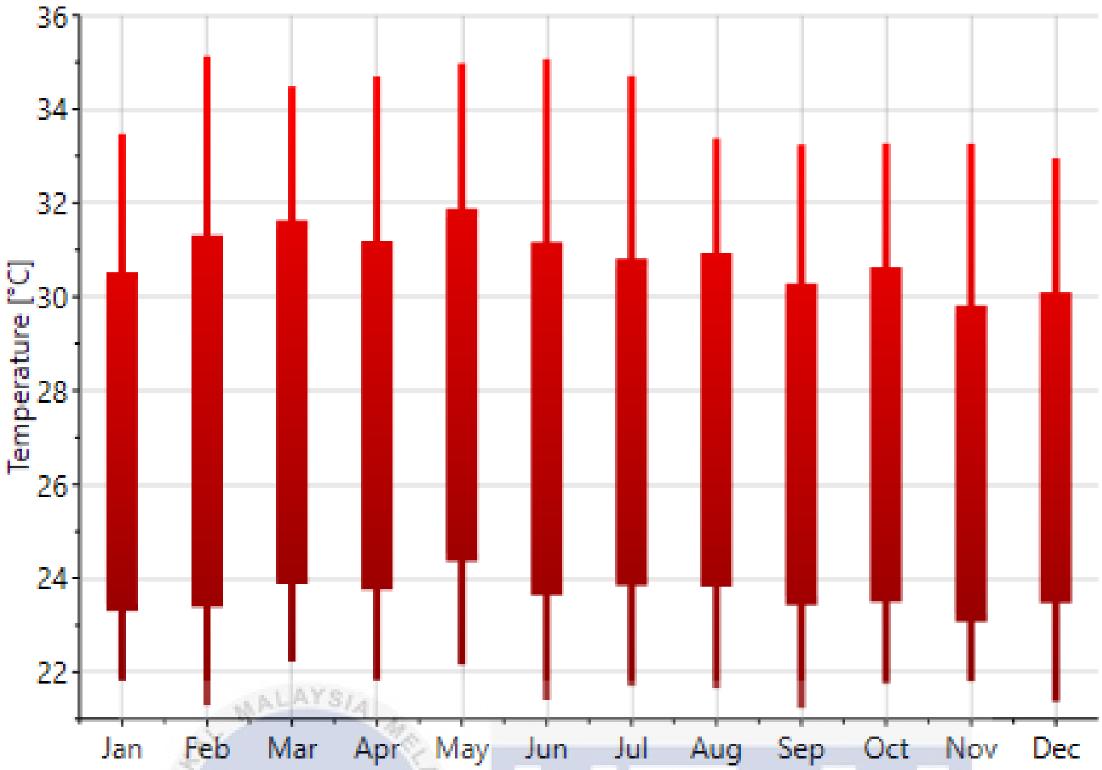

Figure 3.3.10.4: HUKM Monthly Temperature

Figure 3.3.10.4 shows the Meteonorm 7.3 generated data of HUKM's monthly temperature of 2011. The monthly temperature is the average daily mean of temperature if every day of a month.

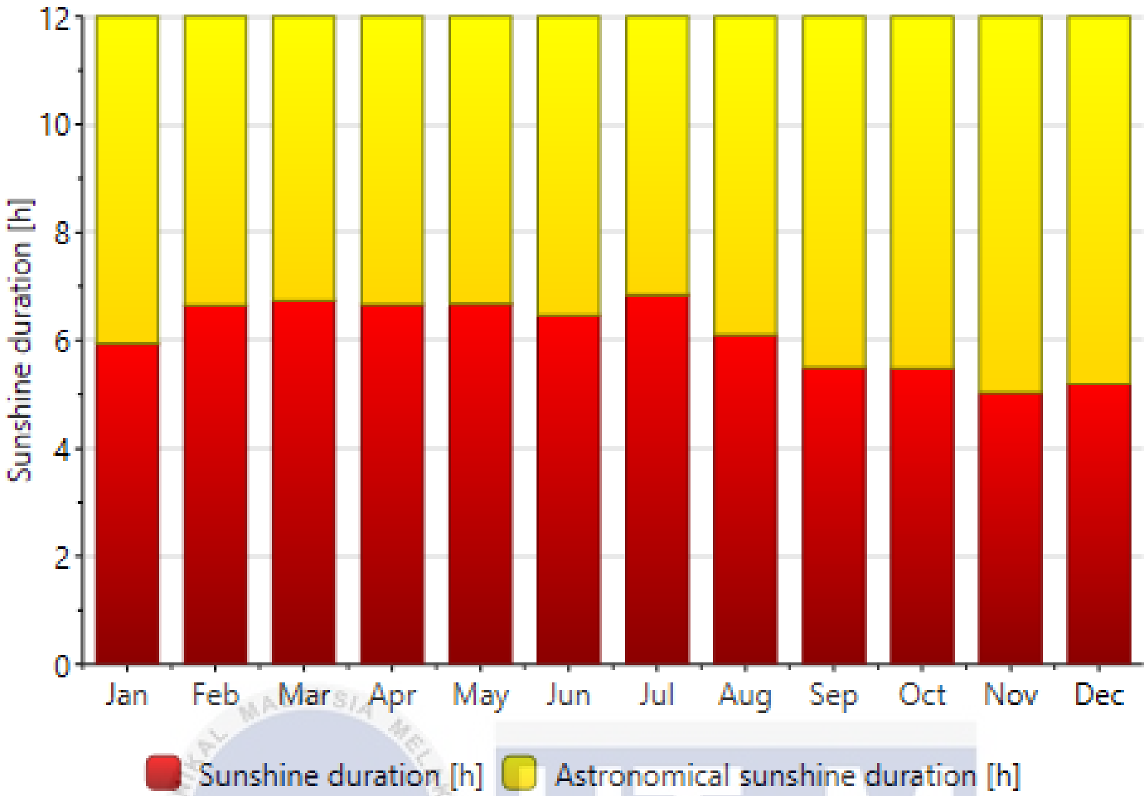

Figure 3.3.10.5: HUKM's sunshine duration and astronomical sunshine duration

Figure 3.3.10.5 shows the Meteonorm 7.3 generated data of HUKM's sunshine duration and astronomical sunshine duration in 2011. Sunshine duration is the period where direct solar irradiance exceeds the threshold amount of 120 watts per square meter (W/m^2). This the level of solar irradiance shortly after sunrise and shortly before the sunset without the presence of clouds.

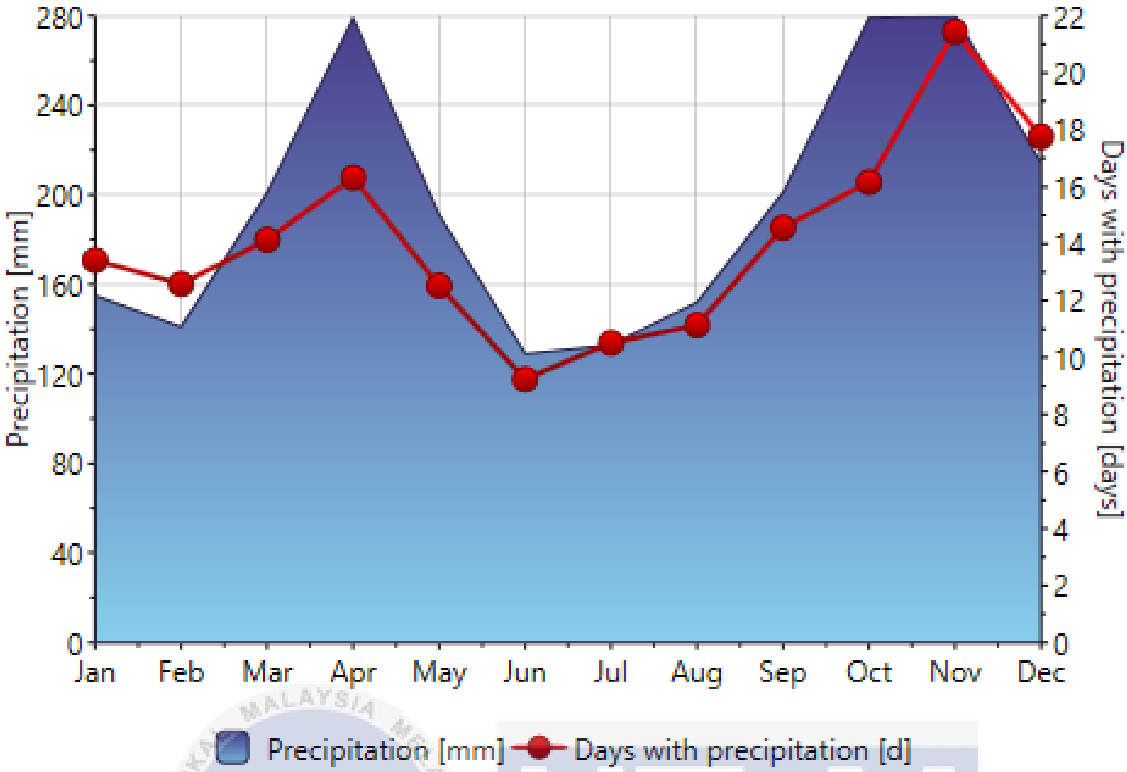

Figure3.3.10.6: Precipitation in the HUKM

The figure above shows the precipitation in the HUKM weather condition of 2011. It is knowing as the weather condition from the sky such as rain, snow, hail or sleet that occurs in certain conditions.

Table 3.3.10.1: Weather Data of HUKM

Month	Gh kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
January	129	78	80	26.7	23.1	3
February	132	82	71	27.3	23.6	3.5
March	150	83	92	27.6	24.1	2.1
April	138	81	80	27.7	24.7	2.1
May	140	72	99	27.9	24.8	3
June	128	73	78	27.6	24	3
July	130	73	81	27.2	23.6	3.5
August	130	78	73	27.2	23.4	3.5
September	128	75	73	27.1	23.8	3
October	131	80	70	26.9	24	2.5
November	117	75	61	26.7	24.2	2.5
December	118	72	72	26.6	23.6	2.1
Year	2011	924	930	27.2	23.9	2.8

The table above shows the data of HUKM generated from Meteonorm software for the year 2017. The data were taken with the average weather data of HUKM from every day and the mean are calculated to provide precise data to avoid tolerance of weather conditions.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This section interprets the results and discussion of the simulation which finds out the performance of flat plate solar collector in TRNSYS simulation software. This results in terms of the temperature input and output of the solar system are discussed where the temperature difference of the system will be showing the performance of the collector. Besides that, the weather data generated using the Meteornorm software will be shown in this section.

The suitable number of the collector in Melaka will be discussed in this section and also for the industry prospect the suitable surface areas for installation in the solar system using the specification of the industry will be discussed here. All of the data, parameters, inputs that have been used in the TRNSYS software will be detailed out in this section. All the results and discussions related to this simulation are also explained in this section.

4.2 Performance of Flat Plate Solar Collector

4.2.1 Solar System Model in TRNSYS

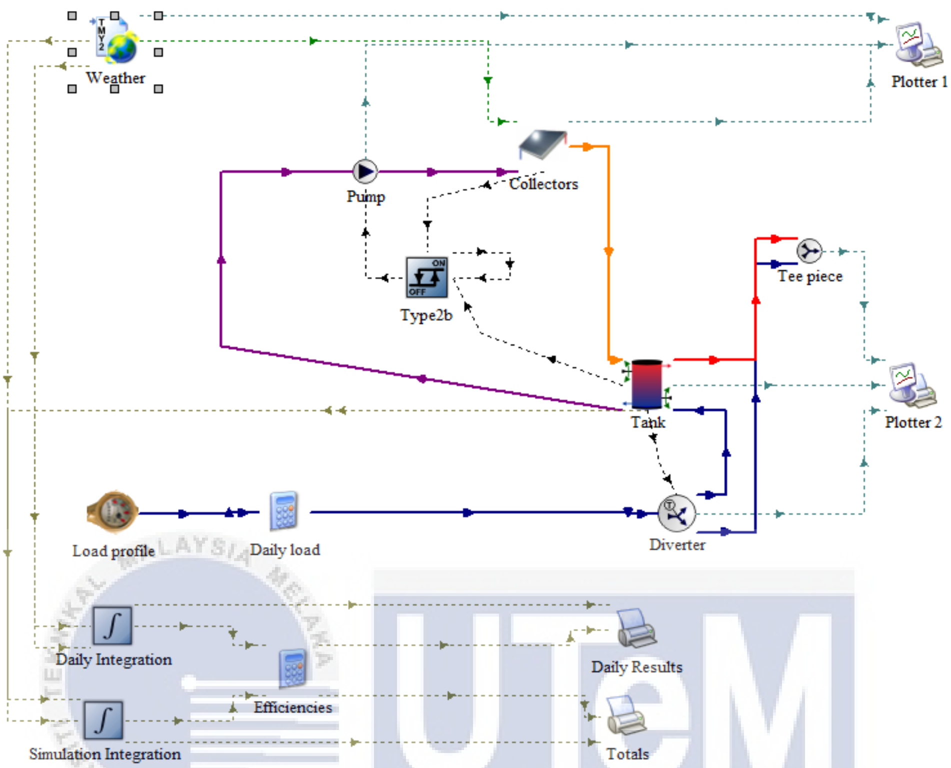

Figure 4.2.1.1: Solar System Model

The weather data of Melaka City which is generated using the Meteonorm software is inserted into the Online Plotter 1 which reads the data of the flat plate collector and the output data will be transferred to the simulation integration formula which uses the Hottel-Whillier-Bliss (HWB) equation to calculate the efficiency of the solar collectors and the calculated data will be segregated in the printer module which gives out the Total value for the entire run hours of the simulations.

The values that have been calculated in the printer module is the intensity of the solar collector module (I) and the useful energy extracted by the collector (Q_u). The weather data also sends the data to the printer module which will calculate the intensity of solar collector module (I) and the useful energy extracted by the collector (Q_u) with daily results of the solar collector.

The data reader mode has to read and measured environmental and the atmospheric conditions that occurred during the experiment and send the appropriate readings to be computed by the Theoretical Solar Collector (Type 73).

For this research, the data model is kept at the default TRNSYS setting and the input file and the parameter file was modified to keep the value logger to measure the file where the input and parameters needed to be converted to the right units that are being used in Malaysia. Table 4.2.1 shows the allocation of the input file parameters of the weather data that has been connected to the daily and total printer modules which lead to the various components of the solar system calibration model. The logical unit of the solar collector is set to 36 units as the minimum value where the collector will work.

The sky model for diffuse radiation is set at four based on the Meteonorm software readings and the tracking model is set with one as the collector is set at a constant position and the sun moves in one direction. The ground reflectance is set at a minimum rate as Melaka is a tropical country and the ground reflectance will less compare to the highest ground reflectance which is 0.7 in the snow-filled country. The slope surface is set at 45 degrees and the azimuth is set at 0 as the sun angle will be moving constantly throughout the day.

Table 4.2.1.1: Weather data Parameters and Input

Parameters	**Values**	**Units**
Data Reader Mode	2	-
Logical unit	36	-
Sky model for diffuse radiation	4	-
Tracking mode	1	-
Input		
Ground reflectance	0.2	-
Slope of surface	45	degrees
Azimuth of surface	0	degrees

The figure below shows the actual weather data which is used in this research in the Transient Simulation System Software. It can be seen that the Melaka City weather data file is used in the system to generate the output.

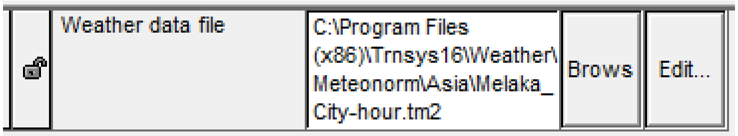

Figure 4.2.1.2: Weather data in TRNSYS

The system process runs starting from the load profile where the data of the water draw will be defined and it will be transferred to the daily load which has the Hottel-Whillier-Bliss (HWB) equation inserted to it. The cold water which will run according to the load profile water draw will move towards the flow diverter.

The flow diverter act as a diverter as it will first send the required amount of cold water into the stratified storage tank. Once the tank has taken enough cold water, the excess cold water will be diverted to the demand tank or most probably to the pipe tank. The differential controller act as a sensor where it detects the optimum number of solar heats at the collector and once it detects it, the controller will let the cold-water flow out of the stratified storage tank to the pump. The differential controller has a 100-degree Celsius high limit cut-out where it will be triggered to allow the water in if the water temperature at the below of the stratified storage tank is at 100 degree Celsius.

The pump will make sure the cold water enters the solar collector in one direction. The heat energy absorbed by the solar collector will be radiated to the cold water where it will turn to hot water. The hot water will then be stored at the stratified storage tank upper region which is the hot region. The stratified storage tank had two water region which cold and hot, the one at the middle of it is known as the thermocline region where the upper layer and the lower layer meets.

It is known as a thin distinct layer where the temperature changes much more with depth than in the layers above or below. The hot water is then transferred to the Tee Piece where the water will be used for household or cleaning activities. The excess water will be moved to the demand tank where it will be kept until the next cycle begins.

The theoretical flat plate solar collector is installed in a series line with a collector area of 5m^{2}. The fluid specific heat of water is used for this research as the domestic hot water is used. The flow rate was tested at 40 kg/hr.m^{2}. The 1st order incident angle modifier (IAM) function will always be kept at the default value of 0.1. The 2nd order was left at 0 as no second solar collectors were used. The IAM is set to track the concentrate on the solar collector.

Table 4.2.1.2: Solar Collector parameter

Parameter	**Value**	**Unit**
Number in series	1	-
Collector area	2.5	m^2
Fluid specific heat	4.19	kJ/kg.K
Tested flow rate	40	kg/hr.m^2
1st-order IAM	0.1	-
2nd-order IAM	0	-

The input of a flat plate solar collector is shown in Table 4.2.1.3 where the inlet temperature is set at 20°C due to cold water is taken as a source. The inlet flow rate is at 100 kg/hr which is hook up the cold water into the collector. The ambient temperature is taken from the weather file where the system ambient temperature is set.

Table 4.2.1.3: Solar Collector Input

Input	**Value**	**Unit**
Inlet temperature	20	°C
Inlet flowrate	100	kg/hr
Ambient temperature	10	°C
Ground reflectance	0.2	-
Incidence angle	45	degrees

The incident solar radiation is known as the rate at which incident radiation hits the sloped collector surface from the weather file while the horizontal diffuse radiation is known as the rate where the diffuse radiation hits a horizontal surface from the weather file. The total horizontal radiation is the rate at which the total solar radiation touches the horizontal surface from the weather file.

All three of the value at set to zero as no strikes of radiation were detected from the weather file. A typical value of 0.2 was set for the reflectance of the surface where the solar collector is located. The angle of incidence from the beam solar radiation and the normal vector to the sloped collector surface is set at 45 degrees to get the maximum light contact.

4.2.2 Simulation outcome using Melaka weather data

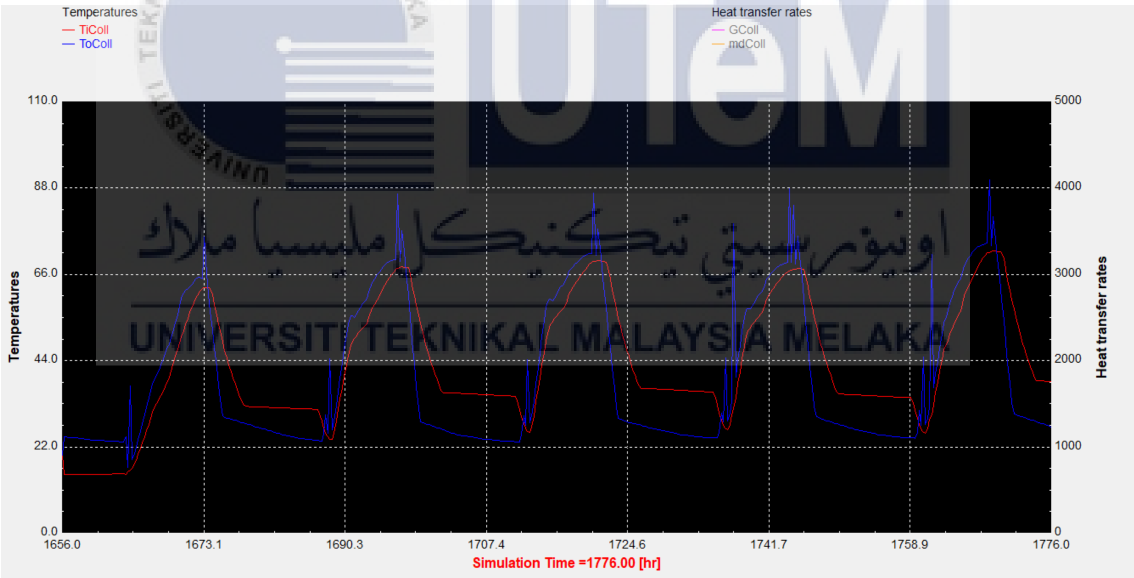

Figure 4.2.2.1: Simulation Outcome of Melaka weather data

Figure 4.2.2.1 shows simulation outcome of a solar collector which was produced by simulating the theoretical flat plate solar collector with a pump system using TRNSYS 17 with the weather data produce from Meteonorm software. The location used is from Melaka City January 2020 weather data for 17 hours' time difference. T_iColl and T_oColl are known as temperature input and temperature output respectively.

In the first 17 hours, the T_iColl and T_oColl started in a constant state with the ambient temperature of Melaka temperature of 20°C and 24°C which was generated by the simulation. The highest temperature output produces from the simulation is 90°C while the lowest is 20°C.

