A SIMULATION STUDY OF DOMESTIC HOT WATER FOR FLAT PLATE SOLAR COLLECTOR USING TRANSIENT SYSTEM SIMULATION SOFTWARE (TRNSYS)

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ABSTRACT

This paper presents a simulation investigation on the flat plate solar collector by finding out the best performance and the suitable number of collectors. A validation on the performance of the flat plate collectors in Cyprus is carried out. The 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 govern by Hottell-Whillier-Bliss equation in TRNSYS. The commercial available flat plate collector was used from MYSOLAR CONCEPT SDN BHD to perform this study. The optimum number of collectors for domestic hot water in Melaka City was determined by using the series 5 MY-60 flat plate collector. The results show that the increase in temperature inlet and the temperature outlet of a solar system will proportionally increase the performance of the flat plate solar collector. The results also show the area of 2.5m² gives a more optimum temperature output for 78.42% of the whole annual heating load of domestic hot water in Melaka.

KEYWORDS: Flat Plate Solar Collector, Trnsys, Domestic Hot Water

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1.INTRODUCTION

Renewable energy resources are contributing to the sustainability of energy supply which is why the usage of renewable energy is shooting up. The increase of renewable energy will reduce the rate of global warming issues because of gas emission due to energy gain from fossil fuels [1]. Malaysia has annual solar radiation of 1643kWh/m² 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 that the solar PV implementations in Malaysia are reduced to mainly standalone PV systems [3].

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. Besides, 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. Therefore, the objectives of this project are to perform a TRNSYS simulation in simulating the temperature input and the temperature output of the flat plate solar collector and finding out the temperature difference between them which will lead to the find of the best solar collector performance. The optimum number of solar collectors to be installed in Melaka City using the weather data of Melaka city 2020 and also the Hottell-Whillier-Bliss equation.

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.

2. Modelling and Validation

2.1 Validation for Cyprus

The general experimental work setup model in Figure 1 in TRNSYS shows the operation of a solar system using a thermosiphon flat plate collector to analyze 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 analyze 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.

As a preliminary result, a validation on the result of the journal by S.A Kalogiroou et al, (2018) study is carried out. The TRNSYS model scheme of Figure 2 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 2 and Figure 3.

Figure 1: Validated Temperature Input and Temperature Output of Collector of Karaikudi

Figure 2: Schematic Experimental Setup

Figure 3: Experimental Setup of Collector and Tank

Figure 4 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 (TTK, top and TTK, 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 (TTK, 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 (TTK, 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 (TTK, top and TTK, 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 (TTK, 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 (TTK, 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 (TTK, 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 (TTK, bottom, sim and T-TK, bottom, validation) and the temperature at the top of the storage tank (TTK, 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 4: Comparison of Temperature.

Figure 5 shows the time history of working fluid mass flow rate ($\dot{m}$). 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 ($T_{e'}$) has a comparison purpose concerning the measured thermosiphon mass flow rate ($\dot{m}$) of the working fluid. The mass flow rate is always in phase with $T_{e'}$. The experimented, simulated and validated outcome of the flow rate is low due to the thermosiphon effect produces by the thermosiphon flat plate collector which circulates the water that is not enhanced by the pump.

Figure 5: Comparison of Fluid Mass Flow Rate

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 [6]. 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. RESULTS AND DISCUSSIONS

3.1 Performance of Flat Plate Collector

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 simulation run hours.

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. 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.

The system process in figure 6 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.

Figure 6: Solar System Model

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. 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.

Figure 7 shows the 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. TiColl and ToColl are known as temperature input and temperature output respectively.

In the first 17 hours, the TiColl and ToColl 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 40°C. 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.

In a closer look based on Figure 8, 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 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 a usage, so this is done for the safety precautions.

Figure 7: Simulation Outcome of Melaka Weather Data

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.

Figure 8: The Temperature Difference between the Simulation Outcome

3.2 Suitable Number of Solar Collectors using Melaka City Weather Data 2020

To find a suitable number of solar collectors, the normal efficiency of flat plate solar collector must be around 70% [7]. Table 1 shows the annual fraction load supplied by the collector size of 2.5m². 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.

Figure 9: The Temperature of Domestic Hot Water Produce

Table 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

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/m² of solar radiation per day [8]. 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 2.5m² for domestic usage. This outcome produces efficiency above 70% which is the best performance. The domestic hot water produces using this area of 2.5m gives a more optimum temperature output as shown in figure 9. 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.

4. CONCLUSIONS

In a nutshell, temperature inlet and the temperature outlet (TiColl and ToColl) plays a significant role to obtain the performance of the flat plate collector. 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 TiColl and ToColl. This proves that the high-temperature difference provides the best performance for a flat plate solar collector in a solar system [9].

For the second objective 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 Meteoronorm software of Melaka city in the year 2020.

A single flat plate collector with an area of 2.5m² is enough for installation in Melaka city. This is due to the efficiency of the flat plate solar collector which exceeds the 70% mark [10]. The domestic hot water produces using 2.5m² gives a more optimum temperature output which affects the efficiency. The increase in mass flow rate will also increase the thermal efficiency of a system, the efficiency also gradually rises with solar intensity during the day[11].

4.1 RECOMMENDATIONS

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. It is recommended that the future study should primarily 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. 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 in projection.

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