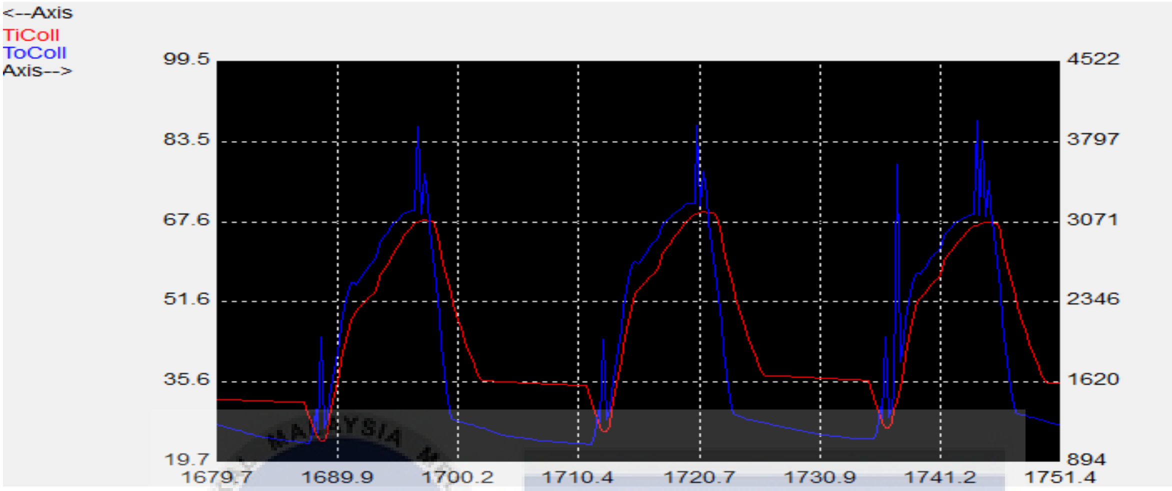

Figure 4.2.2.2: Detailed simulation outcome of Melaka weather data

Both the temperature input and temperature output have constant temperature degradation, this is due to the water draw load profile that has been set to 0 if it's not in use. Every 17 hours have a constant temperature output from the collector where it nearly touches 88°C.

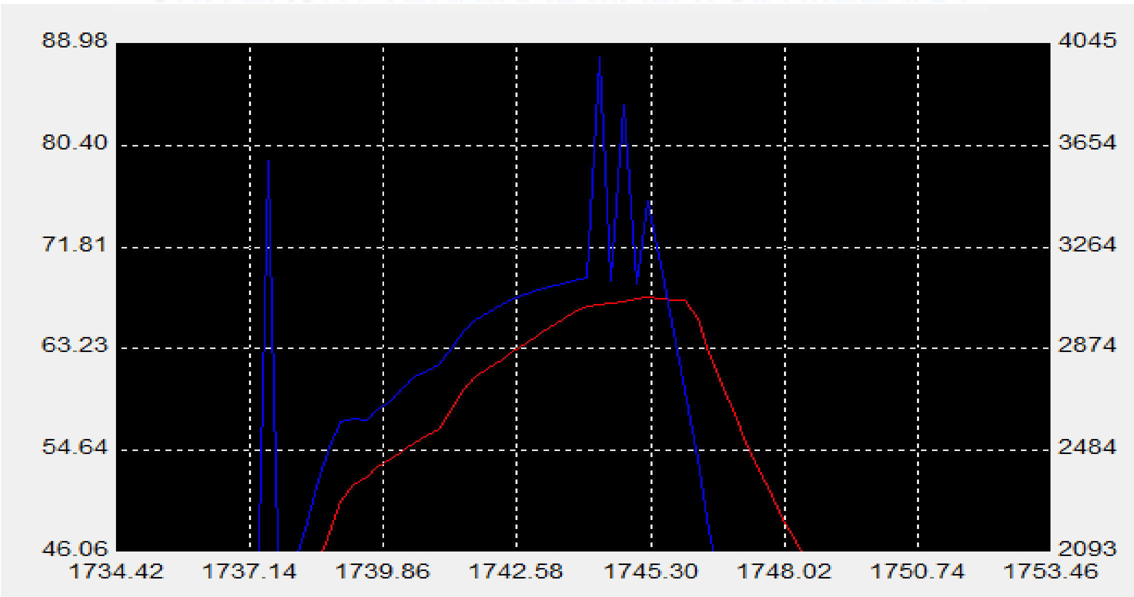

Figure 4.2.2.3: Temperature difference of the simulation outcome

In a closer look based on the Figure 4.2.2.2 above, it can be noticed that the major output is in the mix of 30°C to 66°C which is the optimum temperature for domestic usage suitable for cleaning and bathing. The temperature difference between the temperature input and temperature output is at the lowest difference of 6 °C and the highest is at 20°C higher than the input temperature. It can be noted here that the highest performance level in this entire process is in every hour. The performance level is determined by measuring the temperature difference between temperature input and temperature output.

There is two reason due to temperature difference being between 6°C to 20°C based on Figure 4.2.2.3 below that is because of the cut off high limit which has been set to the 100°C where any form of the temperature reaching to its boiling point is injuries to the users of domestic usage, so this is done for the safety precautions.

Besides that, the demand tank which stores the heated excess temperature will supply the input water, as a result of that the temperature will always be in a moderate temperature. The demand tank is also the reason why the water temperature is not reaching 0°C.

The performance for a domestic hot water system using a flat plate collector can be told that the system produces an optimum temperature output. The results show that the component parameters and input produce an optimum performance for domestic uses only. Due to the limitations set in the differential controller.

4.3 Suitable number of solar collectors

4.3.1 Suitable number of a solar collector using Melaka city weather data 2020

The load profile used is based on the weather data produced by the Meteonorm software of Melaka city in the year 2020. To find a suitable number of solar collectors, the normal efficiency of flat plate solar collector must be around 70% [29]. Table 4.2.2.1 shows the annual fraction load supplied by the collector size of 2.5m^2. The total of a heating load of hot water (L) is measured and the total product between the heating load of hot water (L) and the monthly solar fraction (f) with (x) being the collector losses variables and (y) the incident solar variables.

According to the annual fraction load data of Melaka city 2016, the data shows that Melaka city has an average monthly heating load of domestic hot water in Melaka which is 0.8GJ. Finally, the whole annual heating load of domestic hot water in Melaka is 9.55 GJ and the annual fraction of load supplied by a collector size based on the solar collector is 78.42%. This tells that the solar energy supply to the users is 78.42% which is higher than the optimum efficiency of the solar collector.

Malaysia obtains 17 MJ/m^2 of solar radiation per day [30]. Malaysia is in the region of equatorial that has solar radiation of 400-600 MJ/m^2 per month and abundant sunshine for about 12 hours per day. High temperature and humidity make up the climate of Malaysia. The factors above will magnify the results of the received solar radiation along with a larger surface area of solar collector.

From the table Table 4.3.1.1, the fraction of annual heating load supplied by solar energy is calculated.

Table 4.3.1.1: Annual fraction load supplied by collector size

Month	L(GJ)	X	Y	f	fL
January	0.8131	2.1	1.17	0.76	0.62
February	0.7673	2.3	1.32	0.84	0.64
March	0.7961	2.32	1.61	0.97	0.77
April	0.7615	2.33	1.37	0.86	0.65
May	0.7914	2.33	1.27	0.81	0.64
June	0.7796	2.31	1.18	0.76	0.59
July	0.8093	2.31	1.18	0.76	0.62
August	0.8043	2.31	1.24	0.88	0.71
September	0.7828	2.31	1.3	0.83	0.65
October	0.8135	2.3	1.09	0.72	0.59
November	0.8021	2.3	0.93	0.62	0.5
December	0.8299	2.29	0.92	0.62	0.51
Total	9.5509				7.49

$$F = \frac{fL}{L}$$

$$F = \frac{7.49}{9.5509}$$

$$F = 78.43\%$$

From this calculation, it can be noted that the suitable number of collectors for the installation in Melaka city is only one with an area of $2.5m^2$ for domestic usage. This outcome produces efficiency above 70% which is the best performance. The domestic hot water temperature that is produced using the TRNSYS is shown in the figure below.

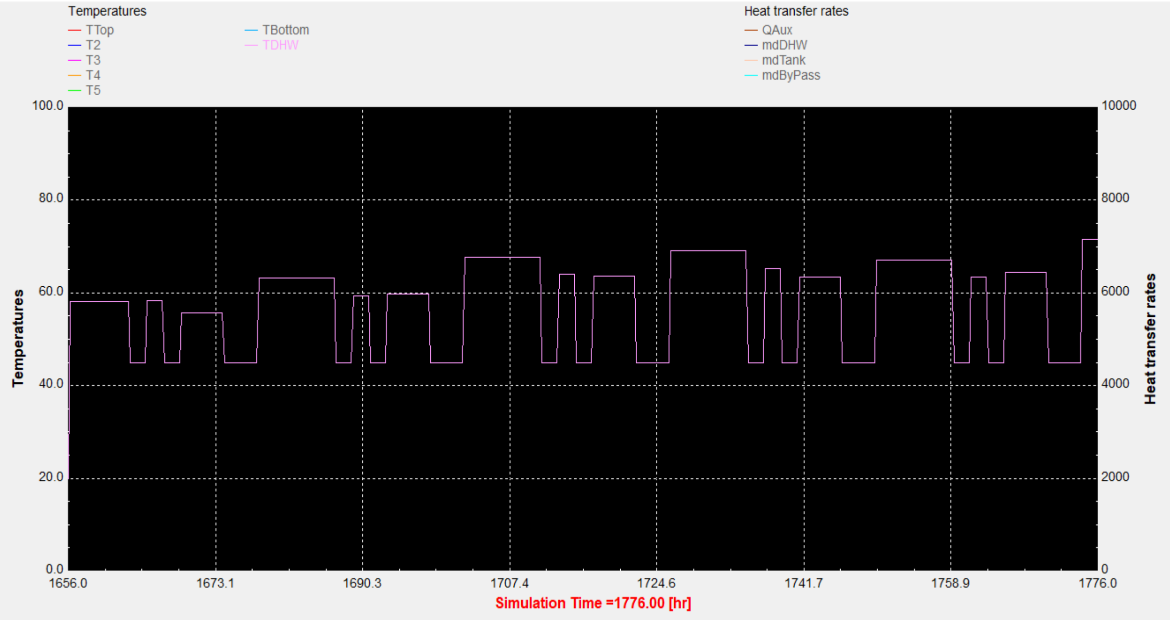

Figure 4.3.1.1: Temperature of domestic hot water produce

The domestic hot water produces using this area of 2.5m gives a more optimum temperature output. The simulation produce will give the users with the right temperature for domestic usage and it will avoid all the heat hazards produced by the solar collectors. It can be noted that the cut-off limit is still implemented in this simulation to prevent the temperature reaching extreme conditions. The demand tank has also been installed in the model to act as an excessive storage tank that stores excessively heated water.

4.4 Suitable area for solar collectors

4.4.1 Flat plate collectors in Malaysia

The flat plate collector used in the industry will only have the standards customize by them. The main components that will be affected by the industry will always be the storage tank and the flat plate solar collector. The flat plate solar collectors vary with the number of people using domestic hot water. According to this study [31], the amount of total domestic hot water is estimated to be 20,388 Millions of Litres Per Day (MLD) in 2020 in the industry. This is the roughly estimated figure by the Malaysia Water Industry Guide 2003 (The Malaysian Water Association, 2003:69).

4.4.2 (a) Area of collectors used for industry specifications

In Malaysia, the large-scale industries consist of more than 10 people in a working environment are using the evacuated tube for solar thermal heating. This is to reduce the cost of installing more numbers of flat plat collectors for domestic hot water usage. The optimum number of flat plate collector usage is for a maximum of 10 people in the small-scale industries.

The flat plate collectors that are being used in the industries for a maximum of 10 users is the series 5 MY-60 solar flat plate collectors. The amount of domestic hot water that can be stored in the storage tank is 276 litres with a weight of 134kg when empty up to overall weight with full storage of 429kg. The storage tank and the collector panel are the two most essential components in the building of a solar system. The characteristics of the storage tank and the collector panel are given below.

For this study, the maximum specification of flat plate solar collector and the storage tank will be installed in the solar system. The industry weather data will be implemented on the simulation. This is to find out the suitable number of flat plate solar collectors that can be installed in the industry. The resulting data will be compared to the evacuated tubes that are being used in most of the industries in Malaysia.

The industry locations that have been chosen for this study is the Hospital Universiti Kebangsaan Malaysia in Cheras, HUKM. This location is at the centre of Malaysia's capital Kuala Lumpur (13km for the city centre). The data was at a total of 13,500 litres per hour of hot water capacity is needed for 24 hours a day [32]. The usage of this hot water in HUKM is for laundry, kitchen, wards, toilets, etc. In this current system, there are 12 strings of solar collectors. Each string consists of 4 solar collector panels, and the panel will have 16 sets of evacuated vacuum tube each. This will make up of 2304 evacuated vacuum tube in total. The optimum temperature needed for HUKM is 45°C to 60°C.

This objective will give us the optimum number of flat plate solar collector and the suitable area of the flat plate that is needed to fuel the hot water in HUKM at the temperature range from 45°C to 60°C.

Table 4.4.2.1: Storage Tank for industries

Cylindrical Material	Stainless Steel
Case Material	Aluminium Stucco
Insulation Material	High-density pressure-injected polyurethane foam
End Cap Material	Aluminum Stucco
Nominal Working Pressure	400 kpa
Laminar Flow Stratified	Available
Cylinder Test Pressure	1200 kpa
Relief Valve Settings	1000 kpa
Electric Booster Elements	2kw with safety thermostat

The table 4.4.2.1 shows the maximum specifications of the flat plate collector that is being produced by MYSOLAR CONCEPT SDN BHD, the Malaysian manufacturer and distributor of flat plate solar collector. The material used for the tank is made up of stainless steel while the case material is made up of aluminium stucco. Stainless steel is used for high corrosion resistance which is needed by the storage tank for a longer life span. The maintenance fee will be less for this material.

A stucco mixture of aluminium is much better than common aluminium and it is much more durable. The stucco version will be much more attractive than the common shiny surface on the tank. A visual treat for people encountering it. It will also reflect less light thus making the people working around it to have less reflection on them. The maximum tested cylinder on this storage tank is at 1200kpa and the relief valve settings will be at 1000kpa.

Table 4.4.2.2: Collector Panel for industries

Design	Ultrasonic Welding
Plate Material	Copper Fin and Tube
Surface Coating	Titanium Blue Panel
Absorption Coefficient	>0.96±0.02
Emission Coefficient	<0.06±0.02
Insulation	Rack Wool with Aluminum Foil
Riser Tube Material	Copper
No of Riser Tube	10 tubes per panel
Panel	2
Net Absorber Area	$3.9m^2$
Number of Users	10
Casing Thickness/ Material	1.3mm Anodized Extruded Aluminum
Glass Thickness/ Material	4mm Low Iron Tempered Glass

The table 4.4.2.2 shows the collector panels for industries that are provided by MYSOLAR CONCEPT SDN BHD, the Malaysian manufacturer and distributor of flat plate solar collector. The flat plate solar collector will be fitting into the system by ultrasonic welding and the material will have copper fin and tube plate material. The reason copper is used because it is the best conductor of heat.

Even though it will cost a fortune to the install copper into the flat plate solar collector but due to its great conductor abilities and less corrosion outcome than aluminium, the copper will be used. Titanium blue panels are used as the surface coating and this is because titanium is corrosion-resistant. It also has the highest strength to density ratio than any other elements of metal. A single collector will support up to 10 number of users.

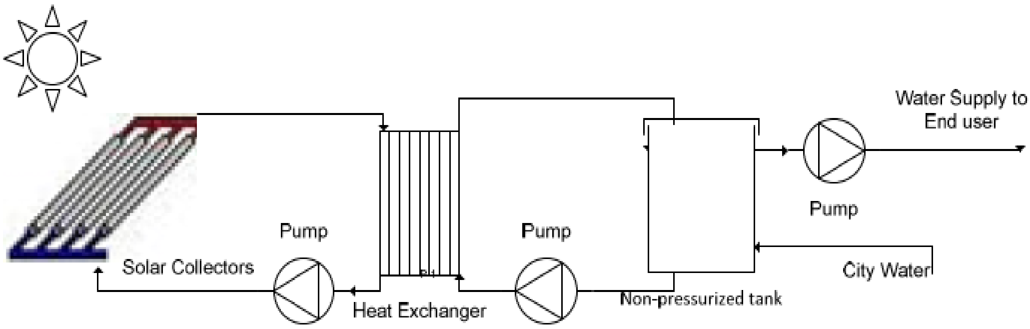

Figure 4.4.2.1 (a): Solar model of HUKM with evacuated tubes

The figure above shows the actual solar model that is installed in HUKM. The solar collectors that are being used in this system are the evacuated tube. The city water will be drawn into the non-pressurised tank where the water will be stored. The water will be at 20 – 40 degrees. The pump will transport the water into the heat exchanger. In the heat exchanger, both the cooling and heating process will take place.

Once the system is ready the pump will force the unheated water from the heat exchanger to the solar collectors. There are a total of 2304 number of evacuated tubes in this entire system. Once the water has reached the optimum temperature set by the hospital, the water will move to the heat exchanger and back to the non-pressurised tank. There are two layers of water temperature in the tank where the middle thermocline layer will be the layer of transition. The pump will force the water out of the tank when the user needs it.

4.4.2 (b) HUKM with Evacuated Tube

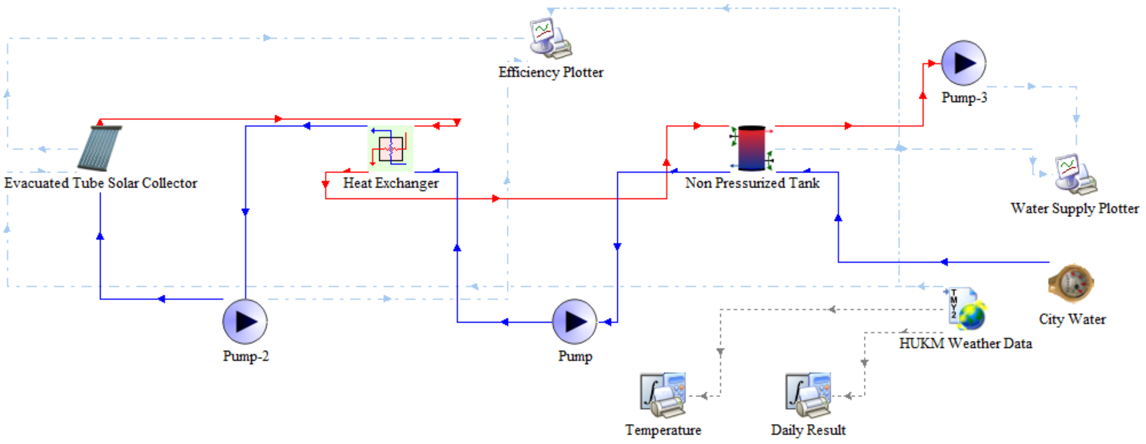

Figure 4.4.2.1 (b): TRNSYS model with evacuated tubes in HUKM

The figure above shows the actual solar system in TRNSYS modelling that is installed in HUKM. The solar collectors that are being used in this system are the evacuated tube. The city water will be drawn into the non-pressurised tank where the water will be stored. The water will be at 20 – 40 degrees. The pump will transport the water into the heat exchanger. In the heat exchanger, both the cooling and heating process will take place. The weather data that has been generated by Meteornorm software is the actual weather data of August 2011.

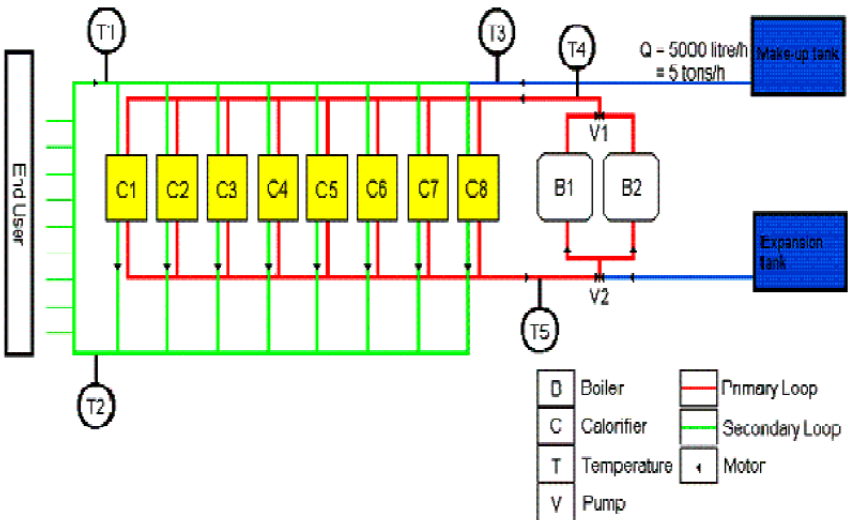

Figure 4.4.2.2(b): Hot water heating in HUKM

The figure above shows the hot water heating in HUKM, there is no temperature limit or cut off limit in this system as the hospital needs different temperature levels for laundry, kitchen, wards, toilets, etc. The consumed water will be replaced by the water stored in the tank. The average water temperature needed for kitchen and wards is 50 – 60 degree Celsius. While the hot water for washing, laundry, sterilization, etc will be having a temperature at 90 degrees Celsius which is at the point of T4. When there is a temperature drop in the system the pump will feed in hot water with the required hot water temperature.

The boiler will work simultaneously will start to burn water until the water flow in the secondary loop reaches 60°C. There will be some water losses in the boiler during this process but it will be replaced by the expansion tank. The water used in the calorifier will be replaced by the makeup tank. The boiler 1 will be in stand by mode where the water will be hot when the system is not in use and the boiler 2 act as a backup if the boiler 1 doesn’t perform appropriately.

4.4.2 (c) HUKM with Flat Plate Collector

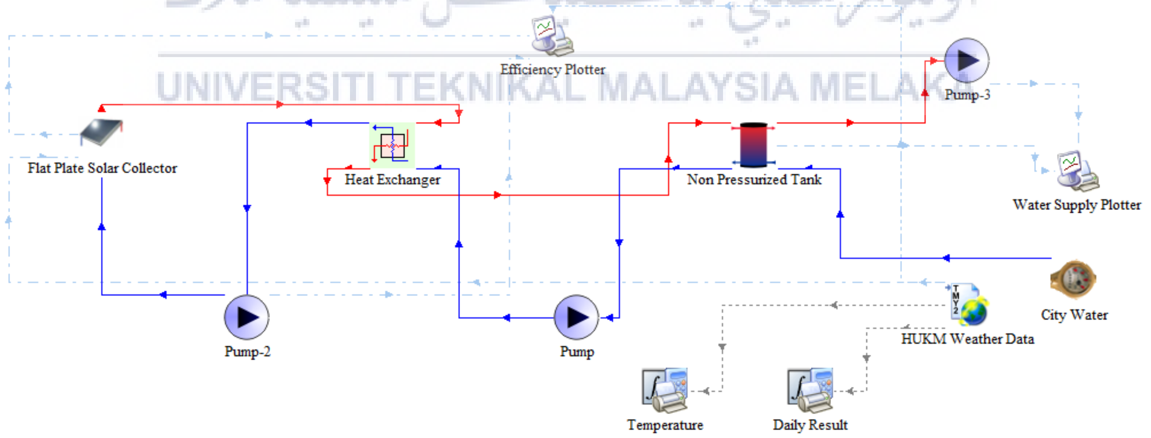

Figure 4.4.2 (c): Solar TRNSYS model of HUKM with Flat Plate Collector

The figure above shows the solar TRNSYS model with flat plate solar collector which is developed according to the system solar model of HUKM with evacuated tubes and the hot water heating loop system in HUKM. The settings are set to similar standards of both this mode except to the solar collectors used which are replaced by the flat plate solar collectors instead of the evacuated tube. The flat plate solar collector also replaces the make up the tank. The flat plate solar collector will act as the make-up tank that will rise the secondary loop temperature and boost the calorifier 80°C. The boiler will be in the standby mode if the temperature is at the required stage. The boiler will be triggered if the temperature drops during traffic.

This flat plate solar collectors will convert the radiant solar energy into heat energy using the effects of the greenhouse. This research is to study and find out the suitable area of flat plate collectors needed in HUKM to run the solar system. The non-pressurised storage tank is used and the maximum tested cylinder on this storage tank is at 1200kpa and the relief valve settings will be at 1000kpa. The heat exchanger and the non-pressurised tank uses the heat transfer rate equation:

$$\mathbf{Q=mc_P\,(T_{out}-T_{in}) = U_0A_0(T_{out}-T_{in})}$$

The performance of the solar water heated will be calculated in the TRNSYS system and this is to find out the suitable areas of flat plate collector needed to be installed in HUKM. The Hottel Whillier Bliss equation is used to find out the thermal performance.

$$\boldsymbol{\eta = F_R\,(\tau\alpha) - F_RU_1\,(T_{in} - T_{out} / H_t)}$$

The flat plate solar collector will be arranged in a series manner to get the best yield of the system. This is due to a series having an increased area for solar radiation and it will maintain a positive change in temperature. The series arrangement also will provide good flexibility and performance of the solar system.

4.4.3 TRNSYS Specifications and Data

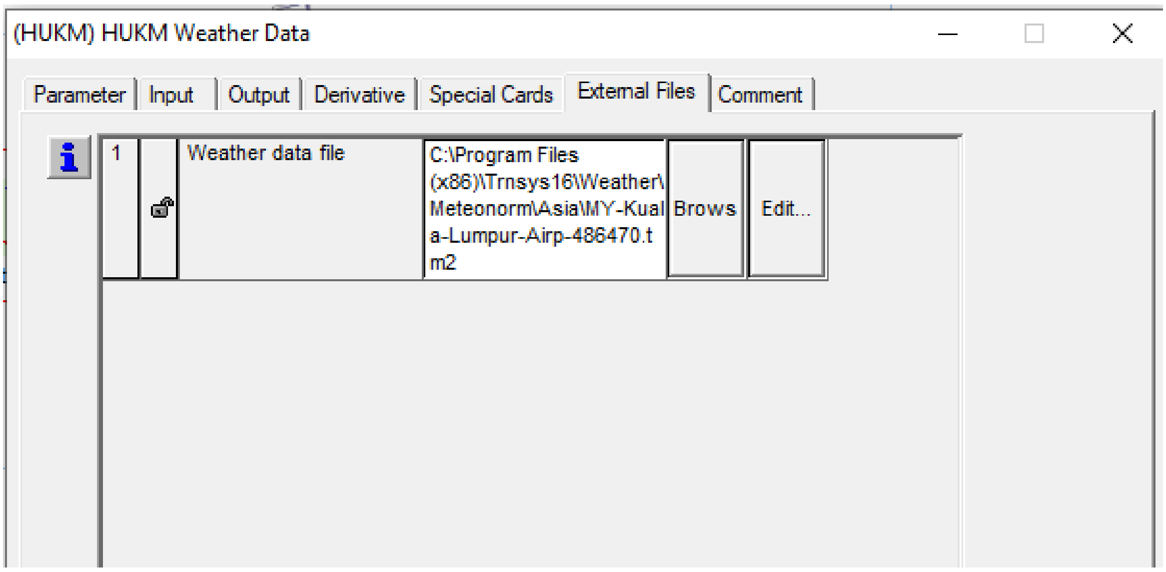

Figure 4.4.3.1: Weather Data of HUKM

The figure above shows the actual weather data of August 2011 is used in this research in the Transient Simulation System Software. It can be seen that the Kuala Lumpur weather data file is used in the system to generate the output. Hospital Universiti Kebangsaan Malaysia is located at Jalan Yaacob Latif, Bandar Tun Razak, 56000 Kuala Lumpur. The weather data of Kuala Lumpur in the year of 2011 is taken. The weather data was taken from the Meteonorm software.

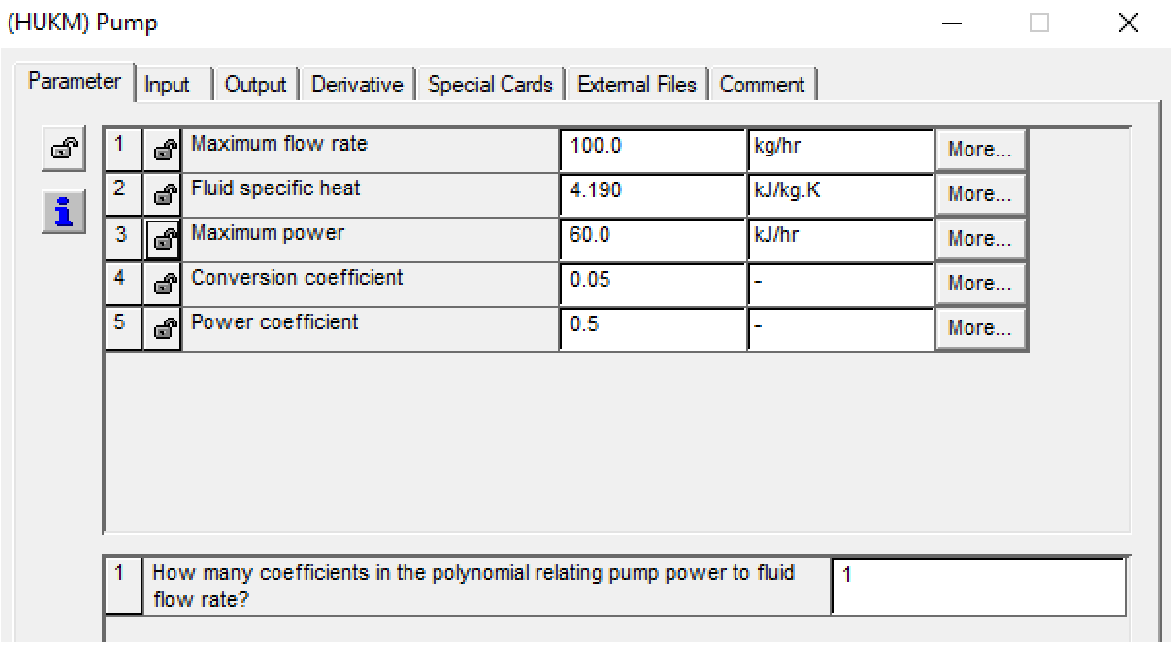

Figure 4.4.3.2: Pump data of HUKM

The figure above shows the pump data of HUKM. There are three pumps in total in the solar system. The first pump comes after the non-pressurised tank where it will trigger the water flow to the heat exchanger. The second pump comes after the heat exchanger where the water flow from the heat exchanger will be directed to the flat plate solar collector to produce the heated water required. The third pump comes in at the end where it will pump the heated water from the hot end of the non-pressurised to the users in the hospital. The maximum flow rate is at 100kg/hr.

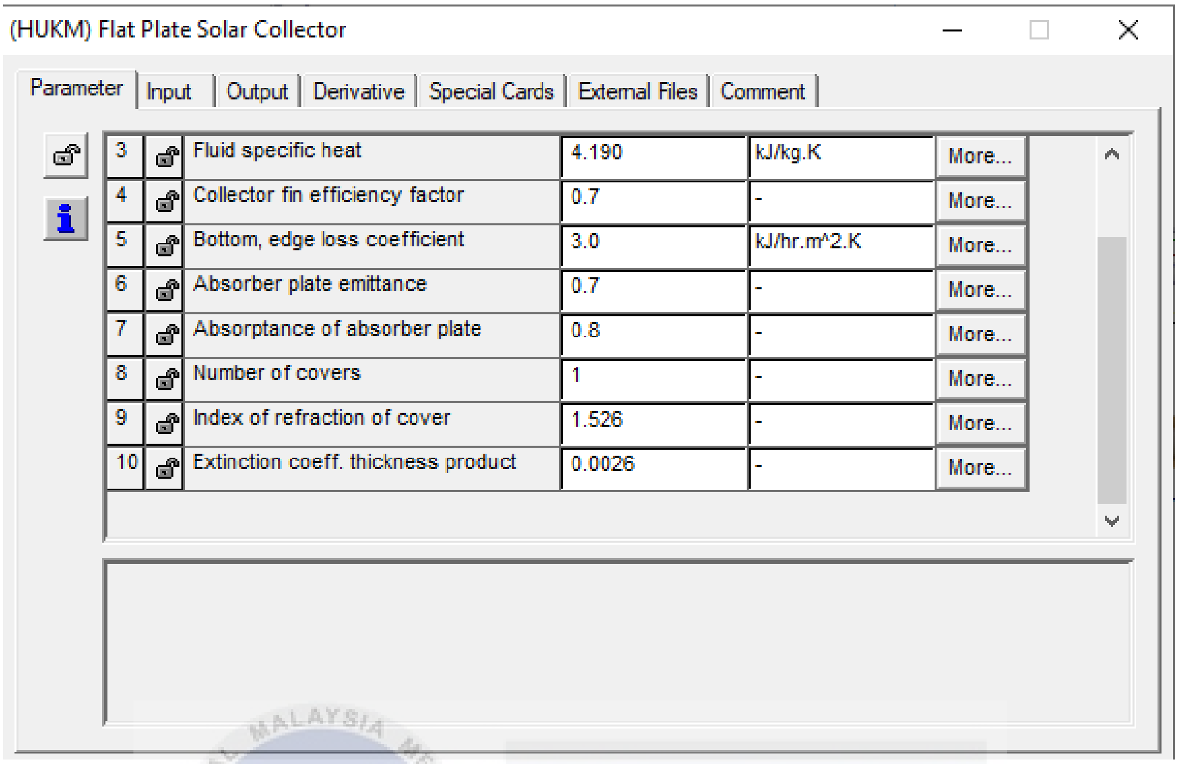

Figure 4.4.3.3: Collector Parameter of HUKM

The figure above shows the flat plate solar collector used in the TRNSYS simulation software for HUKM. The fluid specific heat is used for water which is 4.190 kJ/kg.K with several covers of one. The other parameters a left with the default settings.

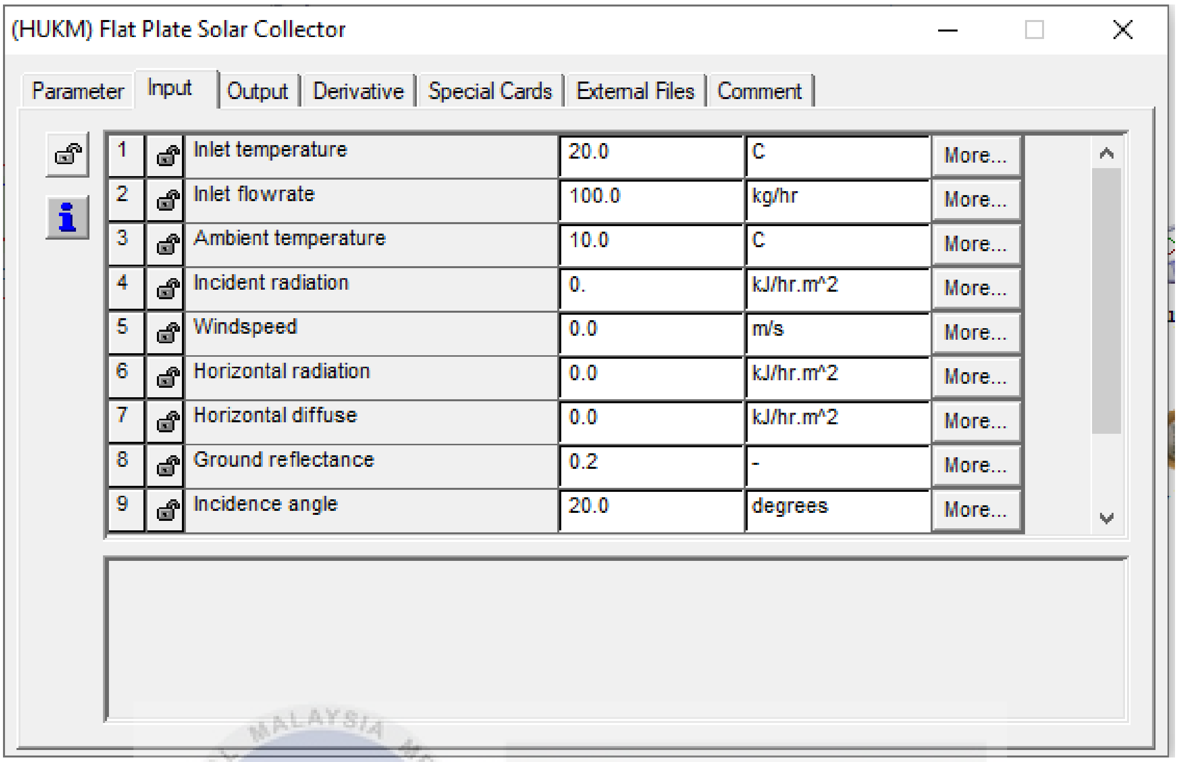

Figure 4.4.3.4: Collector Input of HUKM

The collector inlet temperature is set at 20°C as the water draws from the city water will be a range of 15°C to 25°C cold. The inlet flow rate will be at 100kg/hr. The ambient temperature will be set to 10°C surrounding the system.

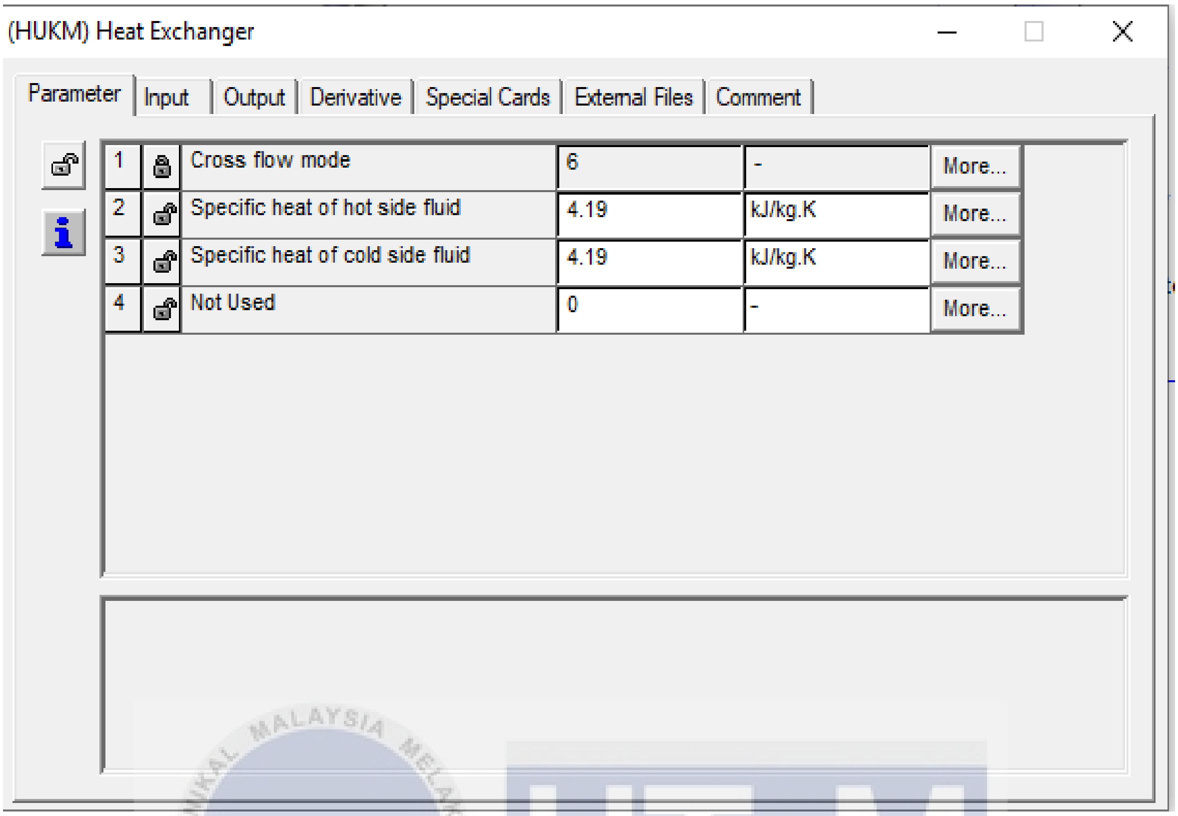

Figure 4.4.3.5: Heat Exchanger parameter of HUKM

The figure 4.4.3.5 shows the Heat Exchanger parameter of HUKM, the crossflow is set at 6, cross-flow is for the direct contact membrane distilled module. The specific heat of both the hot and the cold side stays the same as water will always be constant at any temperature.

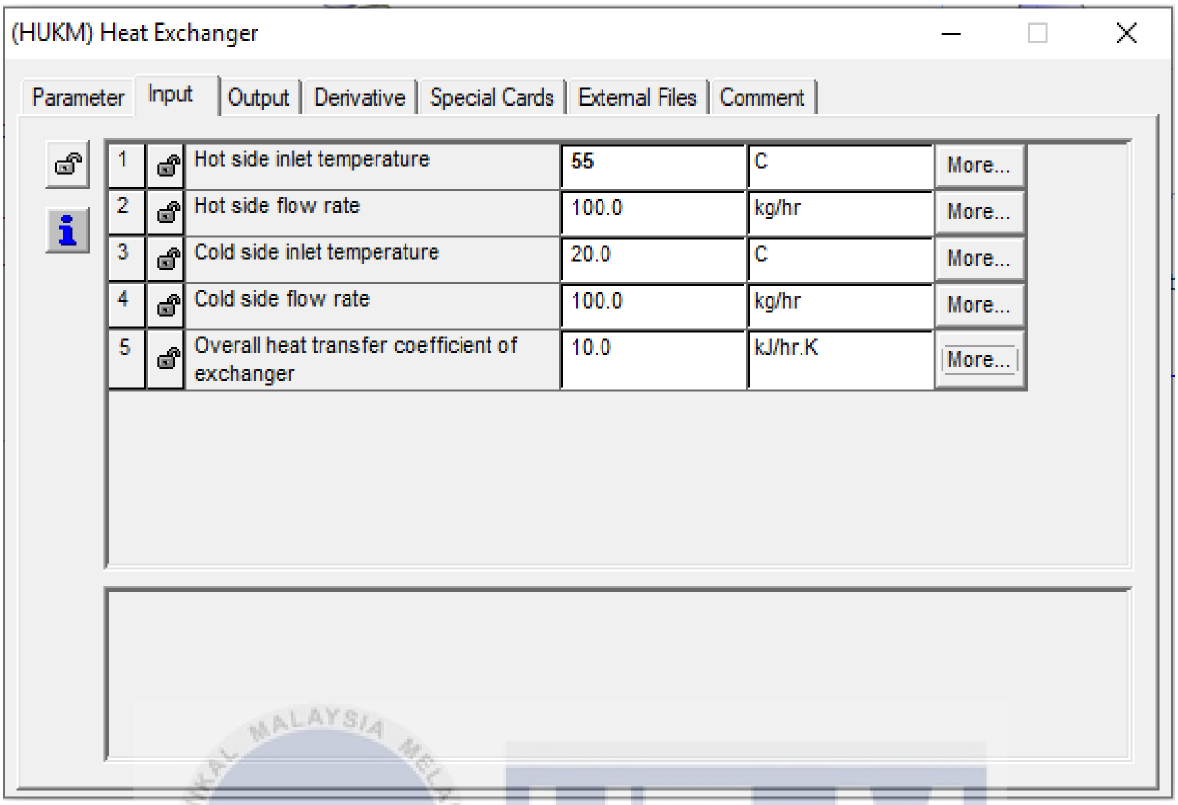

Figure 4.4.3.6: Heat Exchanger input of HUKM

The figure above shows the heat exchanger input where the water has just passed through the flat plate collector and the temperature will be higher than the temperature before entering the collector. The upper part, 55°C is set for the hot side of the inlet temperature of the heat exchanger. The hot side of the flow rate is at 100kg/hr. While the lower part which is the cold part where the water is drawn from the city water before entering the collector. The flow rate of the cold side is also the same as the hot side with 100kg/hr. The heat coefficient of the exchanger is at the constant value of 10kJ/hr.K.

Table 4.4.3.1: Parameter of Non-pressurized tank in HUKM

Parameter	Value	Unit
Variable inlet positions	2	-
Tank volume	0.276	m^3
Fluid specific heat	4.19	kJ/kg.K
Fluid density	1000	kg/m^3
Tank loss coefficient	3	kJ/hr. m^2.K
Height of node	0.05	m
Auxiliary heater mode	1	-
Node containing heating element -1	1	-
Node containing thermostat -1	1	-
Set point temperature for element-1	60	C
Dead band for heating element-1	5	deltaC
Maximum heating rate of element -1	9000	kJ/hr
Node containing heating element -2	1	-
Node containing thermostat -2	1	-
Set point temperature for element-2	60	C
Dead band for heating element-2	5	deltaC
Maximum heating rate of element -2	9000	kJ/hr
Not used (Flue UA)	0	W/K
Not used (Tflue)	20	C
Boiling point	100	C

The non-pressurised tank also known as the stratified tank used in this system is a variable inlet uniform losses tank. The tank has two inlets and two outlets for both the hot and cold water in the system. Both the fluid density and the fluid specific heat is kept constant. The auxiliary heating mode is set to one as it will heat the system when the temperature decreases at some point. The maximum heating rate is set at 9000 kJ/hr and the boiling point of the system is set at 100°C without the cut off ratio. This is due to the high temperature needed by the hospital for laundry, kitchen, sterilisation of hospital equipment, etc.

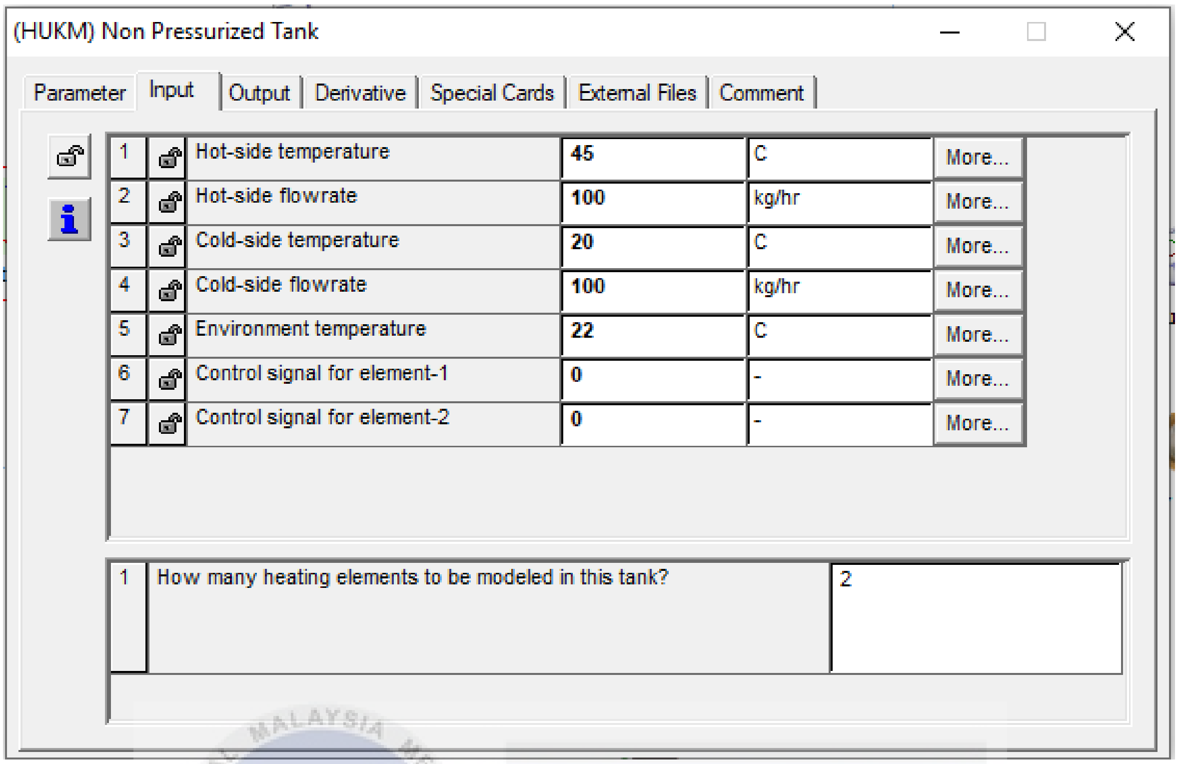

Figure 4.4.3.7: Input of Non-pressurized tank in HUKM

The figure above shows the Non-pressurized tank input where the water has just come through the city water draw and the temperature will be lower before entering the collector. The upper part, 45°C is set for the hot side of the inlet temperature of the heat exchanger. The hot side of the flow rate is at 100kg/hr. While the lower part which is the cold part where the water is drawn from the city water before entering the heat exchanger. The flow rate of the cold side is also the same as the hot side with 100kg/hr.

4.4.4 (a) Verification results on HUKM with Evacuated Tube

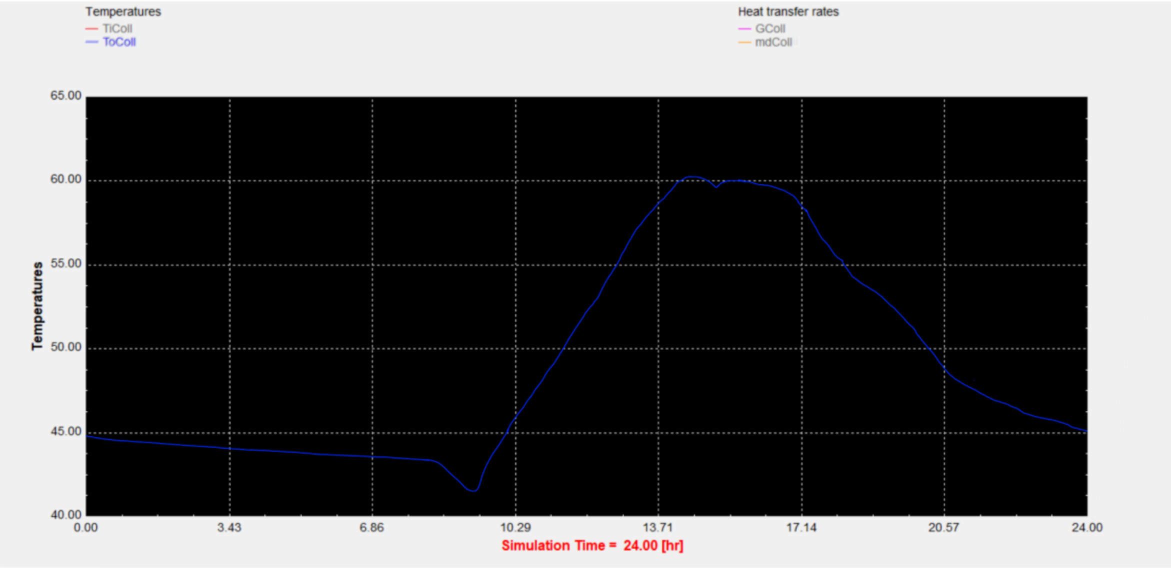

Figure 4.4.4(a).1: Results of Temperature output with the evacuated tube.

The figure above shows the verification results of the temperature output of with evacuated°C tube in HUKM. It can be noted that the temperature output of the collectors starts at 45°C and drops gradually. At the 10 am mark it can be seen in the graph that the temperature output increases up to 65°C and maintained in that level for a few hours. The lowest temperature at that point came around 5:30 pm where the temperature drops at 60°C, it then rises back up before decreasing gradually at 10 pm. To achieve the temperature output specified by the hospital which is to provide constantly heated water from 10 am to 10 pm to the hospital. The remaining 10 pm to 10 am will be covered by the boiler. Besides that, the other requirement by the hospital is to have the temperature output of the storage tank to remain above 40°C at all times during the entire cycle of the solar system.

4.4.4 (b) Results on HUKM with a Flat Plate Solar Collector

The flat plate collector is simulated using the solar system in HUKM and the results are displayed below. The simulation started with one series 5 MY-60 flat plate collector from MYSOLAR CONCEPT SDN BHD with the specifications of 5m^2 of area. The overall weight of the flat plate collector will be at 134kg when empty and 420kg when full with water flow.

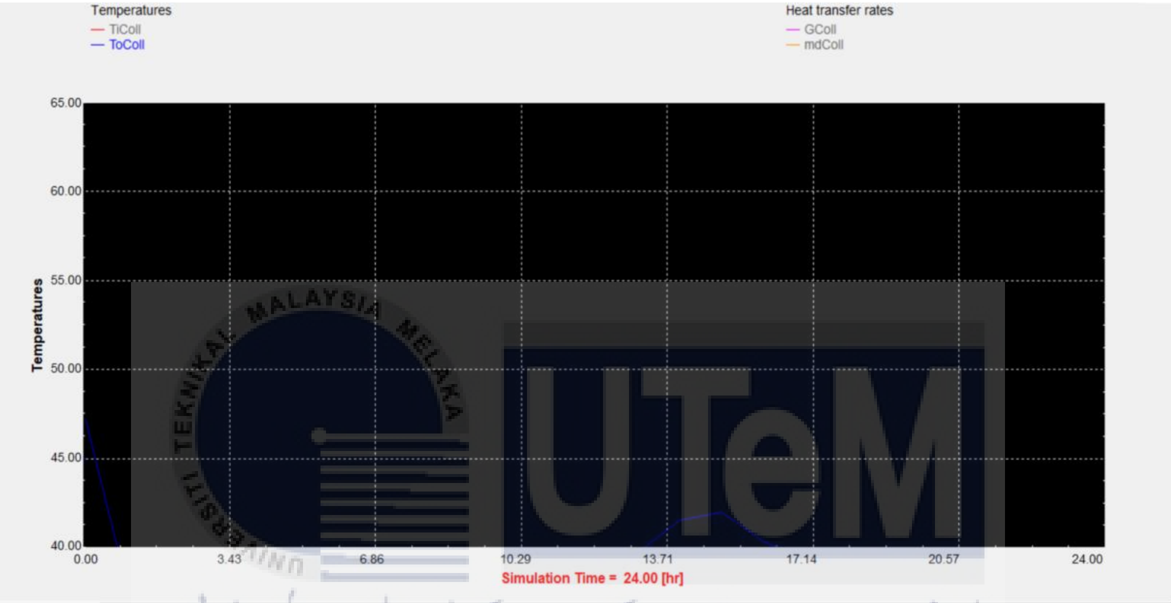

Figure 4.4.4(b).1: Results of Temperature output for one flat plate collector.

The area of flat plate collector that was used to simulate and obtain the graph above is with the dimension of 2.238m x 2.297m. Only one flat plate collector was used to find out the minimum amount of temperature output of the flat plate collector produce to the storage tank. The hot water that is needed by the hospital is from 10 am to 10 pm. After that period the water boiler will undertake the solar collector duty and produce the hot water.

It can be noted that the 5m^2 area of a single flat plate collector can't produce the required amount of average storage tank water temperature. The simulation for this study is done for 24 hours with an hourly data inspection with the specified period given by the hospital. The specified data gave by the hospital also stated that the average temperature should never drop below the 40°C mark. It can be seen in the graph above that the temperature drops significantly below the 40°C mark. The single $5m^2$ of the area is not enough to bear with the demand of the hospital for average temperature produce for the storage tank.

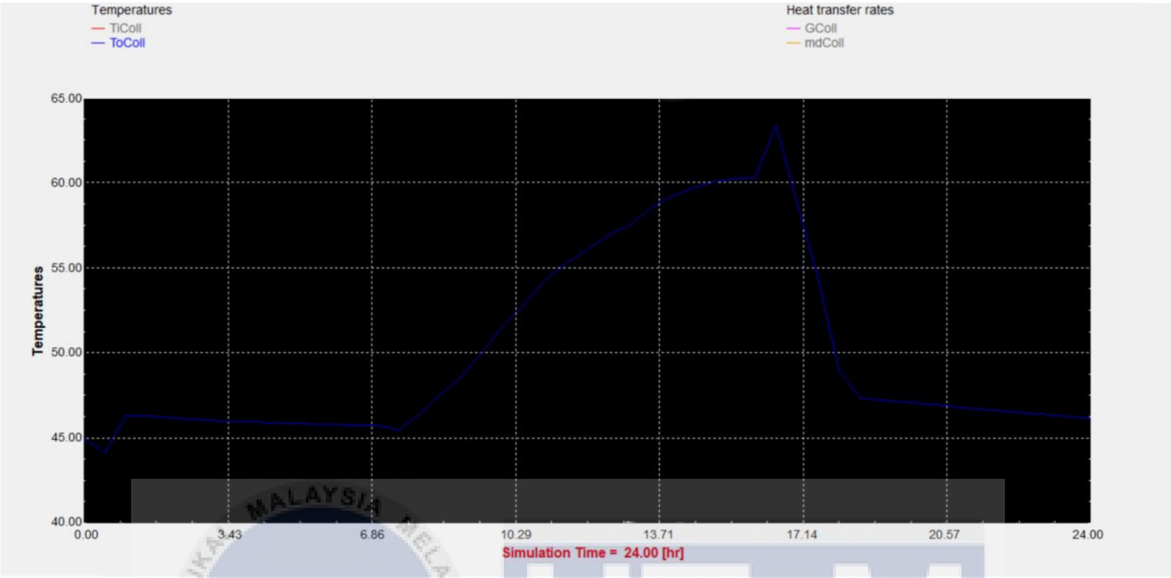

Figure 4.4.4(b).2: Simulated Temperature output of HUKM using flat plate collector

Figure 4.4.4(b).2 shows the results of the temperature output of the hourly average storage tank. It illustrates a major improvement compare to the previous simulated graph with the area of $5m^2$. To achieve the temperature output specified by the hospital which is to provide constantly heated water from 10 am to 10 pm to the hospital. The remaining 10 pm to 10 am will be covered by the boiler. Besides that, the other requirement by the hospital is to have the temperature output of the storage tank to remain above 40°C at all times during the entire cycle of the solar system.

Based on the specified requirements by the hospital, it is obvious that the graph produces in figure 4.4.4(b).2 is to meet all the requirements set by HUKM. The suitable total area needed to produce the hourly average of the storage tank water temperature is $1800m^2$. This area includes a total of 360 number of panels required to be installed in the hospital with the maximum average area of $5m^2$. It can be be seen in the simulated graph that the temperature didn't reduce below 40°C and the temperature output between 10 am to 10 pm is high.

This simulated graph uses $1800m^2$ (360 number of panels), three circulation pumps, a heat exchanger, a non-pressurised tank and the HUKM weather data. This solar system in sync with the existing hot water heating system of HUKM to produce the heated water via boiler from 10 pm to 10 am shift.

With this modelling, the setting is set similarly with the existing heating system except for make-up tank function. The function of make-up tank is to increase the temperature of the system as much as possible for standby mode for the 10 pm to 10 am shift and also for the usage of temperature above the boiling point for the process such as sterilisation of medical equipment.

Thus, it can be seen that the total area of $1800m^2$ (360 number of panels) is the suitable area of solar collectors needed to be installed in the HUKM (medical industry). This is because it manages to achieve the requirements set by HUKM by producing optimum temperature results and also maintaining the temperature at a minimum level.

4.4.5 Comparing the simulated graph with HUKM graph

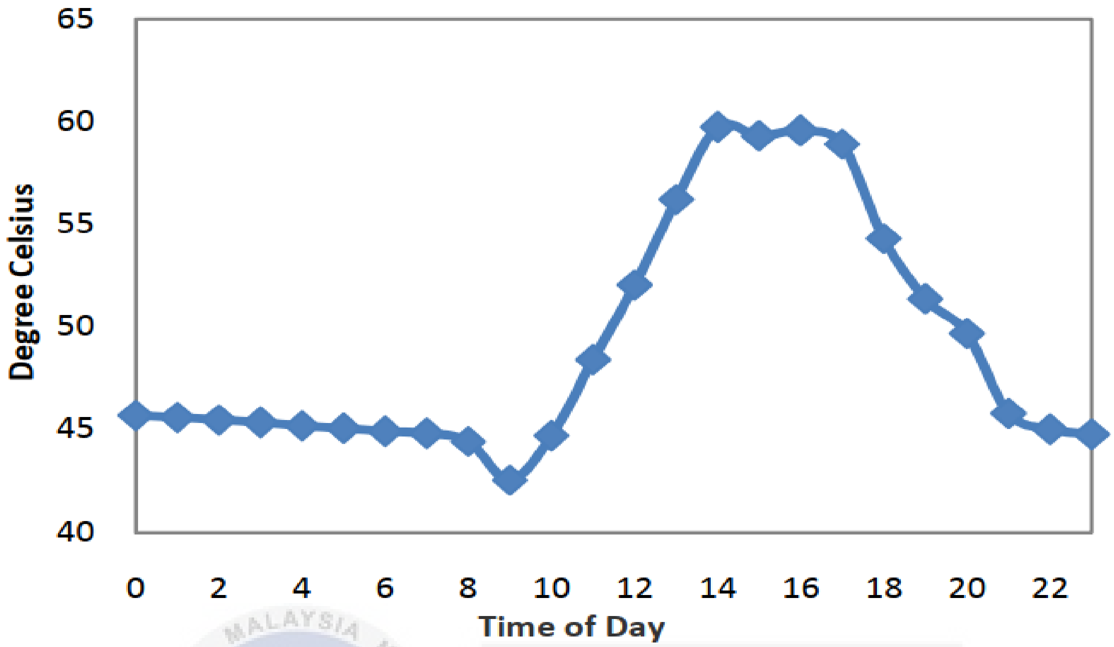

Figure 4.4.5.1: Results of Temperature output of HUKM

The graph produce by HUKM uses 144 panels of the evacuated tube with three circulation pumps, one plate heat exchanger, 15-ton pressurised storage tank, 2 pressurised expansion tank and weather data of HUKM from (2 weeks of August 2011).

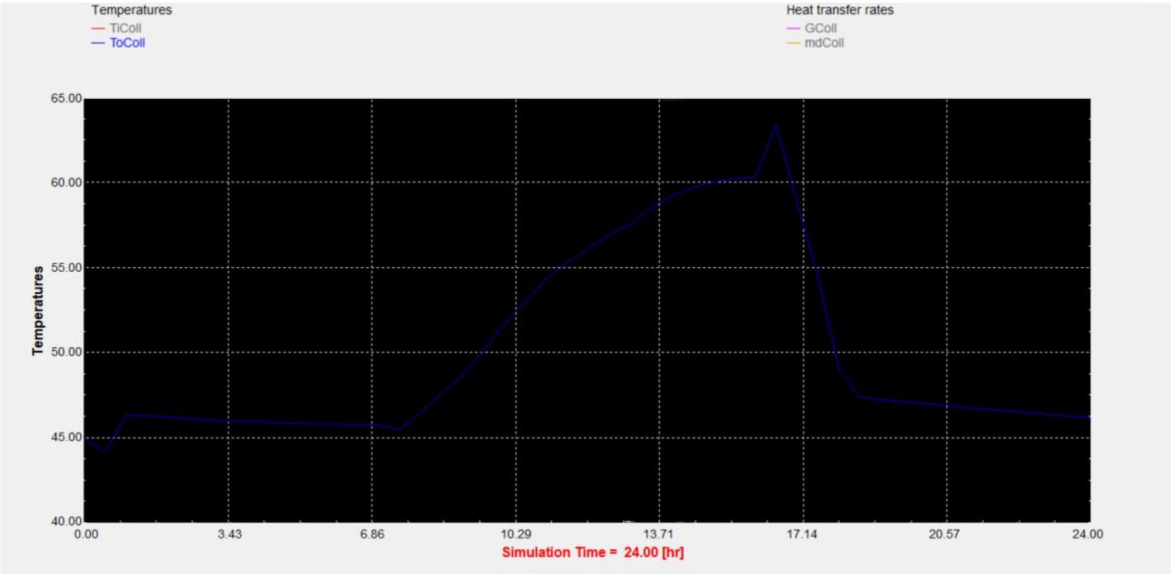

Figure 4.4.5.2: Simulated Temperature output of HUKM

The simulated graph produce by HUKM uses 360 panels of flat plate solar collector with three circulation pumps, one plate heat exchanger, 15-ton pressurised storage tank, 2 pressurised expansion tank and weather data of HUKM from (August 2011).

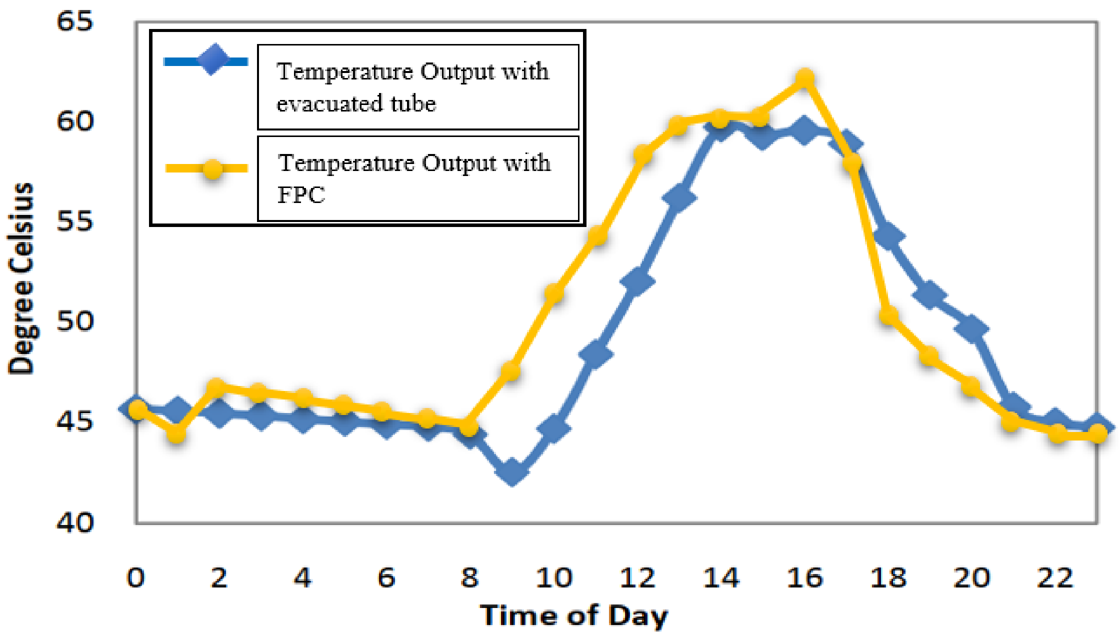

Figure 4.4.5.3: Temperature Output of FPC vs Evacuated Tube

Figure 4.4.5.3 compares the evacuated tube and the flat plate collector graph that produce the hourly average of the storage tank water temperature. Although the water temperature produces by the flat plate collector have it's high and low differences to the evacuated tube, it can be noted that the starting time and the finishing time is the same. Besides that, the temperature didn't drop below 40°C and the temperature output between 10 am to 10 pm is high.

The highest error produces between the temperature output of the flat plate collector (yellow) and the temperature output of the evacuated tube (blue) is during 9 AM. The error that was recorded is 10%. The lowest error recorded between the verification result and the temperature output of the evacuated tube is from 1 pm where the error was at 0.4%. The simulated results of the verification result and the temperature output of the flat plate collector is subject within the confidence interval of the system.

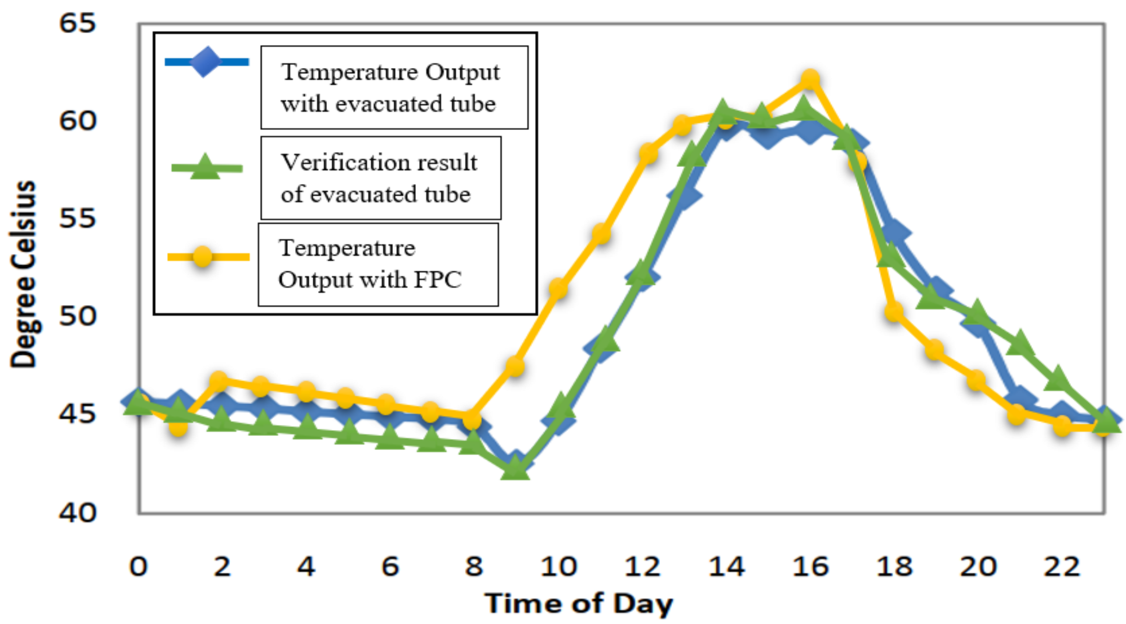

Figure 4.4.5.4: FPC vs Evacuated Tube vs verification of Evacuated Tube

The figure above shows the comparison between the flat plate collectors, evacuated tube and the temperature output of the evacuated tube in a simulation verification. By comparing the temperature output between the three graphs a very good agreement was achieved. The temperature output of the flat plate collector and the evacuated tube is reported. The results that have been recorded from the simulation is for 24 hours and each hour of the point is also recorded. It can be noted that all three temperature output started at 45°C with the temperature output of the flat plate collector

The highest error produces between the verification result (green) and the temperature output of the evacuated tube (blue) is during 9 PM. The error that was recorded is 6.6%. The lowest error recorded between the verification result and the temperature output of the evacuated tube is from 1 pm where the error was at 0.5%.

It can be noted that the starting time and the finishing time is the same between the verification result and the temperature output of the evacuated tube. Besides that, the temperature didn't drop below 40°C and the temperature output between 10 am to 10 pm is high. The simulated results of the verification result and the temperature output of the flat plate collector is subject within the confidence interval of the system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a nutshell, temperature inlet and the temperature outlet (T_iColl and T_oColl) plays a significant role to obtain the performance of the flat plate collector by using the TRNSYS simulation software which is to achieve the objective one of this study. The validation results for the experimental data obtained from the literature study in the journal are compared with the TRNSYS simulation in identifying the best the performance of the flat plate collector is correct. This can ensure that each step and modelling of the research is done precisely to make an almost perfect simulation. Based on the validation results, it proves that when the temperature inlet and the temperature outlet of a solar system increase, it will proportionally increase the performance of the flat plate solar collector and at the same time it also increases the efficiency of the solar system. The best way to find out the performance of the flat plate collector is to figure out the temperature differences of the T_iColl and T_oColl. It can be noticed that the major output is in the mix of 30°C to 66°C which is the optimum temperature for domestic usage suitable for cleaning and bathing. The temperature difference between the temperature input and temperature output is at the lowest difference of 6 °C and the highest is at 20°C higher than the input temperature. This proves that the high-temperature difference will provide the best performance for a flat plate solar collector in a solar system [9].

For the second objective to be achieved which is to determine the suitable number of collectors for domestic hot water in Melaka using Hottell-Whillier-Bliss equation in

TRNSYS. The load profile used is based on the weather data produced by the Meteonorm software of Melaka city in the year 2020. To find a suitable number of solar collectors, the normal efficiency of flat plate solar collector must be around 70% [29].

A single flat plate collector with an area of $2.5m^2$ is enough to be installed in Melaka city. This is due to the efficiency of the flat plate solar collector exceeds the 70% mark which affects the efficiency [33]. The efficiency that is been achieve from this calculation is 78.43%. The domestic hot water produces using this area of 2.5m gives a more optimum temperature output. The simulation produce will give the users with the right temperature for domestic usage and it will avoid all the heat hazards produced by the solar collectors. It can be noted that the cut-off limit is still implemented in this simulation to prevent the temperature reaching extreme conditions. The demand tank has also been installed in the model to act as an excessive storage tank that stores excessively heated water.

Based on objective three, which is to find out the suitable surface areas of the flat plate solar collector according to the industry specifications and needs. shows the solar TRNSYS model with flat plate solar collector which is developed according to the system solar model of HUKM with evacuated tubes and the hot water heating loop system in HUKM. The settings are set to similar standards of both this mode except to the solar collectors used which are replaced by the flat plate solar collectors instead of the evacuated tube. The flat plate solar collector also replaces the make-up tank. The flat plate solar collector will be arranged in a series manner to get the best yield of the system. This is due to a series having an increased area for solar radiation and it will maintain a positive change in temperature which is subject to temperature variation [34]. The series arrangement also will provide good flexibility and performance of the solar system. The actual weather data of August 2011 is used in this research in the Transient Simulation System Software.

The simulation started with one series 5 MY-60 flat plate collector from MYSOLAR CONCEPT SDN BHD with the specifications of 5m^2 of area. To achieve the temperature output specified by the hospital which is to provide constantly heated water from 10 am to 10 pm to the hospital. The remaining 10 pm to 10 am will be covered by the boiler. Besides that, the other requirement by the hospital is to have the temperature output of the storage tank to remain above 40°C at all times during the entire cycle of the solar system. Based on Figure 4.4.4.2, the suitable total area needed to produce the hourly average of the storage tank water temperature is 1800m^2. This area includes a total of 360 number of panels required to be installed in the hospital with the maximum average area of 5m^2. It can be seen in the simulated graph that the temperature didn't reduce below 40°C and the temperature output between 10 am to 10 pm is high. This simulated graph uses 1800m^2 (360 number of panels), three circulation pumps, a heat exchanger, a non-pressurised tank and the HUKM weather data. This solar system in sync with the existing hot water heating system of HUKM to produce the heated water via boiler from 10 pm to 10 am shift.

5.2 Recommendations

As the recommendation, this study only focuses on flat plate collectors (Theoretical Flat Plate Collector in TRNSYS 17) that analyses the performance of the solar system and also to figure out the optimum number of collectors and its suitable area in the industries. It is recommended that for future study the research will focus on other types of flat plate collectors that are available at the market and also in the TRNSYS software of the future. The other types of flat plate solar collectors are the performance map collectors, quadratic efficiency collector and thermosiphon flat plate collectors. This is to get the best flat plate collector that is available in the market.

This research only analyses the performance, number of collectors and the areas of the collectors needed to be installed in Melaka city and also in the industry. It is recommended that the future study should primely focus on other types of existing simulating software such as RET screen, gambit, MATLAB and many more to get the precision and accuracy in solar collector performance.

Finally, this research also uses a theoretical prediction of the performance of the flat plate collectors by analyzing the temperature difference of the first objective and for the second and third objective, the actual data was inserted into the system by implementing the Hottel-Whillier-Bliss equation into the TRNSYS software. The real-life data might be dissimilar from the theoretical data produce by TRNSYS. The actual test is recommended to be carried out with the right equipment, technical and financial supports at the actual location for more in-depth data and results projection.

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APPENDIX

1.0 The TRNSYS Layout

TRNSYS consists of a suite of programs: The TRNSYS simulation Studio, the simulation engine (TRNDll.dll) and it's executable (TRNExe.exe), the Building input data visual interface (TRNBuild.exe), and the editor used to create stand-alone redistributable programs known as TRNSED applications (TRNEdit.exe).

In this study, only the TRNSYS simulation Studio version 17 is used. The studio focuses mainly on finding out the correct components and linking them together is a correct manner. Any sort of incorrect linking will trigger a prompt menu which will inform the user to avoid the linkage.

1.1 The TRNSYS Simulation Studio

The main visual interface is the TRNSYS Simulation Studio (formerly known as IISiBat). From there, you can create projects by drag-and-dropping components to the workspace, connecting them and setting the global simulation parameters. The Simulation Studio saves the project information in a Trnsys Project File (*.tpf). When you run a simulation, the Studio also creates a TRNSYS input file (a text file that contains all the information on the simulation but no graphical information). The graph simulations will be projected in the TRNEXE prompt. The simulation engine is called by an executable program, TRNExe.exe, which also implements the online plotter, a very useful tool that allows you to view dozens of output variables during a simulation.

1.2 TRNSYS add-ons

TRNSYS offers a broad variety of standard components, and many additional libraries are available to expand its capabilities:

• TRNLIB: sel.me.wisc.edu/trnsys/trnlib (free component library)

• TRANSSOLAR libraries: www.transsolar.com

• TESS libraries: www.tess-inc.com

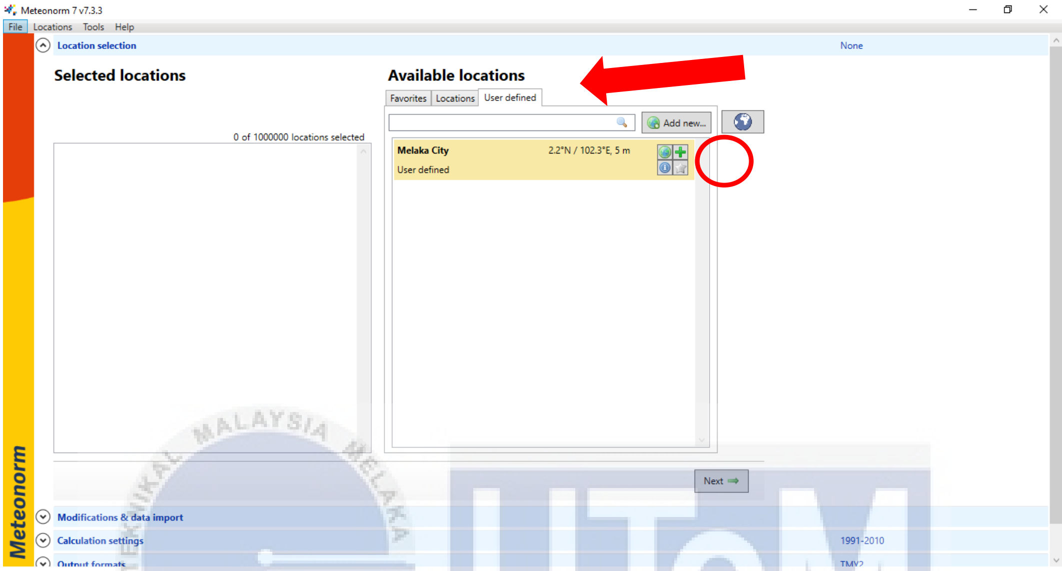
•Meteonorm

In this study, The Meteonorm software version 7v7.3.3 is used to find out the weather data for the locations such as Karaikudi, India, Larnaca, Cyprus, Kuala Lumpur, Malaysia and Melaka City, Malaysia. The data that is generated from the software can be converted to hourly analysis data which is known as ".tm2". The software will generate the solar radiation, solar temperature, precipitation of sunlight, sunshine duration, daily global radiation, the data table and the weather data table.

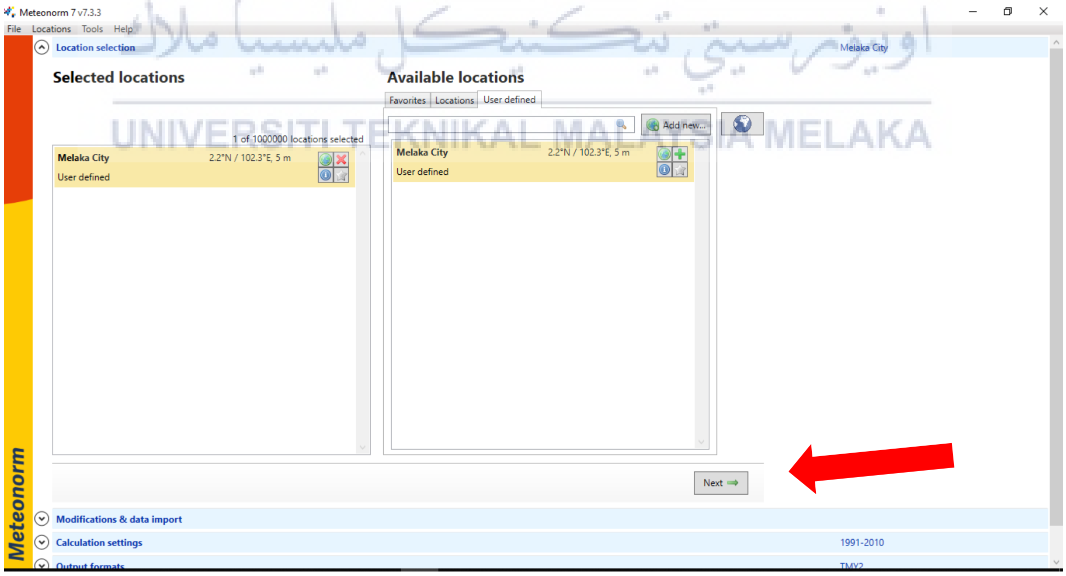
Steps to create a weather ".tm2" file.

Step 1

Run the software, once the first layout opens, go to the user define location. Type in your required location. In this case, the Melaka City is chosen for the study in Melaka.

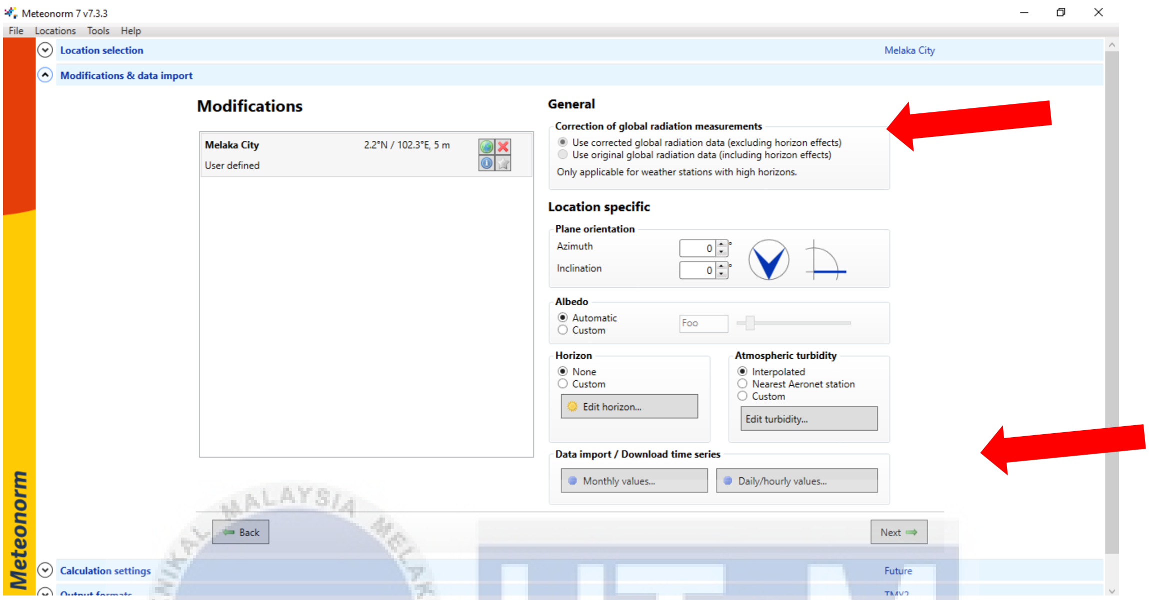


Click on the green plus symbol " + " to move the location to the left side and press next.



Step 2

In the modification and data import section click the "**Use corrected global radiation data (excluding horizon effects)**" and click next.

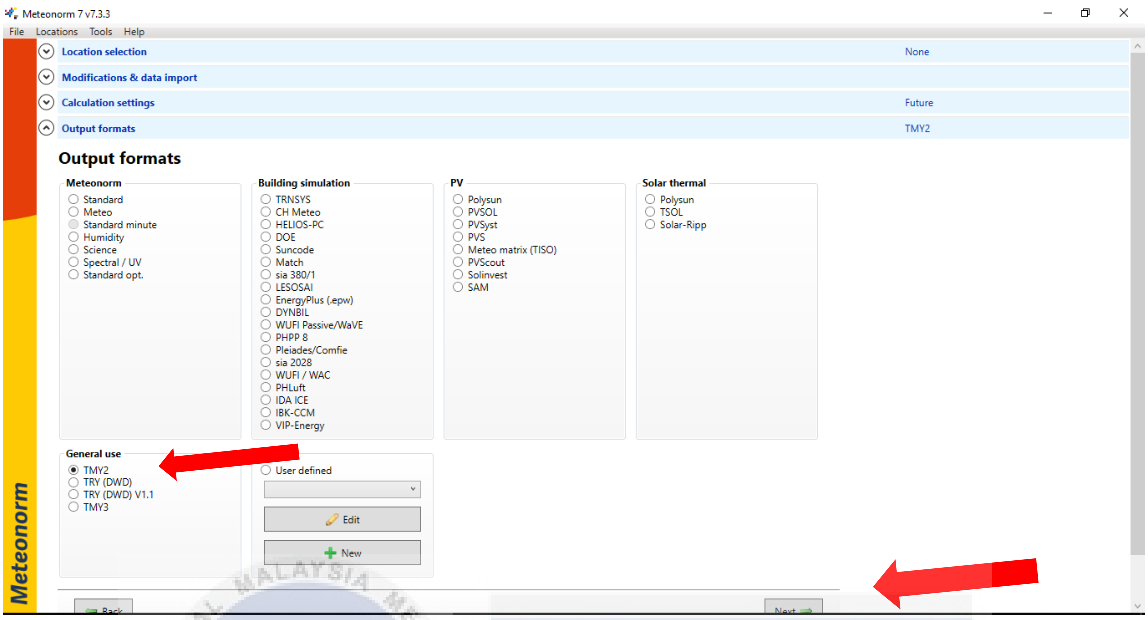


Step 3

Make sure the settings are as follow and click next

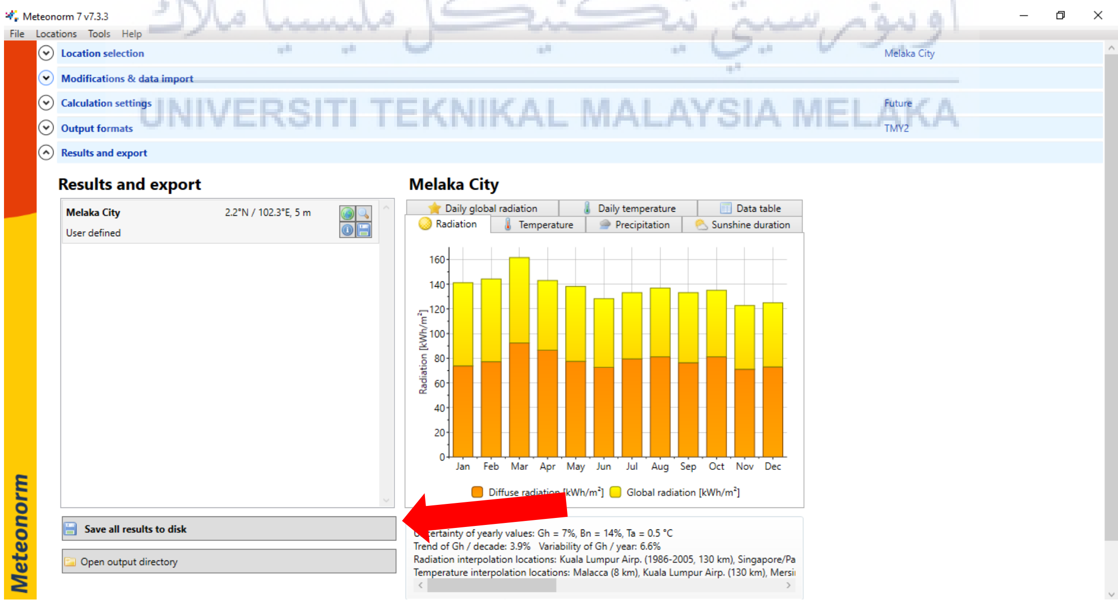
Step 4

At the output format click the TMY2 at the general use and click next

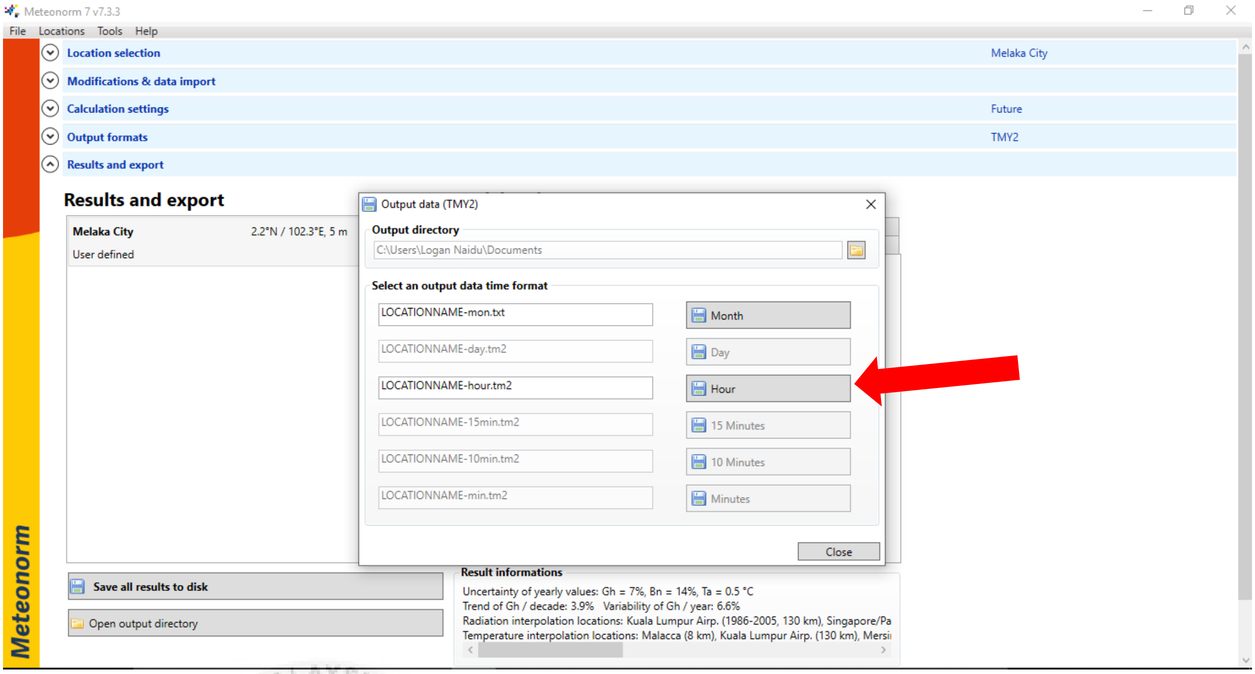


Step 5

At the results and export wait until the weather data is loaded and click at the **"Save all results to disk"**



Save the hour data and transfer it to the TRNSYS software

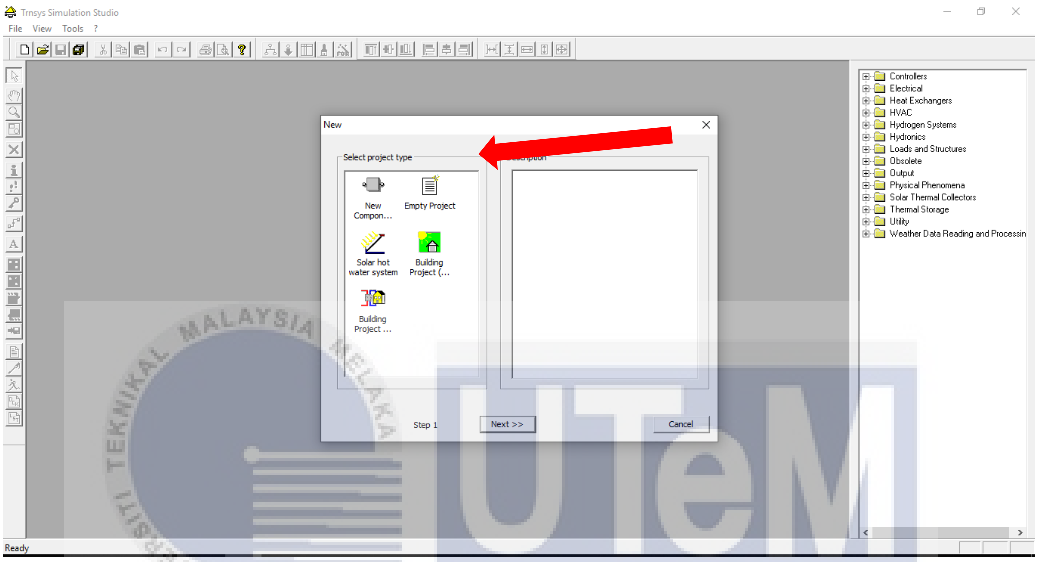


2.0 TRNSYS Tutorial

Below is the step by step tutorial for the 1st objective of the study from the research of A simulation study of Domestic Hot Water using TRNSYS 17.

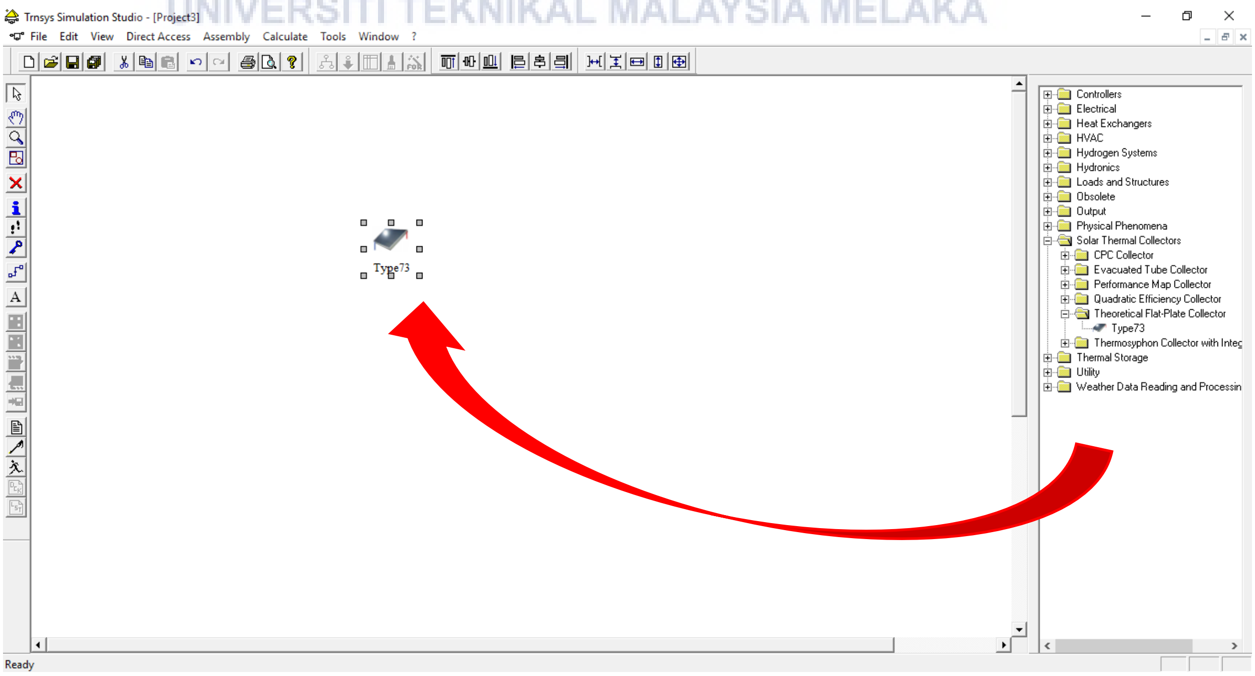
Step 1

Run TRNSYS and open new. Once the pop-up opens choose the empty project.



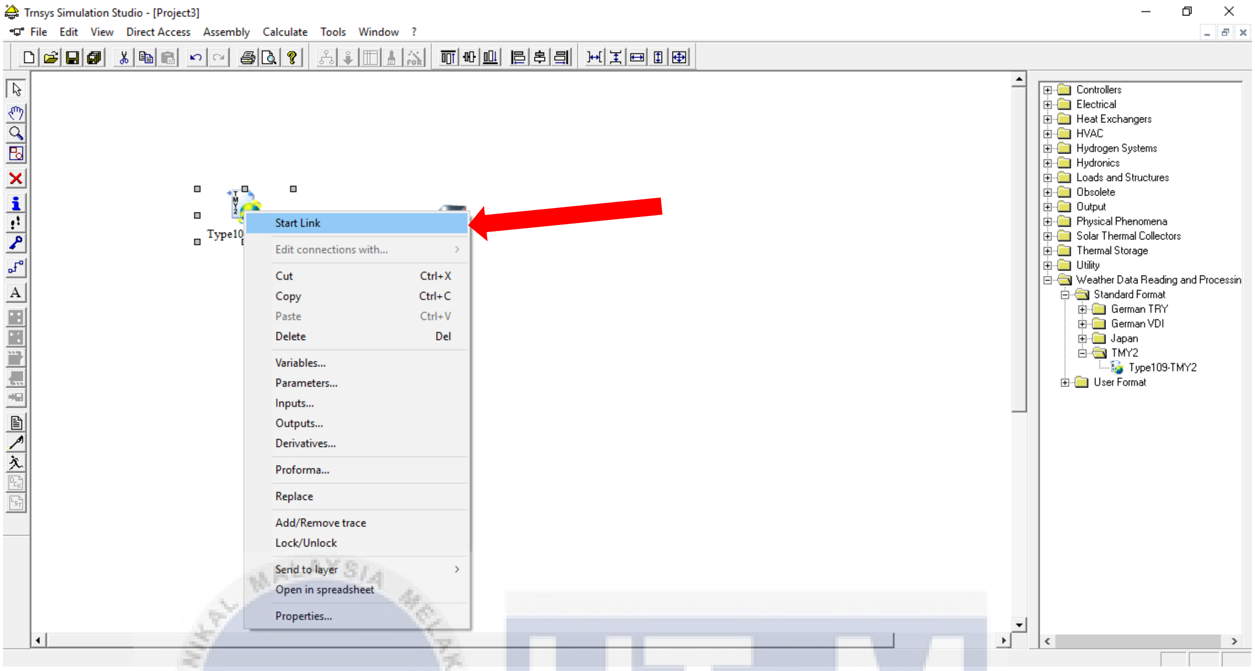
Step 2

Drag the required component and to the white layout.

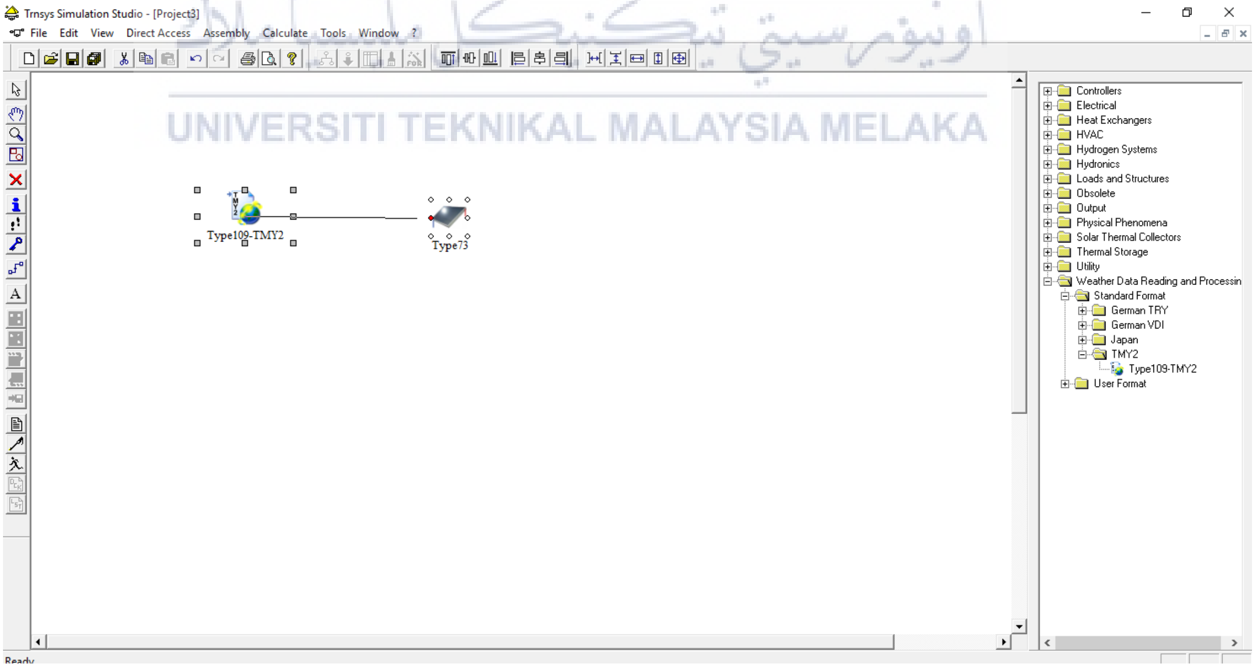


Step 3

To start linking, right-click on the component and click in start link.

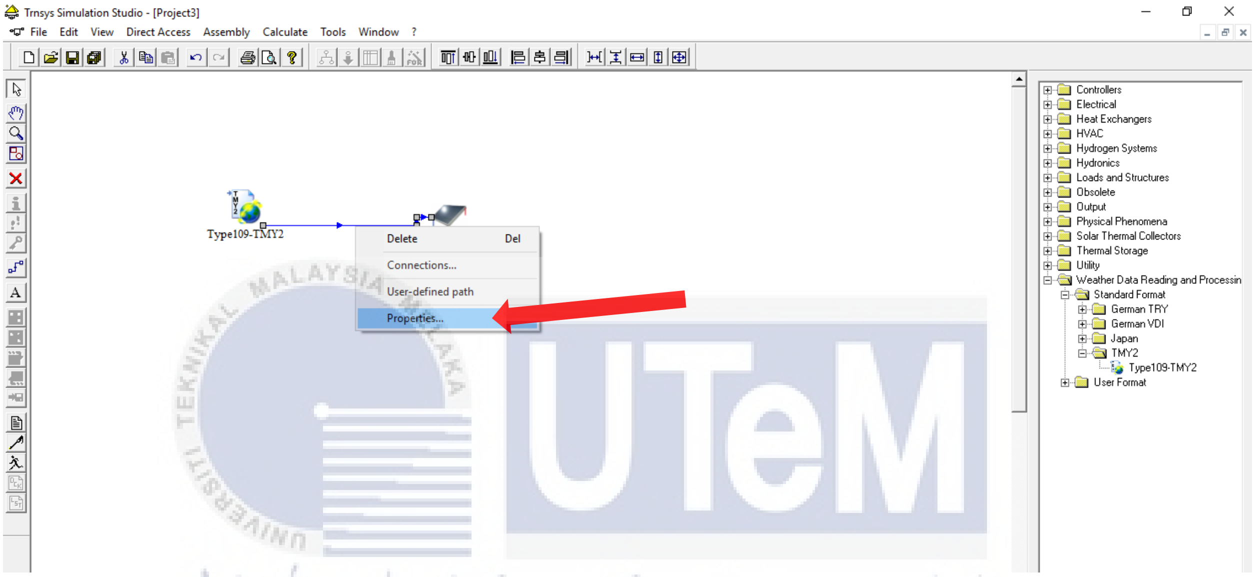


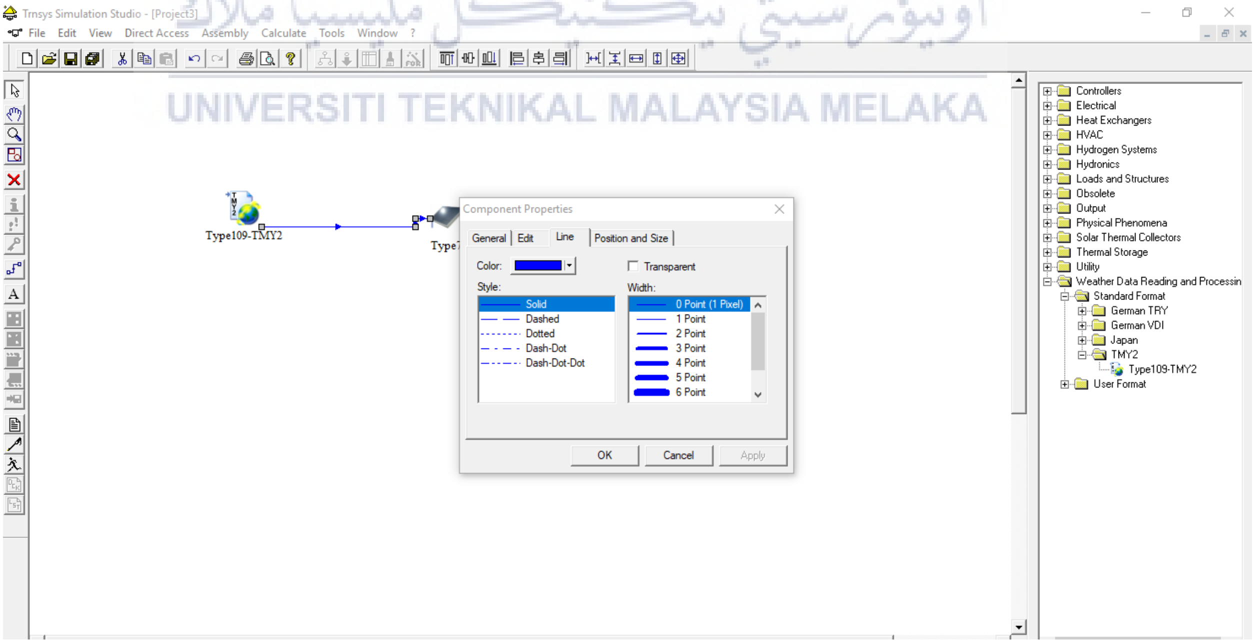
Click on the next component to link both components.



Step 4

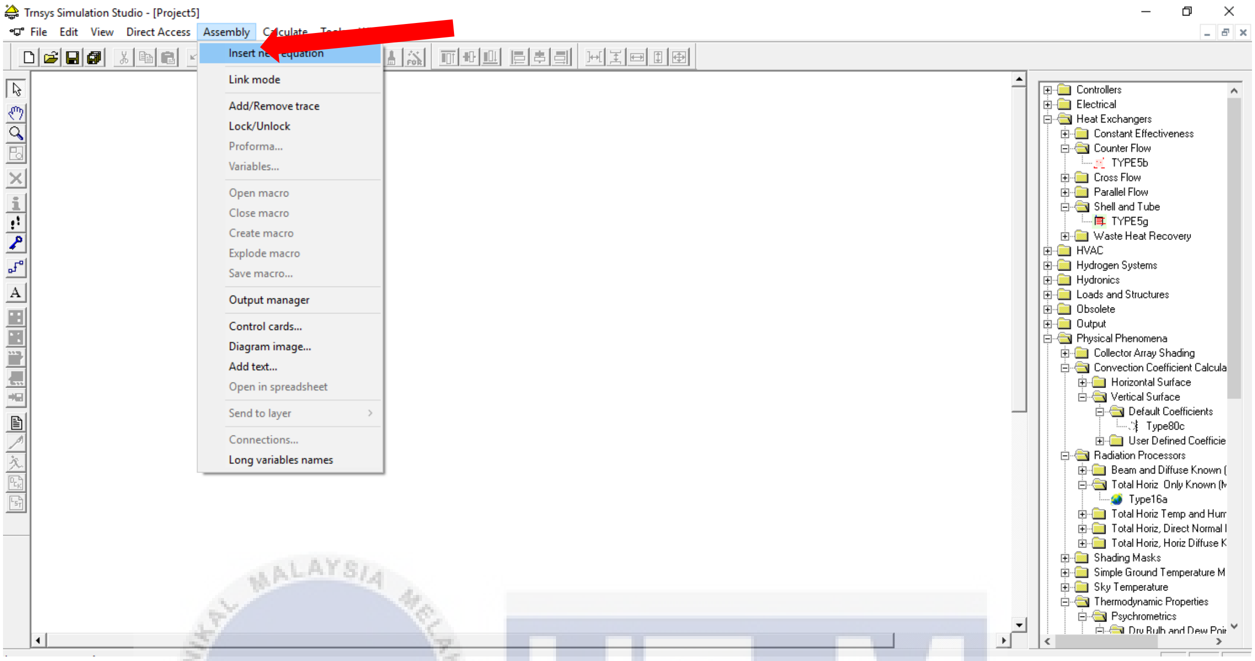
To change the colours or the linkage shape, click on properties and click on the line. In this study blue indicates cold water, red indicates hot water, orange indicates warm water. The solid line indicates component connection where else dotted line indicates plotter, simulation connections or sensor connections. The connection should be set based on the user's preference. The wrong connection will trigger the wrong connection by TRNSYS.



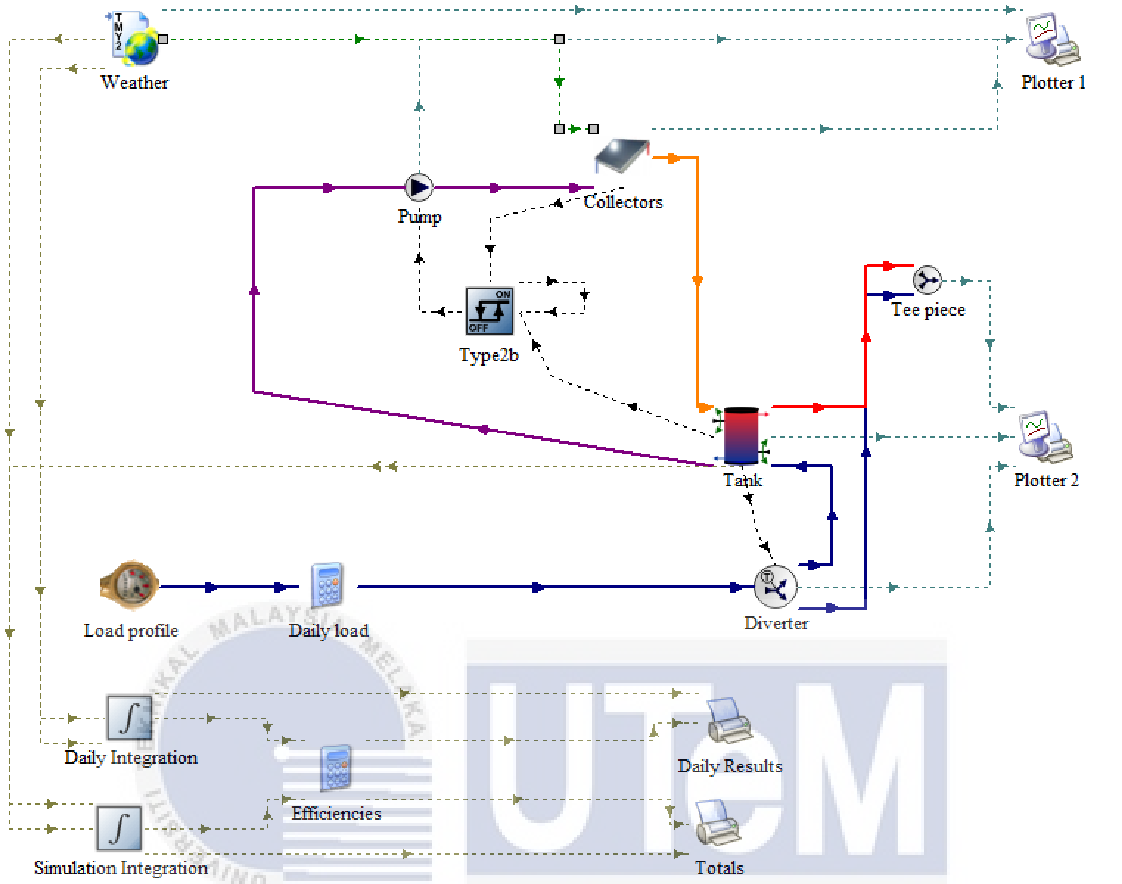


Step 5

To insert the equation, click on assembly and insert a new equation.

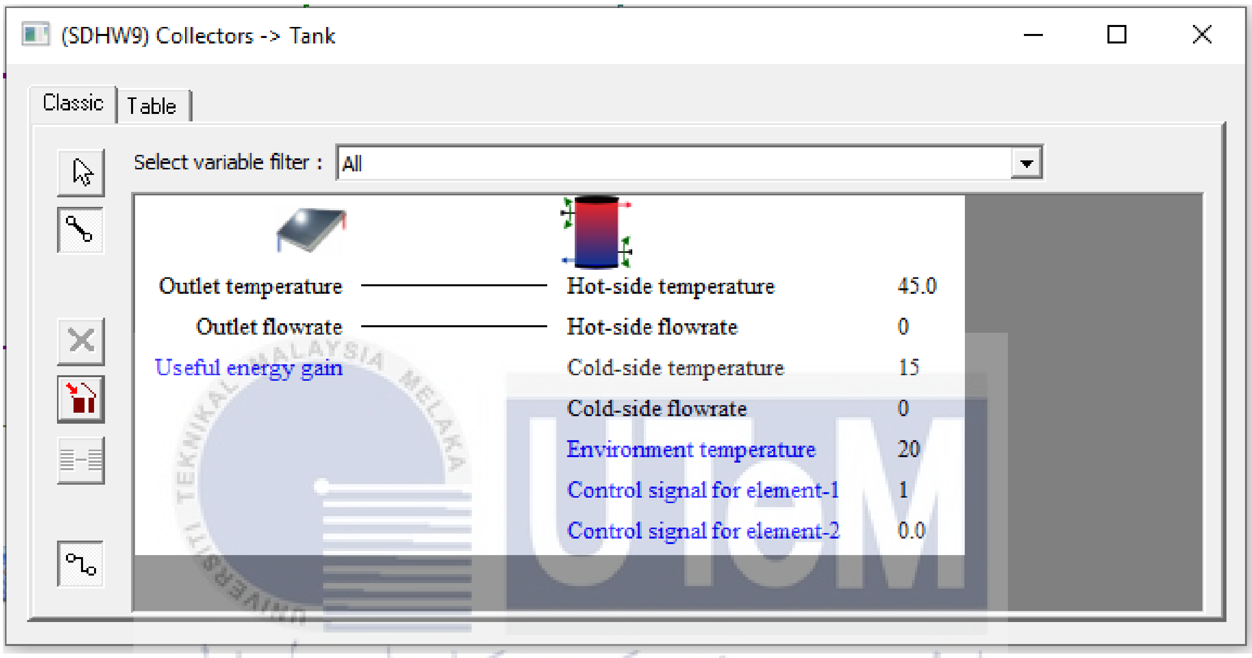


The setup for the first objective.



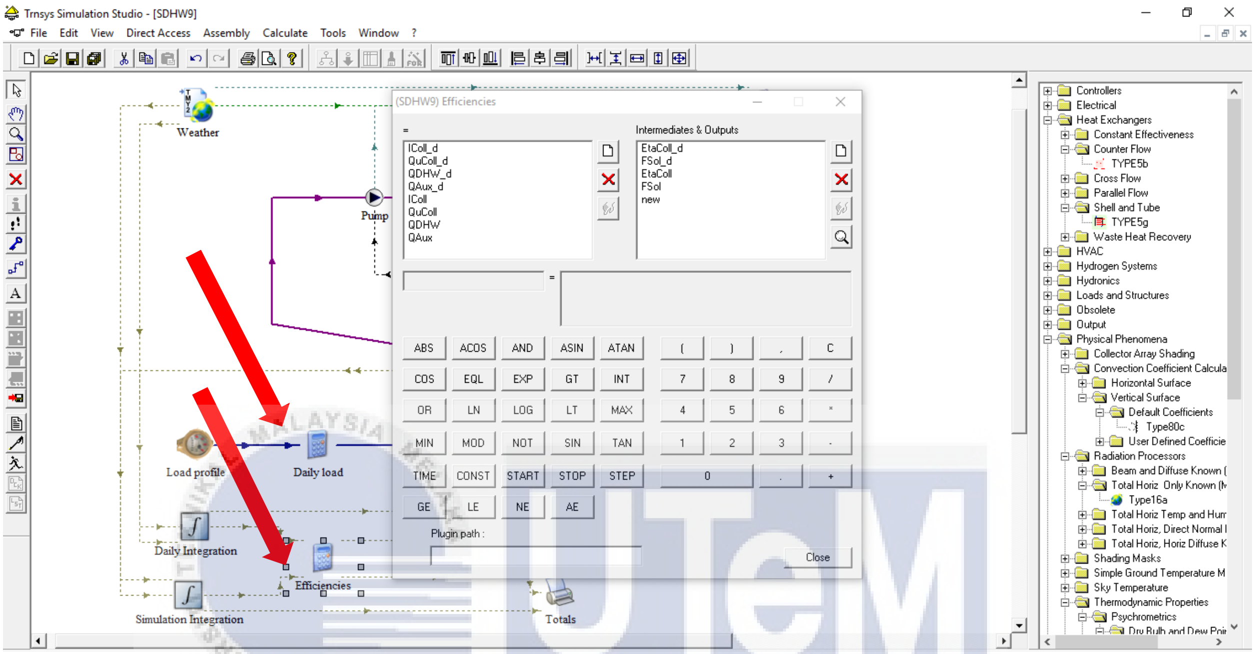
Step 6

Double click on each connection to set up the required connection between both the components. In this case, the solar collector is connected to the storage tank. Where the outlet temperature from the solar collector will go into the hot side of the storage tank while the outlet flowrate will go to the hot side of the flowrate.

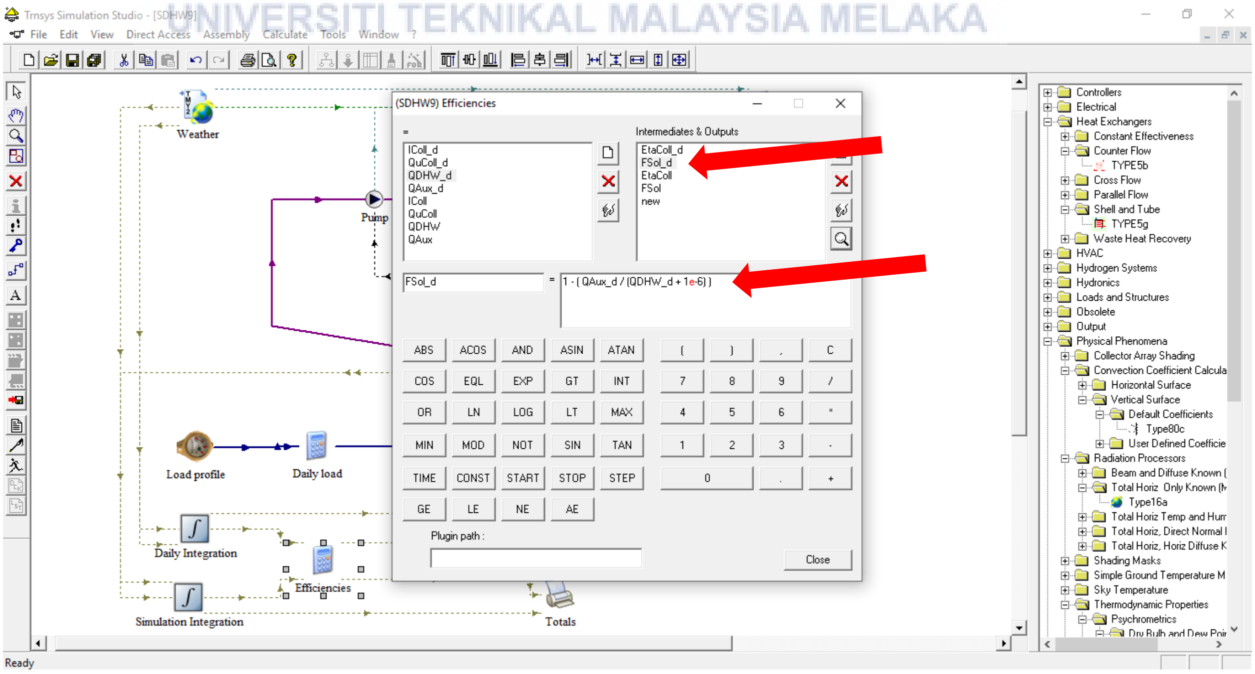


Step 7

For this research, the Hottell Whillier Bliss equation is inserted to the equation section by double-clicking the equation component. The component is then renamed as daily load and efficiency.

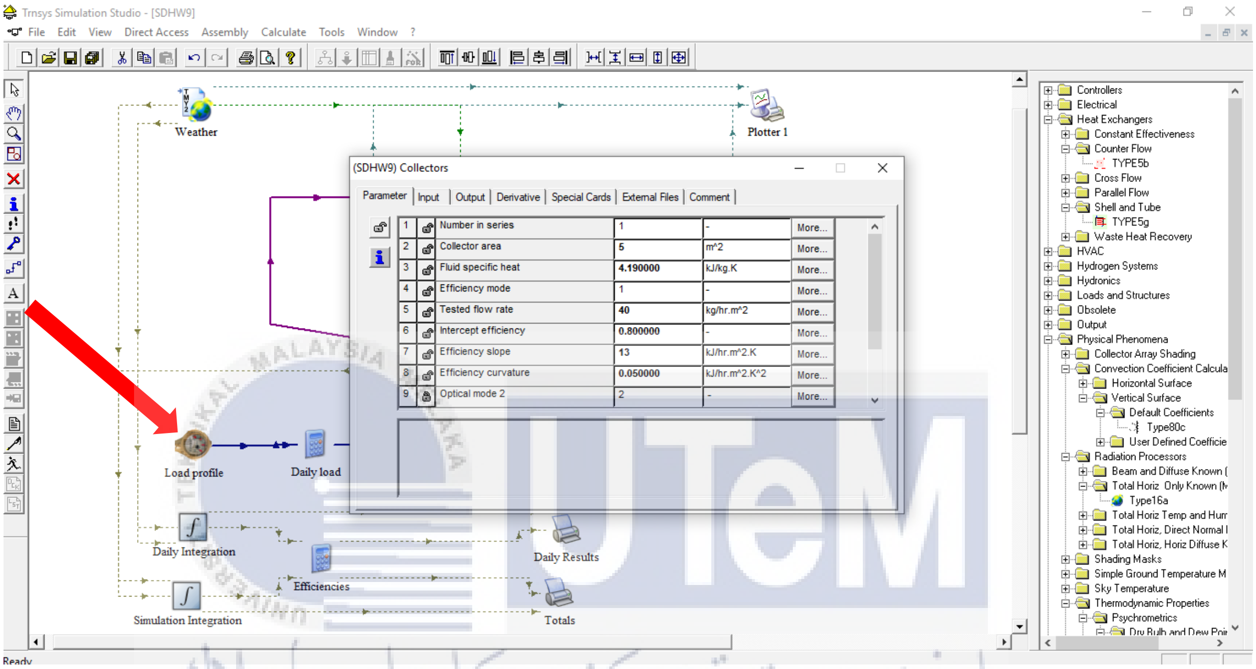


User should make sure that the right equation is inserted so that the formula is right for the simulation to take place.



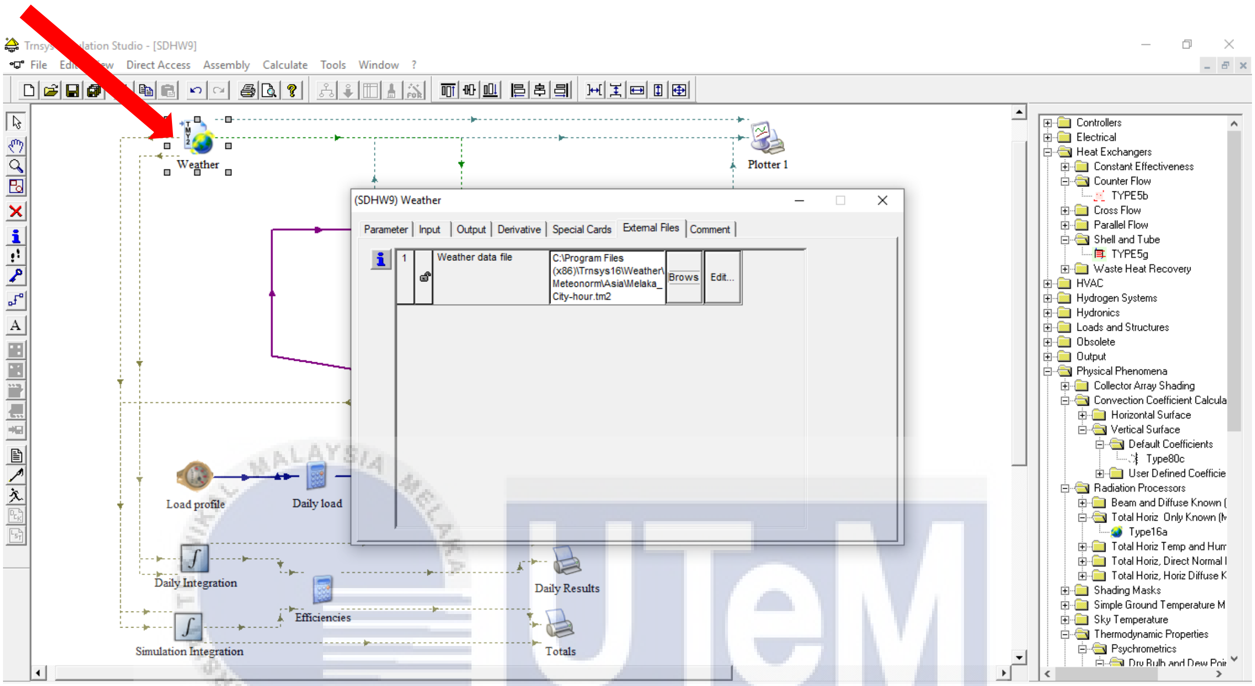
Step 8

For each component, the parameters and the input needed to be set by the users. The constant values should be as the set by the International System of Units. For this figure, the collector's parameters are shown. By the double-clicking on it will give the parameters and inputs display.



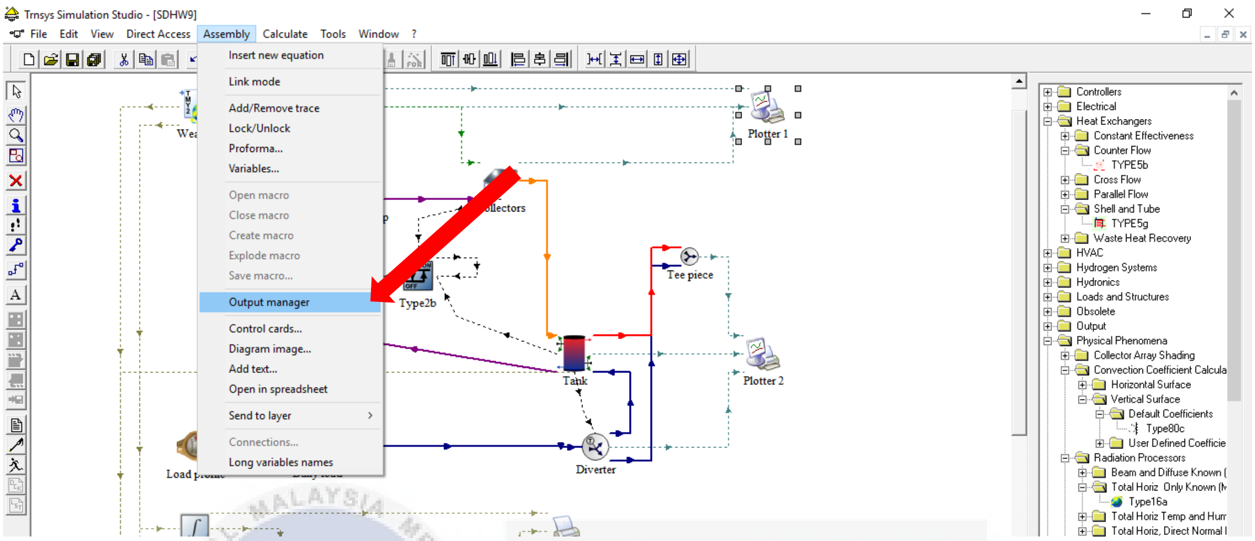
Step 9

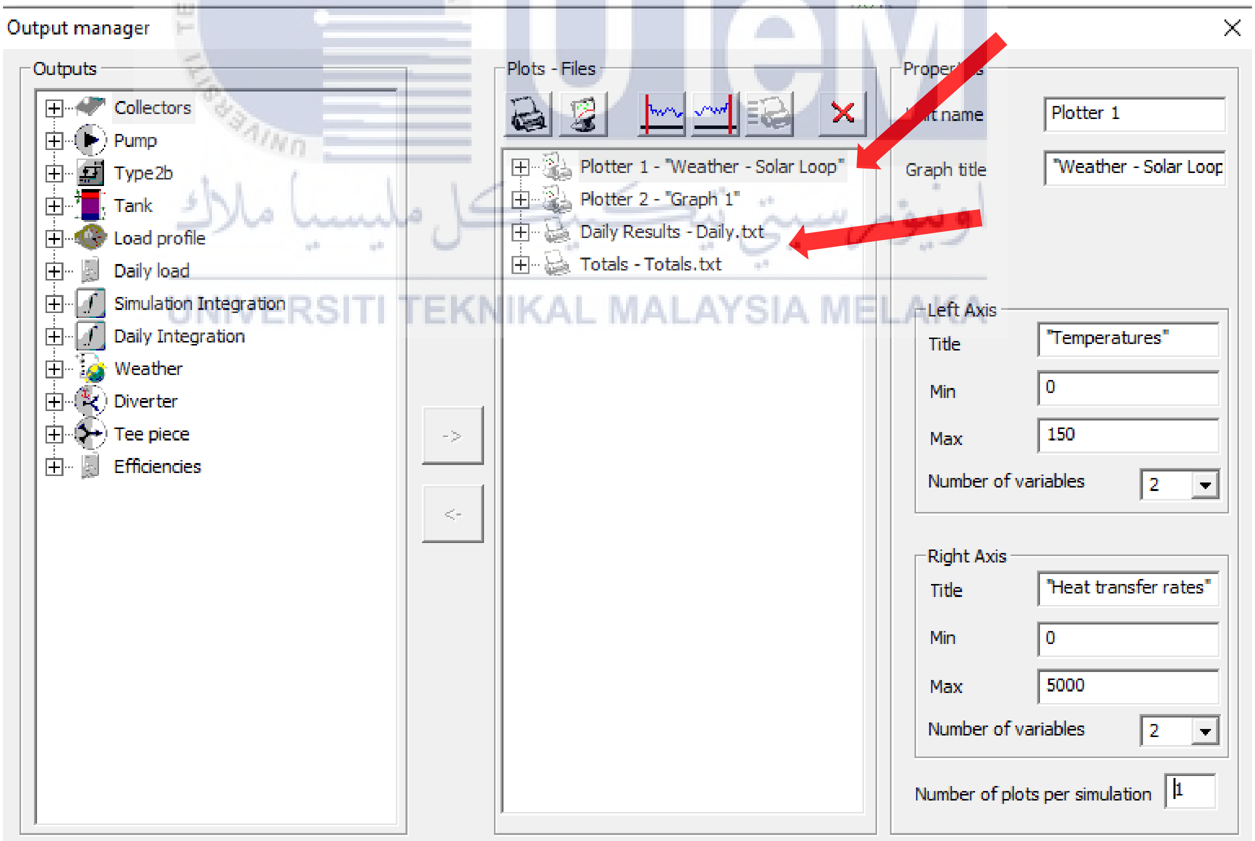
For the weather data, Melaka city weather data is chosen by dragging the saved data generated by Meteornorm software. Click on browse and search the location of the saved data by Meteornorm.



Step 10

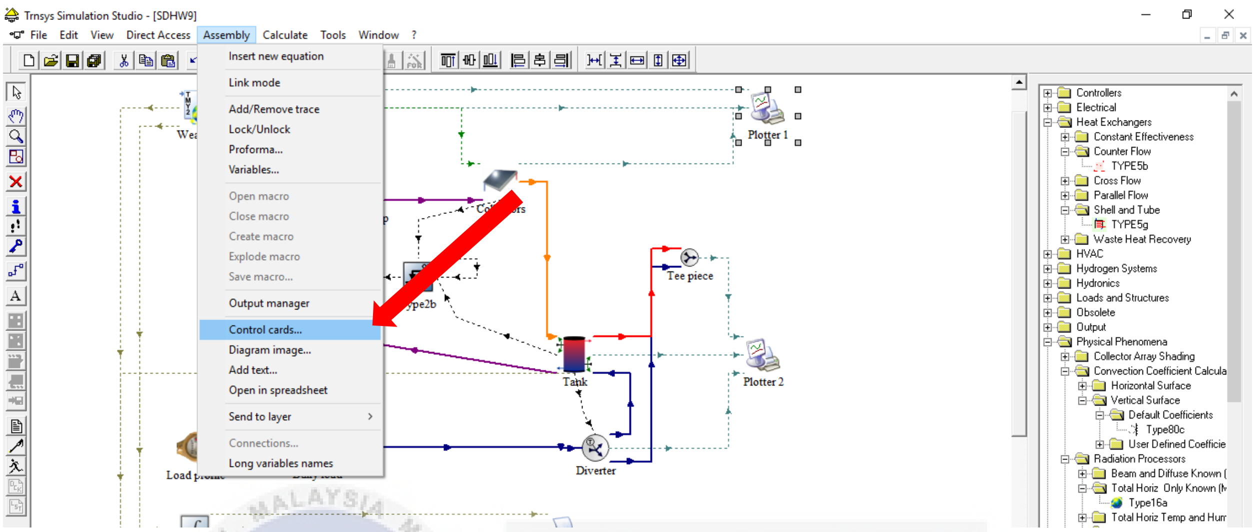
The output manager determines the plots of the simulation graphs. The user has to make sure the connections of the components with the X and Y-Axis of the graphs.

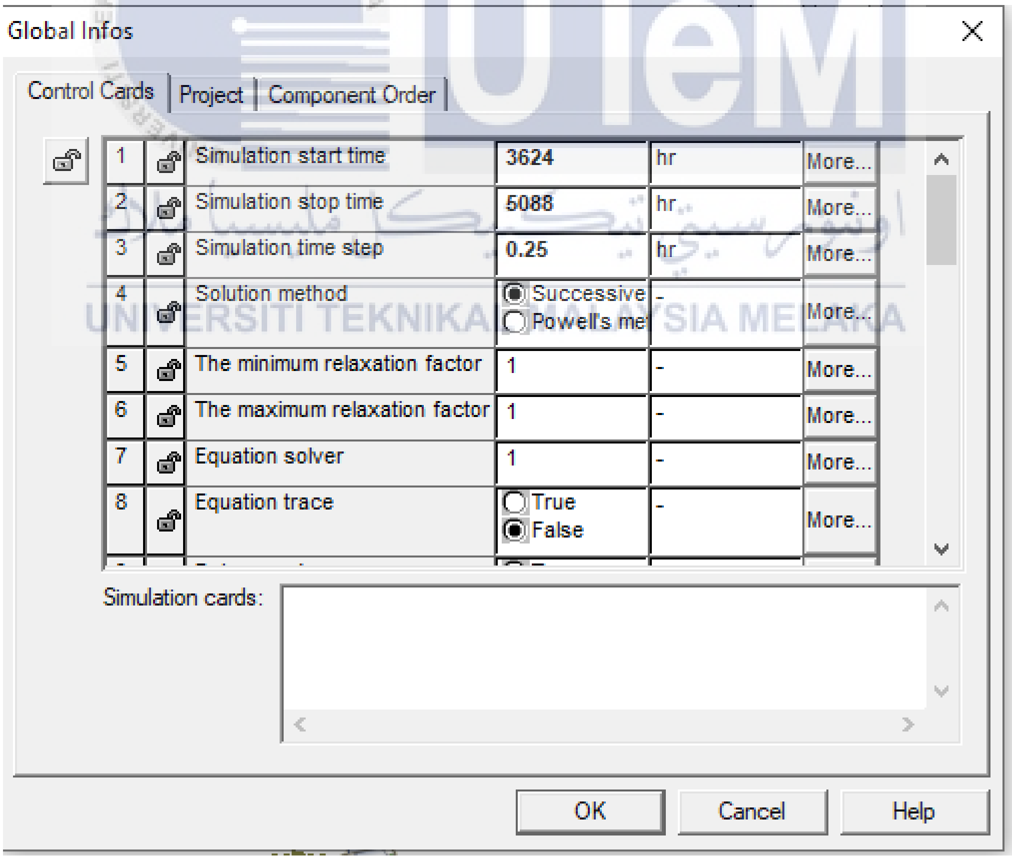




Step 11

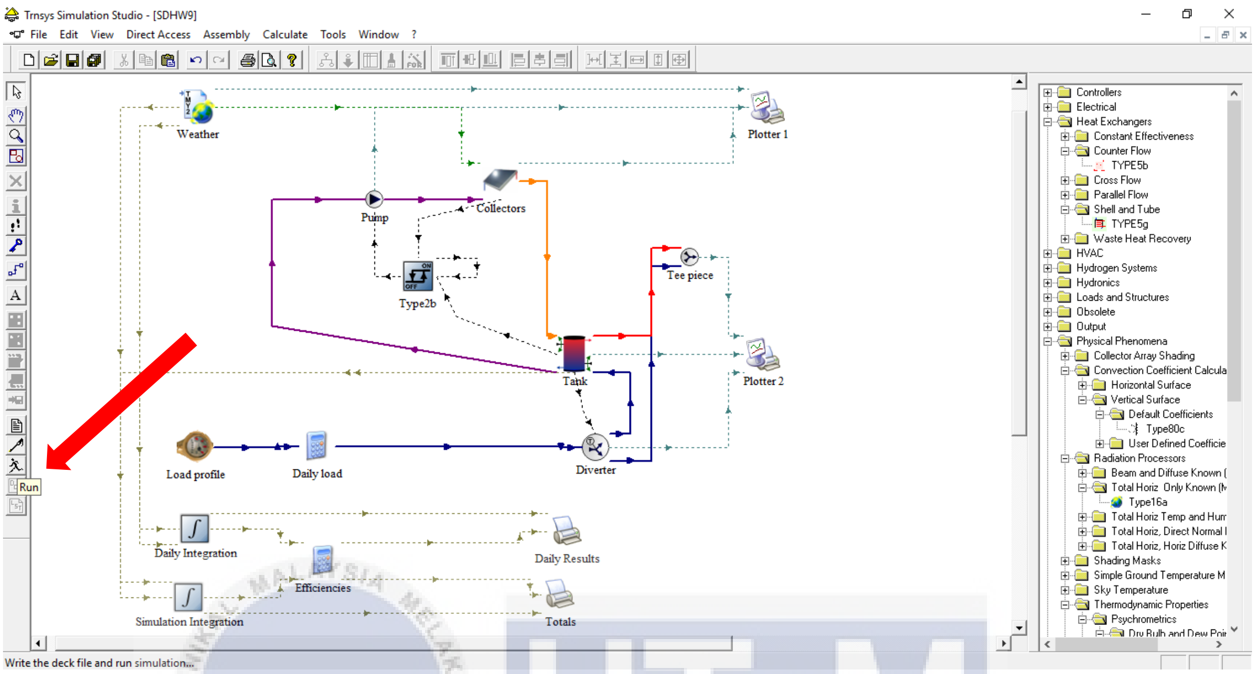
Control cards play an important role in the graph. Here users can set the simulation start and stop time to get the ideal simulations looks.



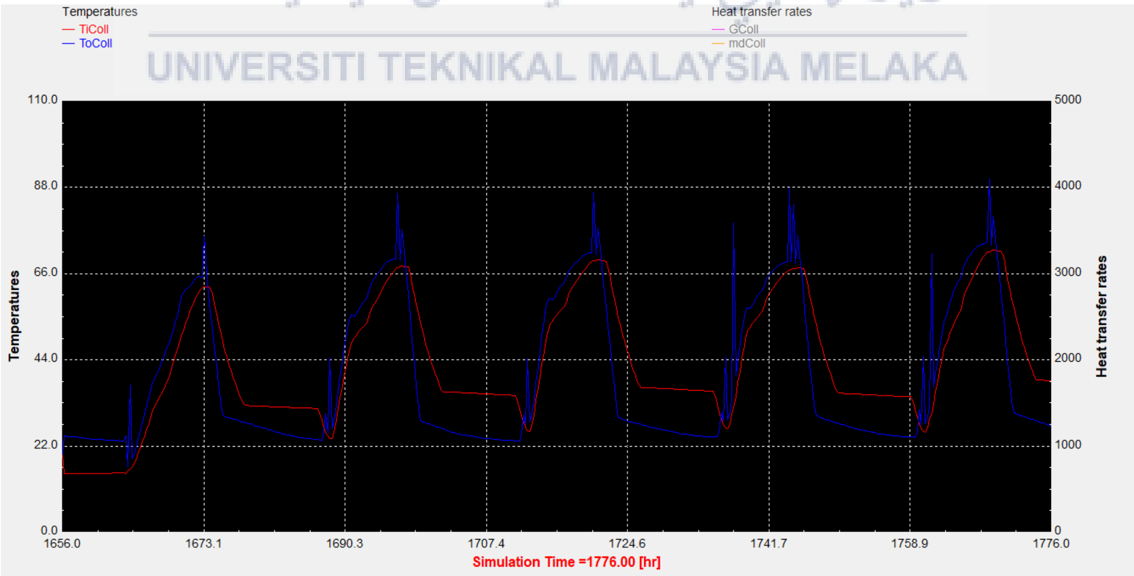


Step 12

Click on run to simulate the entire system.

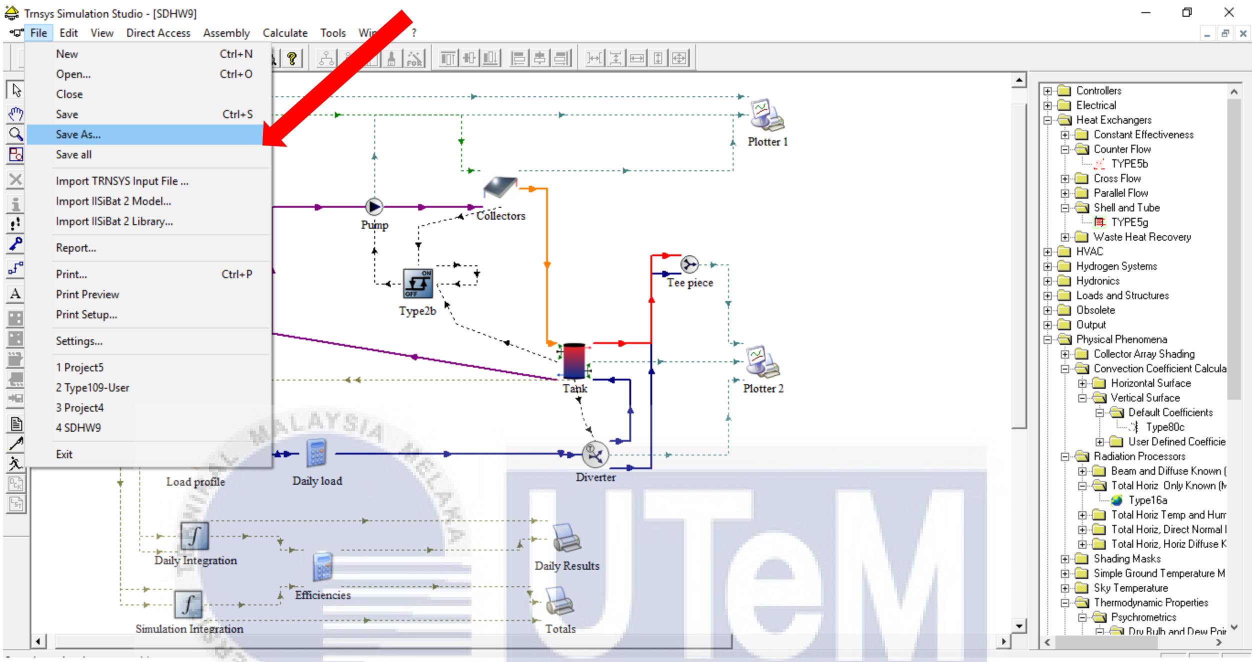


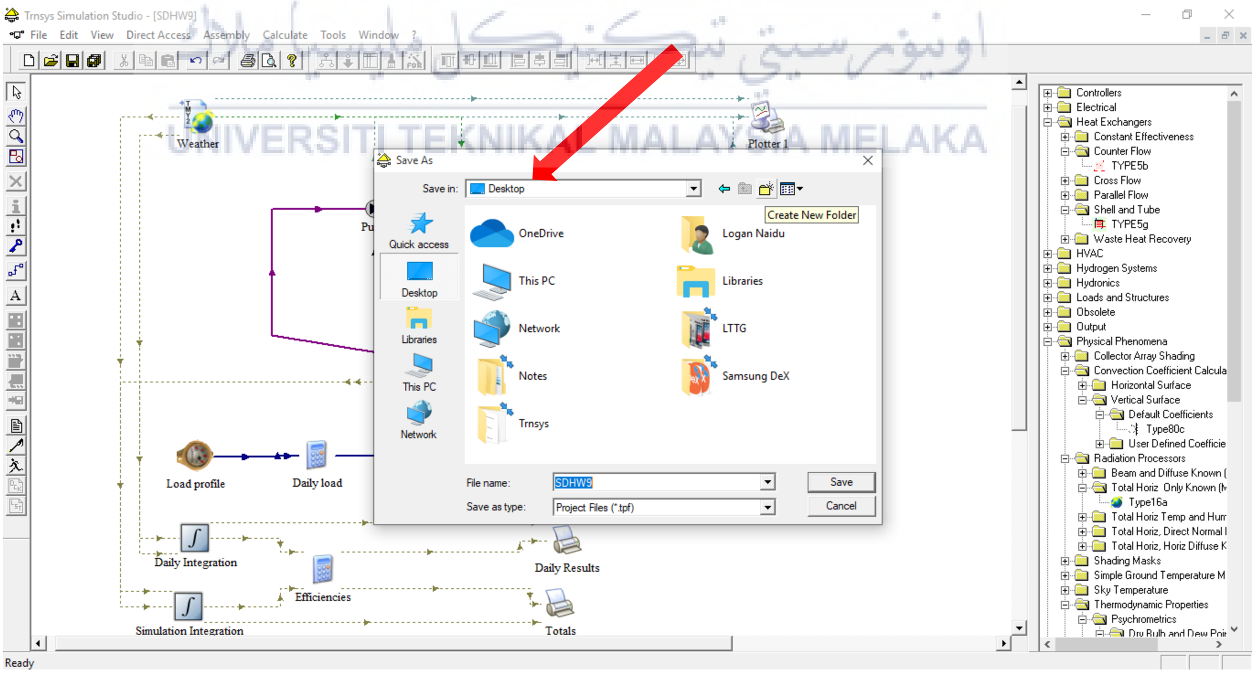
Once the simulation is done, the TRNEXE will prompt to show the simulated graph. The Y-axis values can be changed by double-clicking on it.



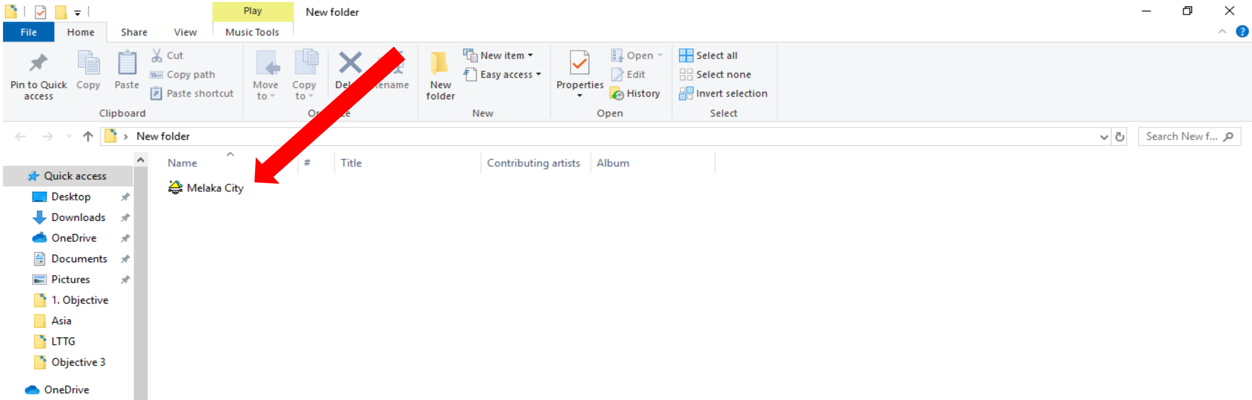
Step 13

To get the daily loads and the total loads the file must be saved in the new folder at the desktop. Then the simulation must be run once more. Once it has done the files will be inside the folder.

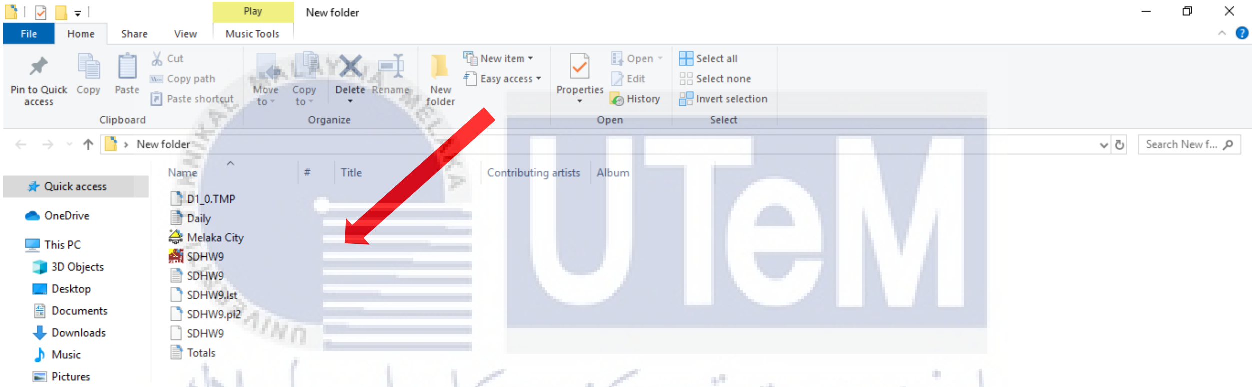




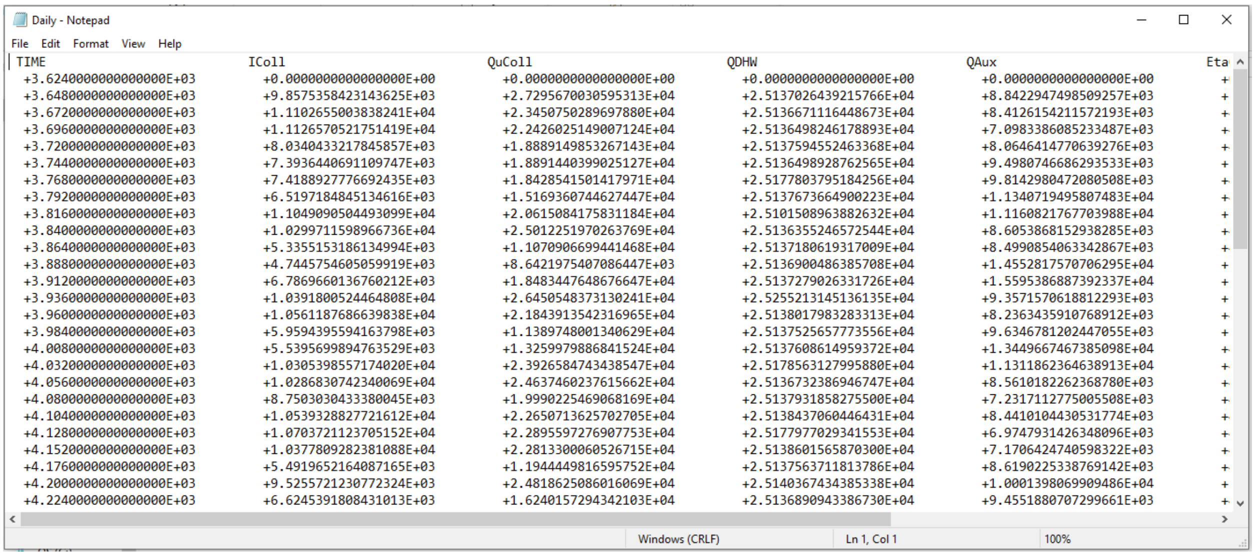
Before running the simulation



After running the simulation, the daily and totals data will be visible in text files in the folder.



Daily data generated by TRNSYS in txt file



TIME	ICoIl	QuColl	QDHW	QAux	Eta
+3.6240000000000000E+03	+0.0000000000000000E+00	+0.0000000000000000E+00	+0.0000000000000000E+00	+0.0000000000000000E+00	+
+3.6480000000000000E+03	+9.8575358423143625E+03	+2.7295670030595313E+04	+2.5137026439215766E+04	+8.8422947498509257E+03	+
+3.6720000000000000E+03	+1.1102655003838241E+04	+2.3450750289697880E+04	+2.5136671116448673E+04	+8.4126154211572193E+03	+
+3.6960000000000000E+03	+1.1126570521751419E+04	+2.2426025149007124E+04	+2.5136498246178893E+04	+7.0983386085233487E+03	+
+3.7200000000000000E+03	+8.0340433217845857E+03	+1.8889149853267143E+04	+2.5137594552463368E+04	+8.0646414770639276E+03	+
+3.7440000000000000E+03	+7.3936440691109747E+03	+1.8891440399025127E+04	+2.5136498928762565E+04	+9.4980746686293533E+03	+
+3.7680000000000000E+03	+7.4188927776692435E+03	+1.8428541501417971E+04	+2.5177803795184256E+04	+9.8142980472080508E+03	+
+3.7920000000000000E+03	+6.5197184845134616E+03	+1.5169360744627447E+04	+2.5137673664900223E+04	+1.1340719495807483E+04	+
+3.8160000000000000E+03	+1.1049090504493099E+04	+2.0615084175831184E+04	+2.5101508963882632E+04	+1.1160821767703988E+04	+
+3.8400000000000000E+03	+1.0299711598966736E+04	+2.5012251970263769E+04	+2.5136355246572544E+04	+8.6053868152938285E+03	+
+3.8640000000000000E+03	+5.3355153186134994E+03	+1.1070906699441468E+04	+2.5137180619317009E+04	+8.4990854063342867E+03	+
+3.8880000000000000E+03	+4.7445754605059919E+03	+8.6421975407086447E+03	+2.5136900486385708E+04	+1.4552817570706295E+04	+
+3.9120000000000000E+03	+6.7869660136760212E+03	+1.8483447648676647E+04	+2.5137279026331726E+04	+1.5595386887392337E+04	+
+3.9360000000000000E+03	+1.0391800524464808E+04	+2.6450548373130241E+04	+2.5255213145136135E+04	+9.3571570618812293E+03	+
+3.9600000000000000E+03	+1.0561187686639838E+04	+2.1843913542316965E+04	+2.5138017983283313E+04	+8.2363435910768912E+03	+
+3.9840000000000000E+03	+5.9594395594163798E+03	+1.1389748001340629E+04	+2.5137525657773556E+04	+9.6346781202447055E+03	+
+4.0080000000000000E+03	+5.5395699894763529E+03	+1.3259979886841524E+04	+2.5137608614959372E+04	+1.3449667467385098E+04	+
+4.0320000000000000E+03	+1.0305398557174020E+04	+2.3926584743438547E+04	+2.5178563127995880E+04	+1.1311862364638913E+04	+
+4.0560000000000000E+03	+1.0286830742340069E+04	+2.4637460237615662E+04	+2.5136732386946747E+04	+8.5610182262368780E+03	+
+4.0800000000000000E+03	+8.7503030433380045E+03	+1.9990225469068169E+04	+2.5137931858275500E+04	+7.2317112775005508E+03	+
+4.1040000000000000E+03	+1.0539328827721612E+04	+2.2650713625702705E+04	+2.5138437060446431E+04	+8.4410104430531774E+03	+
+4.1280000000000000E+03	+1.0703721123705152E+04	+2.2895597276907753E+04	+2.5177977029341553E+04	+6.9747931426348096E+03	+
+4.1520000000000000E+03	+1.0377809282381088E+04	+2.2813300060526715E+04	+2.5138601565870300E+04	+7.1706424740598322E+03	+
+4.1760000000000000E+03	+5.4919652164087165E+03	+1.1944449816595752E+04	+2.5137563711813786E+04	+8.6190225338769142E+03	+
+4.2000000000000000E+03	+9.5255721230772324E+03	+2.4818625086016069E+04	+2.5140367434385338E+04	+1.0001398069909486E+04	+
+4.2240000000000000E+03	+6.6245391808431013E+03	+1.6240157294342103E+04	+2.5136890943386730E+04	+9.4551880707299661E+03	+

Totals data generated by TRNSYS by txt files

The files can be found in this way too.